18TH EDITION

2025 TECH TRENDS REPORT

FTSG

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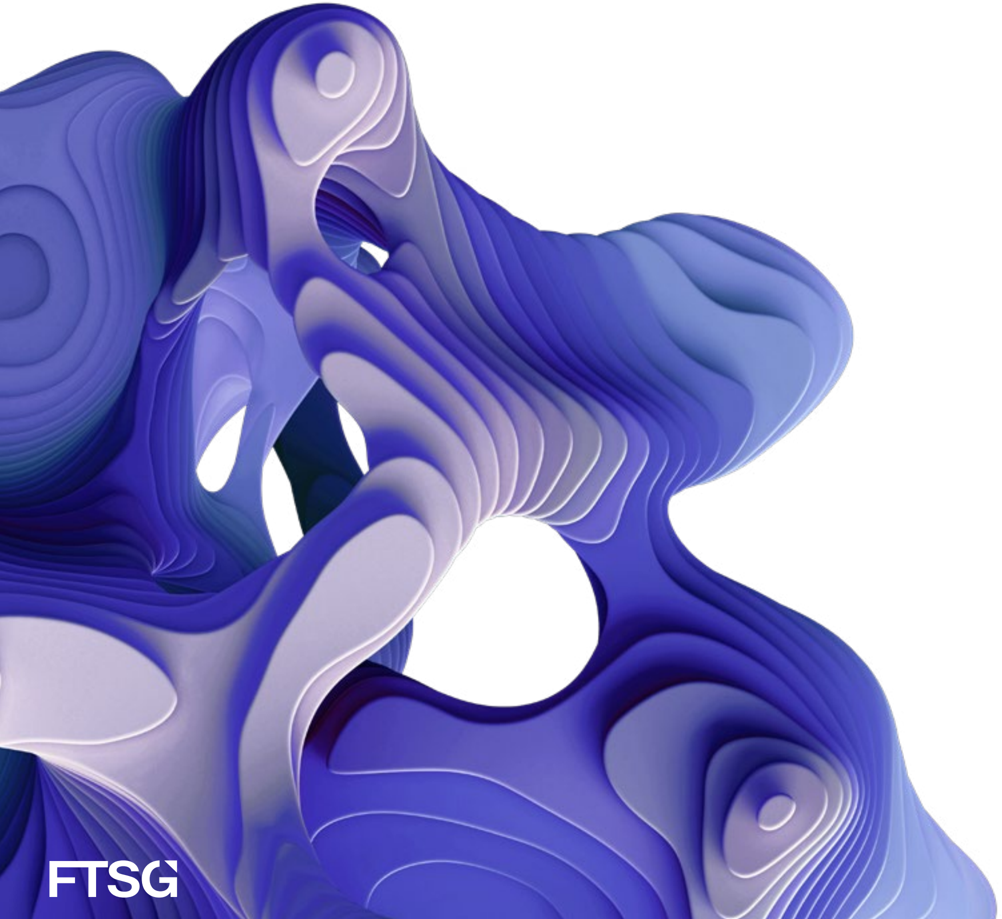

You're reading the 18th annual edition of what was previously known as the Future Today Institute's Tech Trends Report. Our name has changed—we're now Future Today Strategy Group (FTSG)—but our goal remains constant: connecting foresight to strategy to drive meaningful organizational transformation.

This year's analysis spans 1,000 pages divided into 15 comprehensive reports. To access the full report or individual sections, visit ftsg.com.

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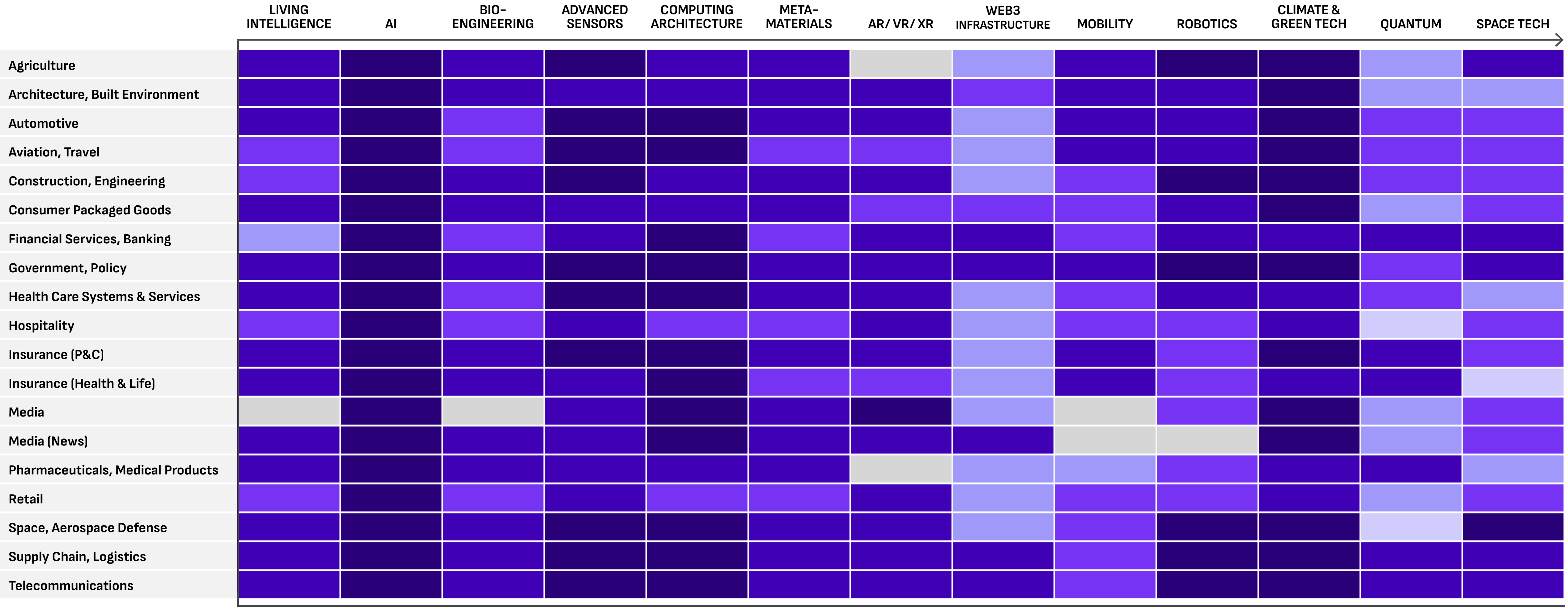
Future Today Strategy Group's 2025 Tech Trend Report

Our 2025 edition includes 1000 pages, with hundreds of trends published individually in 15 volumes and as one comprehensive report. Download all sections of Future Today Strategy Group's 2025 Tech Trends report at **www.ftsg.com/trends.**

Time of impact of trends will vary by industry.



2025 TECH TRENDS REPORT • 18TH EDITION

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INTRODUCTION

Amy Webb
Chief Executive Officer
FTSG

Beyond the Rubicon: Navigating Humanity's Point of No Return

In the past year, humanity crossed multiple points of no return. This didn't happen gradually, but in sudden, irreversible leaps that have fundamentally altered the trajectory of civilization. We've moved beyond our mental models, beyond biological constraints, beyond social norms—into territory we can neither fully explain nor comprehend. Just as the first telescopes revealed the vastness of space, today's science and tech advances are revealing how much we don't understand about our own potential.

Yes, AI has made daily headlines, but it's just one piece of a larger transformation. Two other areas of technology—advanced sensors and biotechnology—are quietly advancing and converging as they evolve. That convergence is creating what we call "living intelligence:" systems that sense, learn, adapt, and evolve. Living intelligence will drive an exponential cycle of innovation, acting as an accelerant for technologies that had previously stalled, from quantum computing to robotics.

For some organizations, this will unlock unprecedented opportunities in everything from drug discovery to energy production to financial services. For others, it will trigger overwhelming disorientation as they struggle to adapt to change occurring faster than their ability to process it. The gap between leaders and laggards will widen dramatically, not over decades, but months.

Let me be clear: The decisions we make in the next five years will determine the long-term fate of human civilization. This isn't hyperbole—it's the sobering conclusion drawn from our best available data. The convergence of tech isn't just changing how we work or live; it's changing what it means to be human. We're building systems that can reprogram biology, reshape matter at the atomic level, and process information in ways that defy classical physics. The implications extend far beyond quarterly earnings or market share.

This report isn't designed to predict the future. Its purpose is to help you navigate it. While individual trends aren't useful in isolation, when combined with scenario planning and strategic foresight, they become powerful tools for decision-making.

In a world that has moved beyond traditional boundaries, the goal isn't to get the future right—it's to get your decisions right in the present.

Welcome to the beyond.

Amy Webb
CEO
Future Today Strategy Group

10 Key Takeaways from the FTSG 2025 Tech Trends Report.

1. Living intelligence merges AI, sensors, and biotech into systems that think, adapt, and evolve beyond our grasp.

2. Action models eclipse language models as AI shifts from talking to doing, reshaping automation's frontier.

3. Robots finally break free from factory floors as advanced technology enables real-world adaptability.

4. Agentic AI systems set their own goals and execute complex decisions, augmenting human expertise.

5. Metamaterials rewrite physical limits, as engineered substances transform how we build our world.

6. Tech giants forge unlikely alliances as AI's demands force former rivals to share computing power and data.

7. The climate crisis spurs rapid innovation as extreme weather events accelerate next-gen technology adoption.

8. Nuclear power resurges as AI's energy appetite drives tech giants to invest heavily in small modular reactors.

9. Quantum computing reaches its inflection point as error correction breakthroughs unlock practical use cases.

10. Private enterprise colonizes cislunar space, birthing an economy between Earth and the moon that reshapes commerce.

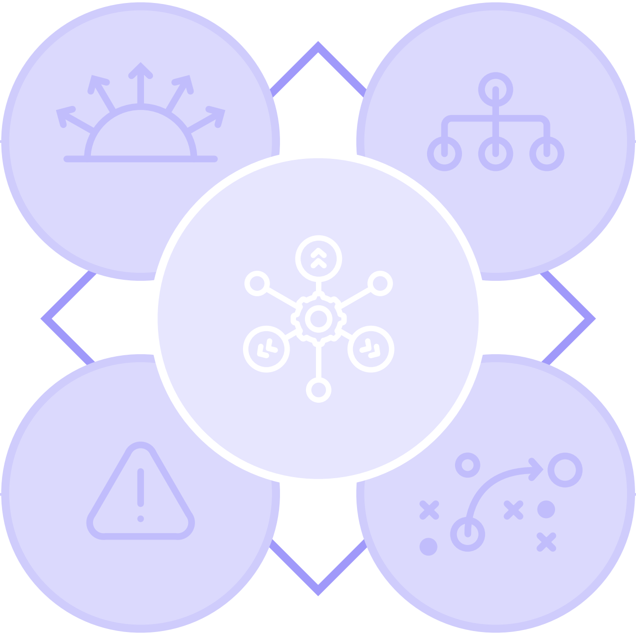
This FTSG Framework helps leaders navigate complexity and make strategic decisions in a world of rapid change. Use our trends to shape your futures.

Strategic Horizon Scanning

Identify which emerging technologies and trends will directly impact your organization's growth and evolution in the next 12-36 months.

Risk & Disruption Mapping

Plot potential disruptions from both expected and unlikely sources. Rather than traditional risk assessment, focus on how technological convergence could create unexpected competitive threats or market opportunities.



Organizational Readiness

Evaluate your current capabilities against future requirements. This isn't just about technology adoption — it's about assessing if your culture, talent, and processes can adapt to and thrive in rapidly evolving market conditions.

Action Planning

Transform insights into executable strategies. Move beyond traditional strategic planning to create dynamic response frameworks that allow your organization to pivot quickly as technological changes accelerate or decelerate.

KEY TAKEAWAYS IN DETAIL

Living intelligence—the convergence of AI, sensors, and biotech—will create intelligent systems that can perceive, learn, and evolve beyond human programming.

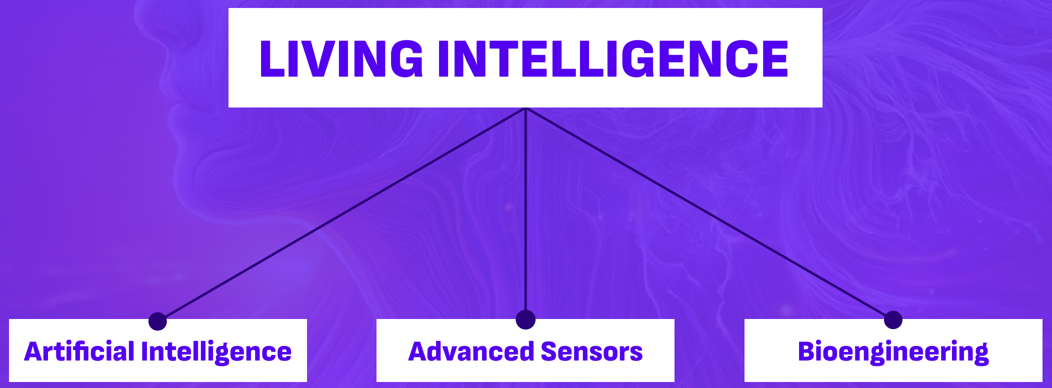
The Great Tech Convergence is Already Here

AI's integration with advanced sensors and biotechnology isn't just another tech trend — it's the birth of systems that can truly interact with and adapt to the physical world. These technologies are combining to create feedback loops between digital and biological systems, enabling capabilities that would be impossible with any single technology alone.

Why Organizations Keep Missing the Signals

Most companies are hyperfocused on AI but are overlooking how sensors and biotechnology will amplify its impact. This myopic view means missing the bigger transformation: systems that not only process data but actively sense, interpret, and modify their environment in real-time. The next wave of innovation will come from this convergence.

> **The interaction and intersection of these technologies will create compounding effects, pushing the world into a new phase of technological disruption.**
>
> - Amy Webb, "The Era of Living Intelligence"



Organizations that fail to understand and prepare for living intelligence systems risk being blindsided by competitors who harness this convergence to create unbeatable advantages.

How this shift will reshape business & society through 2030

The rise of living intelligence will fundamentally reshape competitive dynamics across industries. Companies that grasp this convergence early will build systems that can sense market changes, adapt their operations, and evolve their offerings in real-time. This isn't just about automation or efficiency—it's about creating organizations that can perceive and respond to opportunities and threats with unprecedented speed and precision. Early movers will establish data and capability advantages that become nearly impossible for competitors to overcome.

How leaders are being influenced by this shift today

Our clients are already experiencing the implications of living intelligence. While most started with narrow AI initiatives, leaders are now racing to integrate sensor networks and biological interfaces into their operations. We're seeing health care companies combine AI diagnostics with continuous biometric monitoring, manufacturers deploying adaptive production systems that evolve their processes, and retailers creating environments that sense and respond to customer behavior in real-time.

200 million

protein structures—the number of proteins in AlphaFold Server's free database.

Action models are eclipsing language models as AI shifts from text generation to real-world behavior prediction, fundamentally changing how machines learn.

From Words to Actions

While language models excel at processing text, action models learn from behavioral data captured by ubiquitous sensors. These systems don't just predict what to say—they predict what to do, breaking complex tasks into executable steps and making real-time decisions based on environmental feedback.

The Rise of Personal Action Models

As action models evolve, they'll become increasingly personalized, learning from individual behavioral patterns. We believe that PLAMs (Personal Large Action Models) will seamlessly manage tasks, negotiate deals, and make decisions based on deep understanding of user preferences, while maintaining privacy through edge computing.

Microsoft's work-in-progress LAM started with a training dataset comprised of 76,000 task-plan pairs. Ultimately, 2,000 successful action sequences were used in the final training set.

The shift to action-based AI will create autonomous systems that can execute complex tasks without explicit programming, transforming automation across industries.

How this shift will reshape business & society through 2030

Action models represent a fundamental shift in how AI systems operate in the real world. Unlike language models that operate primarily in the realm of text and content generation, action models will enable AI to understand and predict physical behaviors, movements, and decision-making patterns. This capability will revolutionize everything from robotics to personal assistance to business process automation. As these systems mature, they'll move beyond simple task execution to complex decision-making and strategic planning.

How leaders are being influenced by this shift today

While many of our clients were early to invest in LLMs for content generation and customer service, the real transformations in the future will come from LAMs. Leading organizations are already exploring how LAMs could optimize supply chains, predict maintenance needs, and automate complex operational decisions. The most forward thinking companies in the future will develop hybrid systems that combine language and action models, creating AI that can both communicate and act.

By 2030, more than

125 billion

connected devices will generate continuous behavioral data, fueling LAMs' ability to learn and act autonomously.

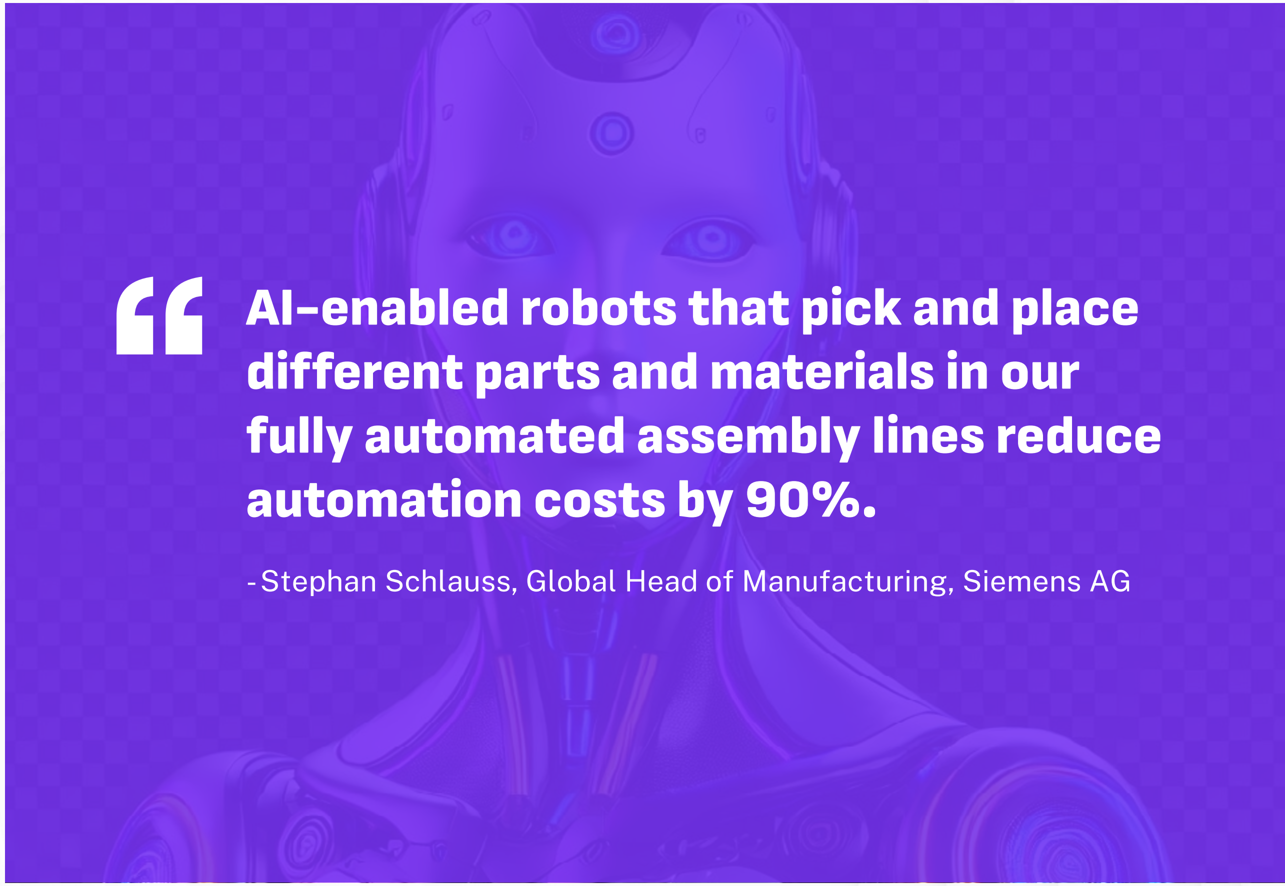
Robotics will hit an inflection point as AI and advanced sensors enable machines to adapt to unstructured environments and learn complex tasks in real time.

The End of Rigid Robotics

Traditional robots were confined to controlled environments, performing repetitive tasks. Now, AI-powered robots can perceive their surroundings, make decisions autonomously, and adapt to changing conditions—marking the transition from programmed to intelligent automation.

Why Scale is Finally Possible

The convergence of AI, advanced sensors, declining hardware costs, and edge computing has removed historical barriers to robotic deployment. Combined with improving ROI metrics and labor shortages across industries, these advances are creating perfect conditions for widespread adoption.



> **"AI-enabled robots that pick and place different parts and materials in our fully automated assembly lines reduce automation costs by 90%.**
>
> -Stephan Schlauss, Global Head of Manufacturing, Siemens AG

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Adaptive robotics will transform industries far beyond manufacturing, creating new operational paradigms in health care, agriculture, and construction.

How this shift will reshape business & society through 2030

Robotics will expand beyond traditional industrial applications into more complex, human-centric environments. In health care, surgical robots will enhance human capabilities; in agriculture, autonomous systems will enable precision farming; in construction, robots will perform dangerous or repetitive tasks. At least initially, this shift won’t replace human workers but augment them, creating new roles focused on robot supervision and strategic decision-making.

How leaders are being influenced by this shift today

Manufacturing leaders we advise are rapidly reevaluating their automation strategies as adaptive robots become more viable. We’re seeing health care executives explore robotic surgical assistants that could triple procedure efficiency, while construction firms are piloting autonomous equipment for site preparation and basic assembly. However, most organizations are struggling with integration challenges and workforce concerns. The most successful deployments focus on augmenting human capabilities rather than replacing workers.

The convergence of advanced sensors and AI will increase robotic autonomy by more than

60%.

(Boston Dynamics)

Agentic AI marks the transition from passive tools to autonomous systems that can set goals, make decisions, and execute complex strategies independently.

The Rise of AI That Acts

Beyond pattern recognition and prediction, agentic AI systems can understand context, formulate strategies, and take independent action. These systems don't just respond to commands—they identify opportunities, set objectives, and orchestrate resources to achieve them.

Multi-Agent Collaboration Changes Everything

The real power emerges when multiple AI agents work together, each specializing in different tasks while coordinating toward common goals. This creates networks of AI systems that can handle complex, interconnected challenges that would overwhelm single agents.

72%

of enterprises using AI agents achieve business process efficiency gains.

(Stanford HAI Survey, 2024)

Organizations must prepare for a world where AI systems make and execute decisions autonomously, fundamentally altering business operations.

How this shift will reshape business & society through 2030

Agentic AI will transform how organizations operate, moving from human-directed automation to AI-orchestrated autonomy. These systems will manage supply chains, optimize resource allocation, and coordinate complex business processes with minimal human oversight. The shift will be gradual but profound—starting with discrete business functions before expanding to cross-functional operations. Success will depend on building trust, establishing clear governance, and creating new frameworks for human-AI collaboration.

How leaders are being influenced by this shift today

While executives recognize Agentic AI's potential, most struggle with implementation challenges. Leading organizations are starting small, deploying autonomous agents in controlled environments like inventory management or predictive maintenance. We're seeing increased concern about security, compliance, and control as these systems become more autonomous. The most successful companies are investing heavily in training, governance frameworks, and change management to prepare their organizations for this transition.

AI-powered agents could automate

80%

of coding tasks by 2030.

(MIT CSAIL)

Metamaterials are revolutionizing construction and manufacturing, creating substances with properties that transcend natural limitations.

Nature's Rules Are Being Rewritten

Metamaterials, designed at the microscopic level using advanced tech, can manipulate light, sound, heat, and mechanical stress in ways previously impossible. These engineered substances represent a fundamental shift from simply discovering materials to designing their properties from scratch.

From Theory to Commercial Reality

AI has accelerated metamaterial development from theoretical models to practical applications. What required decades of research can now be simulated and optimized in hours, enabling rapid prototyping and commercialization of materials with unprecedented capabilities.

> **"In metamaterials, we go beyond natural arrangements to a new level of organization. We design our own collection of tiny structures using multiple materials (such as gold and glass). Like regular materials, the electromagnetic properties of metamaterials depends on how we shape and arrange these structures. The difference is, we can create new properties that are not found in nature. And that's what metamaterials are all about.**
>
> -Dr. Nader Engheta, H. Nedwill Ramsey Professor, School of Engineering and Applied Science at University of Pennsylvania School of Arts and Sciences

Metamaterials will transform the built environment, enabling self-cooling buildings, ultra-resilient infrastructure, and adaptive structures.

How this shift will reshape business & society through 2030

Metamaterials will revolutionize industries from construction to energy to telecommunications. Buildings will regulate their own temperature, infrastructure will adapt to environmental stresses, and communication systems will achieve unprecedented efficiency. The technology will be crucial for climate resilience, enabling structures that can withstand extreme weather while dramatically reducing energy consumption. This shift will create new design paradigms and force industries to rethink traditional approaches.

How leaders are being influenced by this shift today

Construction and engineering executives are scrambling to understand metamaterials' implications for their industries. While some view the technology as distant, leading firms are already forming partnerships with metamaterial startups and research institutions. We're seeing increased investment in R&D and pilot projects, particularly in energy efficiency and structural resilience. However, most organizations still lack the expertise to evaluate and implement these new materials.

Acoustic metamaterials can reduce sound transmission by up to

94%,

enabling quieter buildings, aircraft, and industrial environments.

(Boston University)

Tech giants are forming unprecedented partnerships as AI's massive computational demands force former competitors to share resources and infrastructure.

Competition Gives Way to Coopetition

The sheer scale of AI development—from computing power to specialized hardware—has made going it alone impossible. Even the largest tech companies are finding they must collaborate with rivals to remain competitive and innovative.

The Cloud Becomes the New Battleground

As AI workloads grow exponentially, control of cloud infrastructure becomes crucial. Strategic alliances between cloud providers, chip manufacturers, and AI companies are creating new power dynamics that will reshape the tech landscape.

Tech giants and sector leaders have a synergistic relationship: industry expertise helps make technology advancements actionable, and industry leaders can't advance without new computational and AI capabilities.

The era of tech companies operating in isolation is ending, as AI's demands create complex networks of interdependent partnerships.

How this shift will reshape business & society through 2030

These strategic alliances will fundamentally alter how technology is developed and deployed. Cross-company collaboration will become the norm, with shared infrastructure, data, and research accelerating innovation. However, this consolidation raises concerns about market concentration and competition. Organizations will need to navigate complex partnership networks while maintaining their competitive advantage.

How leaders are being influenced by this shift today

We've observed that business leaders are challenged by a transformed vendor landscape where traditional competition lines blur. Many are finding their strategic planning complicated by uncertain alliances and shifting partnerships. While some embrace multi-vendor strategies to maintain flexibility, others are forming deeper partnerships with specific tech ecosystems. The most sophisticated organizations are creating partnership strategies that balance access to innovation with vendor lock-in risks.

Amazon committed up to

$4 billion

to support Anthropic's AI research, embedding its Claude models into AWS infrastructure.

Extreme weather events are accelerating technological innovation as climate adaptation becomes an urgent business imperative across every industry.

Crisis Drives Commercial Breakthroughs

Climate disasters are forcing rapid advancement in resilience technologies. What began as defensive measures is evolving into new markets for climate adaptation, spanning infrastructure, agriculture, and emergency response systems.

Smart Systems Reshape Climate Response

The convergence of AI, sensors, and biotechnology is enabling unprecedented capabilities in climate prediction, response, and adaptation. These technologies are creating early warning systems and resilient solutions previously thought impossible.

82%

of investors believe that publicly held financial services companies that better anticipate environmental risks are more likely to succeed financially.

(Harvard Business Review)

Organizations must integrate climate adaptation into their core strategy as extreme weather reshapes markets and creates new business imperatives.

How this shift will reshape business & society through 2030

Climate adaptation technologies will become central to business operations and infrastructure development. Advanced materials will protect against extreme conditions, while emerging tech will optimize resource usage and predict environmental risks. Biotechnology breakthroughs will create climate-resistant agriculture and carbon-capture solutions. Organizations that fail to adapt will face increasing operational disruptions and market disadvantages.

How leaders are being influenced by this shift today

Corporate leaders are shifting from viewing climate technology as a compliance issue to seeing it as a strategic necessity. We're seeing increased investment in resilient infrastructure, AI-powered climate modeling, and a host of other solutions. Leading organizations are integrating climate adaptation into their core business strategies, while others struggle to balance short-term pressures with long-term climate resilience needs.

By 2050, climate change could put $26 trillion in global financial assets at risk, forcing central banks to integrate climate risk into monetary policy.

(IMF)

Nuclear power's revival will reshape energy markets and corporate strategy as tech companies become major players in power generation.

Big Tech Drives Nuclear Renaissance

Tech companies are bypassing traditional utilities to invest directly in nuclear power. The push for reliable, carbon-free energy to power AI systems is making nuclear innovation a Silicon Valley priority.

SMRs Change the Nuclear Equation

Small modular reactors offer a new paradigm: scalable, safer, and faster to deploy than traditional nuclear plants. Their standardized design and reduced complexity are transforming nuclear power's risk-reward profile.

Microsoft's new nuclear plant at Three Mile Island is expected to open in 2028 and will be renamed the Crane Clean Energy Center. The plant will power Microsoft's data centers.

Small modular reactors emerge as tech giants' answer to AI's massive energy demands, marking nuclear power's transformation from pariah to savior.

How this shift will reshape business & society through 2030

The rise of SMRs could democratize nuclear power, enabling new deployment models beyond traditional utility structures. Tech companies will emerge as major energy producers, potentially disrupting traditional utility markets. This shift will accelerate the transition to carbon-free energy while raising new questions about power generation control and infrastructure security.

How leaders are being influenced by this shift today

Energy-intensive industries are closely watching tech companies' nuclear initiatives. Many are reevaluating their power strategies, considering direct investment in SMRs or partnerships with nuclear developers. Some organizations are now developing comprehensive energy strategies that include nuclear as part of their sustainability and operational resilience plans. However, concerns about public perception and regulatory uncertainty remain.

Small modular reactors can be manufactured in factories and deployed within

3–5 years,

accelerating nuclear adoption.

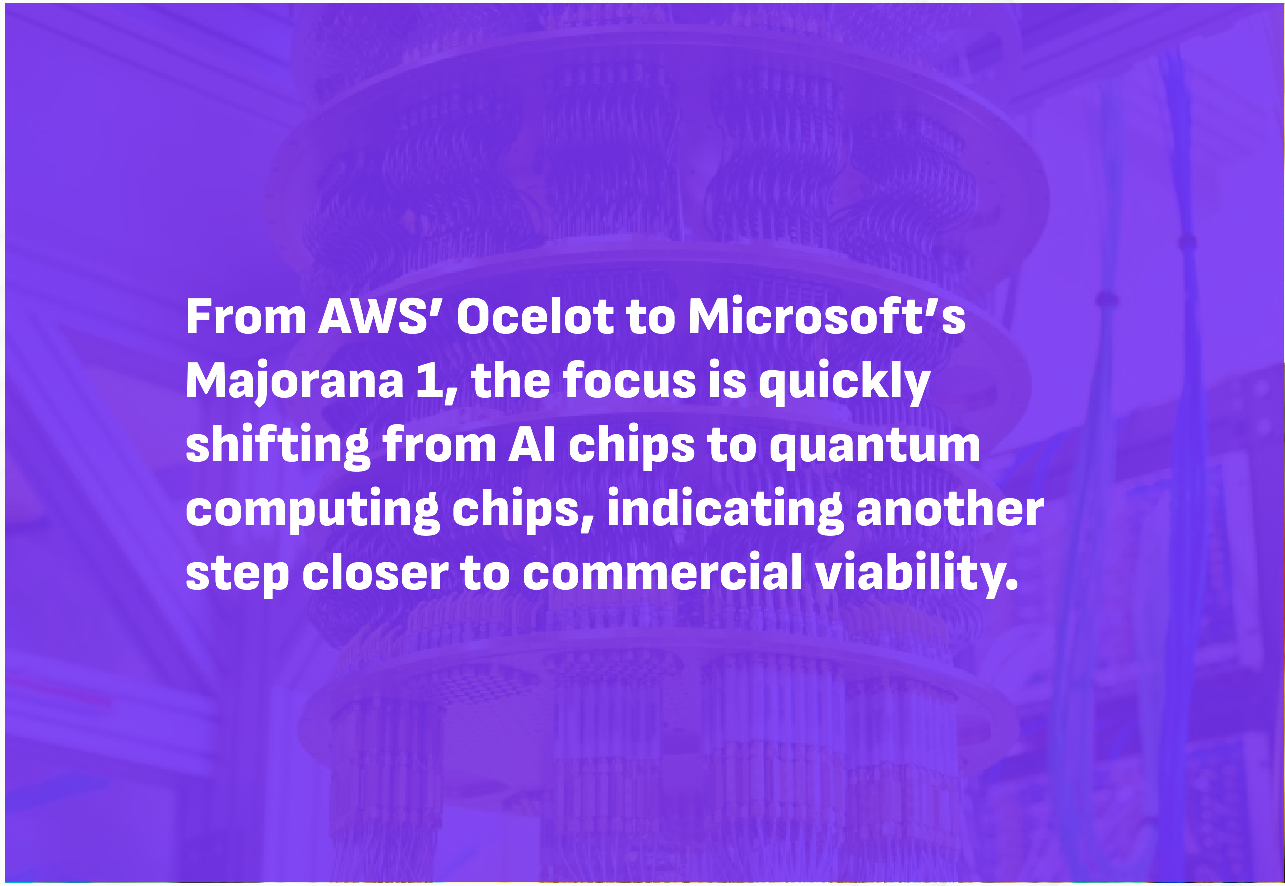
Quantum computing reaches its inflection point as error correction breakthroughs and hybrid systems bring practical applications within reach for the first time.

Error Correction Changes Everything

After decades of theoretical promise, quantum error correction breakthroughs are finally enabling stable qubit operations. This fundamental advance removes the key barrier that has held quantum computing back from practical applications.

Hybrid Systems Bridge the Gap

The integration of quantum and classical computing systems is creating immediate value, even before full quantum advantage. Organizations can begin capturing benefits while the technology continues to mature.



Organizations must prepare for quantum's impact on encryption, optimization, and simulation as the technology moves from research labs to real-world deployment.

How this shift will reshape business & society through 2030

Quantum computing will revolutionize fields requiring complex simulations and optimization, from drug discovery to financial modeling. Early applications will focus on specific use cases where quantum offers clear advantages, gradually expanding as the technology matures. Organizations must balance preparation for quantum's transformative potential with realistic expectations about implementation timelines.

How leaders are being influenced by this shift today

While most executives acknowledge quantum's long-term opportunity, they struggle with strategic importance and timing their investments. Some organizations are building quantum literacy, identifying potential use cases, and developing quantum-safe security protocols. The most sophisticated companies are already experimenting with hybrid quantum-classical systems, gaining practical experience while preparing for quantum's broader impact.

Quantum algorithms could cut energy grid inefficiencies by

20%,

saving billions annually.

(Siemens Quantum Energy)

Private enterprise is colonizing the space between Earth and the moon, creating a new economic frontier that will reshape commerce and resource extraction.

Space Infrastructure Goes Commercial

The privatization of space is moving beyond launches to include orbital manufacturing, refueling stations, and maintenance services. This emerging infrastructure network will enable sustainable operations throughout cislunar space.

New Resources Drive New Markets

The discovery of lunar water ice and rare minerals, combined with zero-gravity manufacturing capabilities, is creating unprecedented economic opportunities. Space resources will transform industries from pharmaceuticals to semiconductors.

$1.8 billion

Estimated size of the space economy by 2035

(World Economic Forum)

The cislunar economy will create new industry leaders as space capabilities become critical for competitive advantage across sectors.

How this shift will reshape business & society through 2030

The commercialization of cislunar space will extend Earth's economic sphere to lunar orbit. In-space manufacturing will enable the production of materials impossible to create under gravity, while lunar resources will reduce dependence on terrestrial mining. This expansion will create new logistics networks, insurance markets, and financial instruments. Organizations that establish early positions in this economy will gain significant advantages.

How leaders are being influenced by this shift today

While space remains a frontier market, forward-thinking executives are already developing cislunar strategies. Manufacturing companies are exploring zero-gravity production possibilities, while logistics firms plan for orbital supply chains. However, most organizations struggle to evaluate space opportunities against terrestrial investments. Leading companies are forming partnerships with space startups to gain early access to these capabilities.

More than

$100 billion

is being invested by private companies and national space agencies in cislunar infrastructure.

BEYOND TRENDS

Many organizations confuse what’s trendy with true strategic trends.

Trends are measurable changes occurring over time, not buzzy headlines or viral tech fads. Yet most organizations chase shiny objects while missing real strategic signals. This problem compounds when companies only track trends in their own industry, which blinds them to the powerful convergences happening at the intersections. True disruption rarely emerges from a single trend. It comes from the collision of multiple forces across different domains. By tracking the right trends consistently and understanding their broader implications, any organization can develop stronger foresight capabilities and make better strategic decisions.

Understanding the difference between trends and uncertainties shapes better strategic decisions.

Trends are what we *can* know

- Measurable changes occurring over time, backed by data and research.
- Observable patterns that show consistent movement in a specific direction.
- Developments that can be tracked, quantified, and validated through evidence.

Uncertainties are what we *cannot* know

- Future conditions that defy precise prediction or measurement.
- Variables that could develop in multiple different directions.
- Events whose outcomes remain unknown despite careful analysis.

Trends reveal transformative opportunities, but only if you ask, "What if?"

Our research uncovers what others are missing, such as:

Topological qubits could finally solve quantum computing's stability problem. Microsoft's breakthrough shows a path to scalable quantum systems without the massive error correction overhead.

Spatial computing will transform workplace collaboration, enabling seamless integration of virtual and physical spaces. Early movers will reshape how teams interact and solve problems.

Generative AI is revolutionizing how robots learn, combining sensor data, human demonstrations, and internet-scale training. This breakthrough will finally make robots adaptable enough for real-world deployment.

Nanotech breakthroughs in materials science will enable self-healing infrastructure and smart surfaces. Researchers can develop products with unprecedented properties and capabilities.

Edge computing combined with 5G will enable real-time processing at unprecedented scale. Organizations can deploy new solutions anywhere, creating truly distributed operations.

Synthetic biology will create new possibilities for sustainable manufacturing and carbon capture. Teams can redesign supply chains and create innovative climate solutions.

GenAI-powered search is evolving from link lists to conversational answers. Marketers can transform how they reach customers by optimizing for this new paradigm of discovery and engagement.

Augmented reality will transform customer experiences and worker training. HR leaders can create immersive interfaces that blend digital and physical worlds.

Smart materials will enable adaptive infrastructure and self-optimizing systems. Designers can create buildings and products that respond to environmental changes.

These trends also create new vulnerabilities.

Here's where your organization might be most exposed

Small language models make AI deployment easier and cheaper, creating security blind spots as departments bypass IT to implement their own solutions without proper oversight.

Synthetic biology democratizes biotech capabilities, but also creates new risks. Safety protocols designed for traditional threats can't handle these emerging biological hazards.

Privacy regulations can't keep pace with AI's data analysis capabilities. Legal teams using traditional compliance frameworks will leave organizations exposed to new forms of liability.

Spatial computing creates new attack surfaces in physical spaces. Facility managers and security teams lack protocols for securing augmented and mixed-reality environments.

Decentralized systems challenge traditional governance structures. Risk managers using centralized control models will struggle as operations become more distributed.

Computer vision advances enable unprecedented surveillance capabilities. Ethics boards lack frameworks to address the responsible use of these powerful monitoring tools.

Deep learning models can make critical decisions without clear audit trails. Compliance teams can't explain AI decisions using traditional accountability frameworks.

Cross-platform data flows create new vulnerabilities. IT teams focused on securing individual systems miss risks in the interconnections between emerging technologies.

Fast-learning robots could make entire skill sets obsolete overnight, forcing rapid workforce transitions. HR teams aren't prepared for this pace of role displacement and retraining.

To thrive in a world of rapid change, organizations must be agile, resilient, and future-ready.

We recommend that every organization do the following now.

- Organizational leadership should embed foresight into strategy by regularly assessing tech disruptions and aligning long-term vision with emerging trends.
- Require tech literacy at the board level to ensure informed decision-making on disruptive innovations.
- Allocate capital for innovation, balancing short-term returns with long-term investments in emerging technologies.
- Integrate scenario planning and strategic foresight into annual planning to anticipate volatility and new opportunities.
- Monitor weak signals and track emerging tech, geopolitical shifts, and societal trends to anticipate disruptions early.
- Strengthen infrastructure by upgrading networks, cloud systems, and cybersecurity to handle rapid shifts in technology.
- Develop cross-industry partnerships and collaborate beyond traditional sectors to drive innovation and expand market reach.
- Expand global intelligence capabilities to track geopolitical, economic, and tech shifts to anticipate disruptions and opportunities.
- Adopt agile governance and implement flexible policies that can evolve with emerging technologies and global uncertainties.
- Develop experimental sandboxes to test emerging tech, fostering a culture of rapid prototyping and iteration.

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ARTIFICIAL INTELLIGENCE

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AI's bleeding edge now changes by the hour, not year. What next?

AI is moving at breakneck speed, reshaping industries, workflows, and everyday life faster than we can document. On the day we wrote this, people were still breathlessly marveling at China's DeepSeek, which achieved OpenAI's top-tier performance with a fraction of the usual price tag and computing power—challenging everything we thought we knew about what it takes to build advanced AI. Hours later, researchers at Stanford and the University of Washington debuted yet another new model, s1, which outperformed both DeepSeek's R1 and OpenAI's o1 reasoning models using even fewer resources.

That's the nature of AI right now: What's bleeding-edge today might be old news ... *later today.*

Here's what we know for certain. Last year, OpenAI CEO Sam Altman met with sovereign wealth fund managers and investors, hoping to raise up to $7 trillion for an AI chip company. In January 2025, Stargate, a newly formed joint venture between OpenAI, Oracle, and SoftBank, said it would raise $500 billion for chips, AI data centers, and their massive power requirements. Not to be outdone, Microsoft, Meta, and Google have each announced plans to invest hundreds of billions of dollars in AI infrastructure. But if now anyone can replicate a multimillion dollar model with only modest resources, won't AI models quickly become commoditized? If so, this would pressure Big Tech to move very fast, building and scaling ever-advancing AI systems in order to stay competitive in the market.

In the race to win AI, critical evaluation has become a casualty of speed. We meet regularly with the research teams building SOTA models, heads of frontier labs working to advance AI, and executives at the big tech giants. While we are certainly excited about the incredible technological progress being made, there is the practical reality of organizational readiness. The makers of AI systems—and the professional service firms promising overnight transformation—are operating in a reality far removed from everyday organizations.

What we've observed in the past year advising CEOs and their management teams on AI strategy and implementation is that regardless of AI's tantalizing developments, most organizations face substantial technical debt in data standardization and maintenance, creating operational friction in deployment. They are also struggling with the basics of change management, which is often deprioritized (or forgotten entirely) ahead of implementation. As a result, we are seeing new strategic risks for organizations that overindex on technological readiness without addressing fundamental operational and cultural barriers to deployment.

Breakthrough advancements have also accelerated the AI race between the US and China, intensifying it into a full-blown geopolitical contest, with both nations leveraging technology as a tool for global influence. To wit: during Donald Trump's globally televised inauguration, execs from America's biggest technology companies sat directly behind him—while his cabinet appointees and family members sat in rows farther back. This US-China rivalry is forcing allies to take sides, escalating tensions and fueling concerns over national security, supply chains, and technological sovereignty. What emerges is a fragmented AI landscape, dominated by a Digital Cold War that threatens to reshape global alliances and economic power structures.

How—*exactly*—will AI reshape our world in the coming months? The honest answer is: nobody can know. At this stage, avoiding costly mistakes, and smart planning for the future, matters more than predicting exact outcomes. Leaders need a strategic compass, not a crystal ball.

That's the purpose of this trend report: to highlight emerging AI trends and use cases so you can plan for multiple possibilities. Because in an AI landscape moving at warp speed, strategic clarity is your competitive edge.

Expect a continued frenzy of activity as AI companies compete for market share, though investments and policies will concentrate influence among several key players.

1

Harder, better, faster, stronger

DeepSeek's R1, and s1 from Stanford and the University of Washington achieved strong reasoning capabilities while remaining cost-efficient, challenging the convention that progress requires ever-larger models and raising questions about future AI scalability.

2

Your AI now has eyes and ears

Recent advancements in multimodal AI, like Google Gemini Live and OpenAI's Sora, are quickly transforming how machines process and generate text, audio, and video, unlocking new possibilities for richer and more interactive AI experiences.

3

Learning how to think

AI performance is improving, elevating models like OpenAI's o1 and Google's Gemini 2.0 Flash Thinking Mode from mere information engines to thought partners. In late 2024, OpenAI's o3 scored 85% on the ARC-AGI benchmark, matching the average human score.

4

From assistance to autonomy

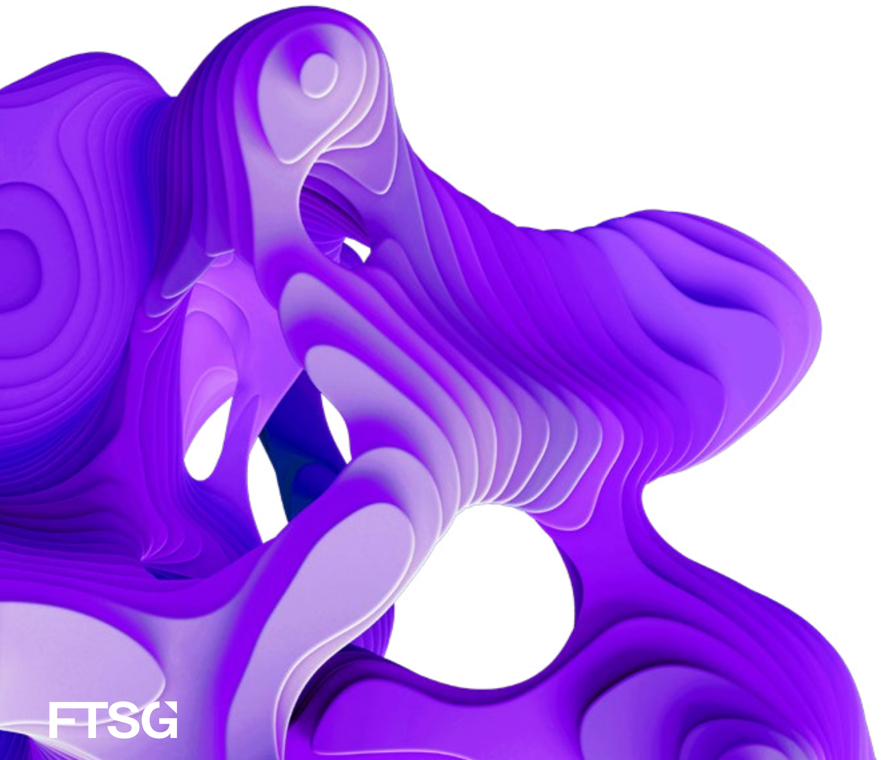
Agentic AI is evolving from supporting tasks to autonomously reasoning and taking action across workflows. This year, AI agents will not only assist but also execute complex processes, transforming industries with greater efficiency and automation.

5

US and China race ahead

The US and China are locked in a high-stakes competition for AI dominance, shaping the future of technology and global power. As both nations invest in AI research, infrastructure, and regulation, they are redefining innovation, security, and economic influence.

Artificial intelligence will fundamentally rewire dynamics and competitive frontiers in 2025.



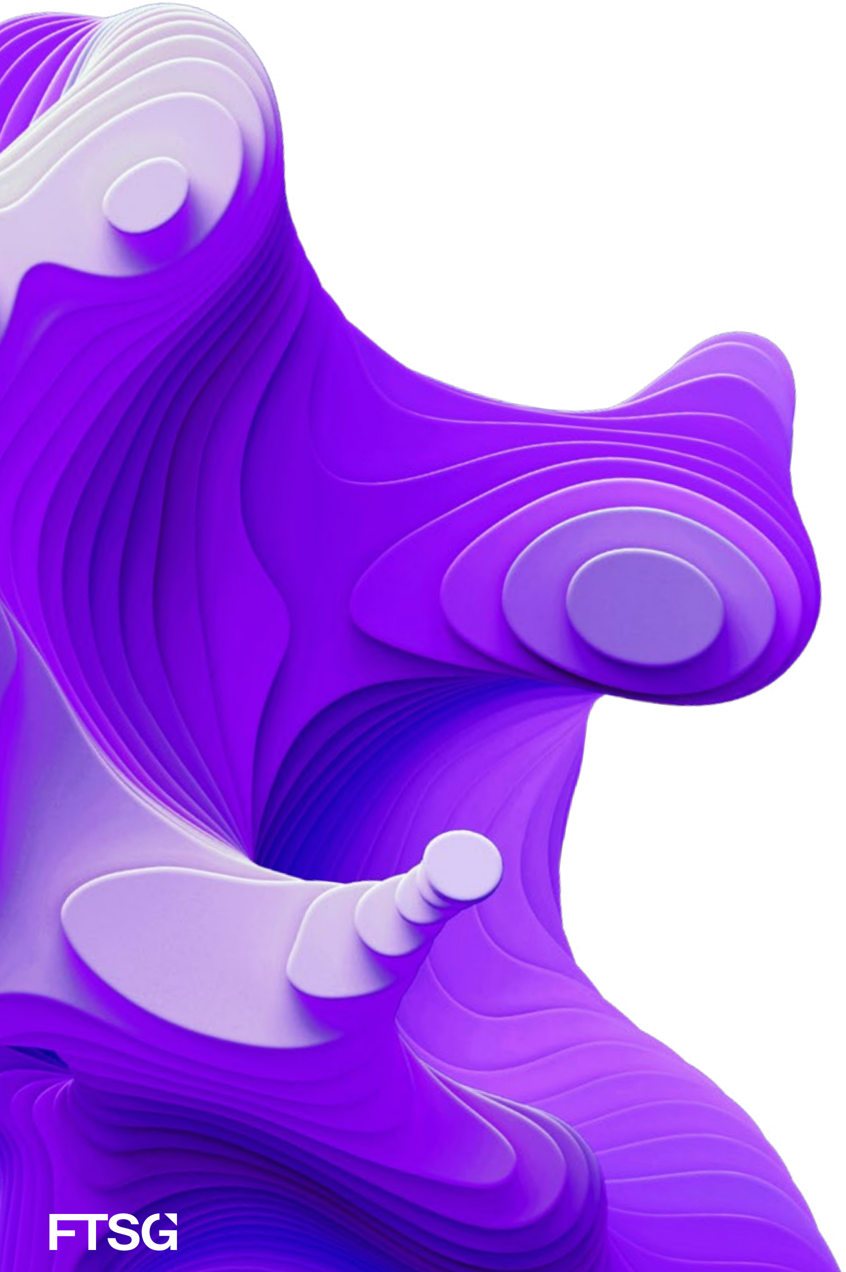
It's no secret that AI's landscape has transformed dramatically since we wrote the State of Play section last year. GPT-4 set early benchmarks with its multimodal capabilities and professional-level performance, but since then, Google DeepMind's Gemini Ultra raised the bar further, exceeding GPT-4 on most benchmarks.

The field has split between proprietary and open-source approaches. Meta's release of Llama 2 sparked an open-source revolution, with developers rapidly fine-tuning variants that rival larger commercial models. This success prompted even OpenAI's CEO Sam Altman to admit that the company might have been "on the wrong side of history" regarding closed systems.

Cloud partnerships have become crucial. Microsoft bet big on OpenAI ($10B), while Amazon and Google split their support for Anthropic ($4B and $2B respectively). These alliances provide AI companies with massive compute power while securing cloud providers' positions in the AI race. However, this concentration of resources raises concerns about market consolidation.

China has emerged as a formidable AI power. Baidu's Ernie 4.0 claims GPT-4-level performance, while Alibaba released more than 100 open-source models under Qwen 2.5. ByteDance's Doubao chatbot gained significant market share. Also making huge strides are Zhipu AI, MiniMax, Baichuan Intelligence, Moonshot, StepFun, and 01.AI—collectively known as the country's "Six Little Tigers." Despite US chip restrictions, Chinese firms are adapting with domestic alternatives like Huawei's Ascend and Baidu's Kunlun chips.

Investment has exploded, with more than $22 billion flowing to generative AI startups last year alone, representing nearly half of all AI funding. Traditional VCs are competing with tech giants throwing billions at AI, driving valuations skyward.



We see six macro themes emerging:

1. Big Tech will continue to dominate funding, often through strategic partnerships
2. Valuations are reaching dot-com era levels, raising legitimate bubble concerns
3. Traditional tech sectors are seeing funding dry up as AI sucks the oxygen out of the room
4. Investment is flowing directly to cloud providers for compute power
5. Competition is intensifying between proprietary and open-source models
6. China is rapidly closing the gap with Western AI capabilities

Looking ahead, funded AI companies must prove real business value. The winners will likely be those that can balance innovation with sustainable monetization while navigating increasing regulatory scrutiny.

AI giants raced to AGI as Chinese rivals proved formidable.

MAY 2024

OpenAI Launches GPT-4o

The new AI model is capable of real-time reasoning across audio, visual, and text inputs.

DECEMBER 2024

O3 Closes In on AGI

OpenAI says its o3 model has passed the ARC-AGI challenge, considered a leading benchmark for artificial general intelligence.

JANUARY 2025

Nvidia enters the AI PC market

Nvidia unveils its Project DIGITS, a personal AI supercomputer.

JANUARY 2025

DeepSeek Disrupts

Chinese AI company DeepSeek releases R1, its reasoning model and competitor to OpenAI's o1.

JANUARY 2025

Tech Giants Introduce 500B AI plan

Political, tech, and financial leaders announce Stargate, a joint venture that aims to invest $500 billion in US AI infrastructure.

« PAST

Tech titans will face pivotal AI tests in 2025.

FUTURE »

MARCH 2025

Huang to Preview Next-Gen AI Chips

Nvidia's GPU Technology Conference will feature CEO Jensen Huang's keynote on what to expect from this critical chip manufacturer.

MAY 2025

AI Integrates

Google I/O's new generative AI updates will signal how AI will further integrate into consumer services and enterprise tools.

MAY 2025

Nvidia's Growth Is Tested

Nvidia could show record-breaking revenue—unless DeepSeek portends an alternative future requiring fewer chips.

JUNE 2025

Apple Bets Big on a Smarter Siri

In a "make or break" moment for proving AI's necessity in consumer products, Apple is poised to debut a new Siri with generative AI.

JULY 2025

China Shows Its AI Hand

The World AI Conference will showcase China's latest AI innovations and initiatives.

Beyond the AI hype, these six structural changes are already determining which organizations will thrive.

Speed Is the New Scale

For better or worse, AI is compressing decision cycles from weeks to minutes. The advantage is shifting to organizations that can harness AI for rapid experimentation and learning—as long as they're making good decisions about data governance, vendor selection, and change management.

Your Competitors Won't Wait

Someone in your industry is already using AI to cut costs and boost productivity by 30%–40%. AI is automating certain labor intensive knowledge tasks, but it will soon lead to new workflows and business models. The question isn't whether your organization will adapt to AI, but whether you'll do it before or after your margins get squeezed from all directions.

The Middle Office Is Melting

AI is automating coordination and decision-making tasks that traditionally required human middleware, and organizations clinging to manual coordination and approval processes will find themselves structurally uncompetitive. The future org chart is flatter and faster.

The Talent War Has New Rules

The best talent now expects to work with the best tools. They're not just looking for good pay—they want AI-enabled workplaces that multiply their impact. Your ability to attract and retain top performers increasingly depends on your AI readiness.

A Hidden AI Tax

The cost of AI isn't in buying the technology—it's in powering it. As demand for AI computing skyrockets, organizations will face a new economic reality: Buy in early to start their AI transformation, but unwittingly pay an increasingly steep premium later.

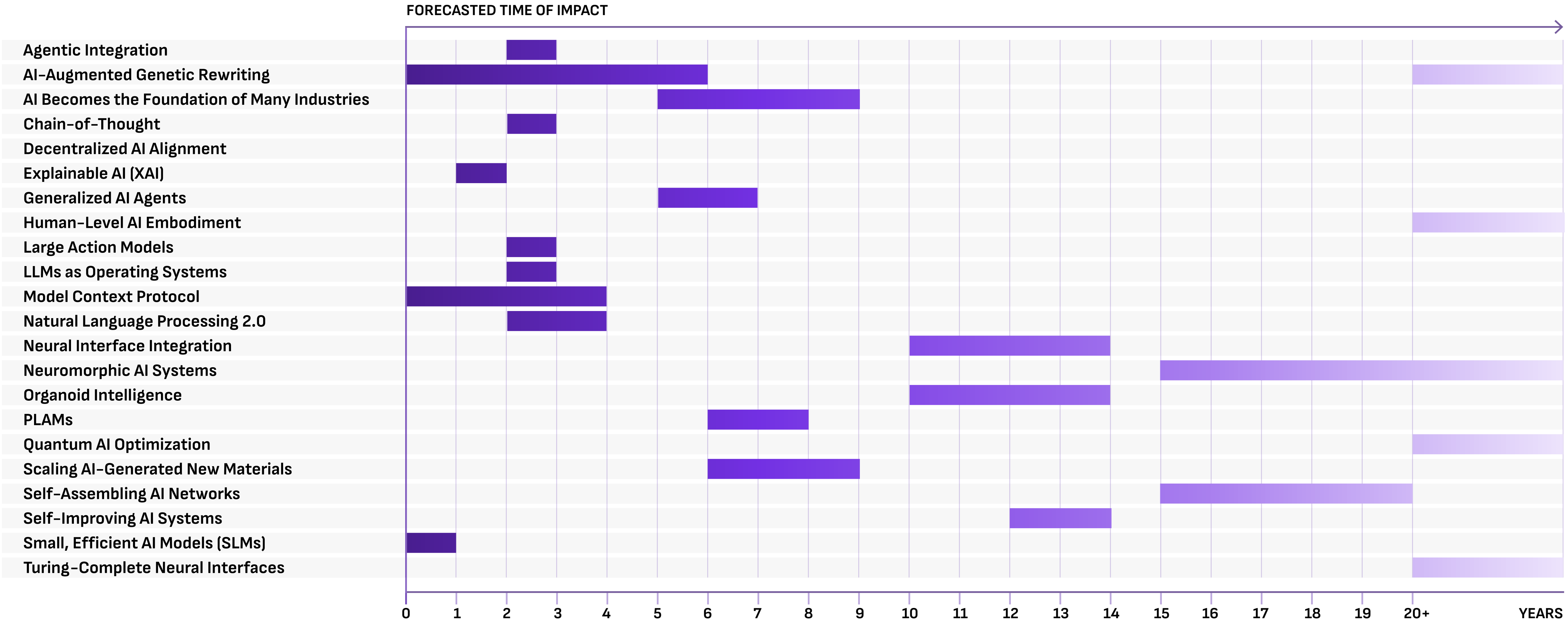
Your Interface Is Costing You Customers

Natural language is eating your user interface, turning it into abandonware. Every app, database, and system will soon be accessible through simple conversation. Organizations clinging to traditional interfaces will find themselves with the corporate equivalent of a flip phone in an iPhone world.

Scale Out Over Scale Up

History shows that core technologies inevitably become cheaper and more widely distributed. The same pattern is emerging in AI, and the companies that only chase ever-larger models and data centers risk being disrupted by nimble upstarts that can spin up smaller, more efficient systems, at lower cost.

Generative technologies advance over the next several years, while computing methods like organoid and neuromorphic computing drive developments in the long term.



Below, we highlight high level near-term developments to keep an eye on across industries.

SCALING

Enormous amounts of training data are still required for most AI models to learn. For example, recommender systems coupled with generative AI could lead to deep personalization for the hospitality and health care sectors—as long as data is made available. Historically, data is locked inside proprietary systems built by third parties, and regulation often hinders access to certain forms of data.

INVESTMENT

AI has seen cycles of enthusiasm and disillusionment, leading to either too much or not enough capital. Investors prioritize commercialization over basic R&D—though the latter yields bigger impact and often stronger returns. Investors' patience will influence progress and commercialization.

CONSTRAINTS ON ADOPTION

Even if a technology is maturing, constraints on its adoption can hinder its impact. For example, a business may refuse to adopt an automated system because it challenges existing orthodoxy or an existing successful strategy. This is especially true in health care, insurance, and financial services.

REGULATIONS

Advances in technology typically outpace regulatory changes. This has benefited AI, which until very recently was not targeted for regulation. Additionally, factors like whether local regulations are conflicting or complementary can influence adoption in the marketplace.

MEDIA MENTIONS

Increased awareness and enthusiasm can influence the momentum of a technology, even when there's been no real breakthrough. Future media bursts will drive AI momentum, especially if those stories are easily understood by the public.

PUBLIC PERCEPTION

How the public understands and responds to AI advancements will create or quell demand. This is especially true of generative AI and education/creativity/intellectual property/misinformation, as well as the role assistive technologies will play in shaping the future workforce.

R&D DEVELOPMENTS

The pace of new research breakthroughs can't be scheduled to coincide with a board meeting or earnings report. Factors like funding, quality, size of staff, and access to resources can improve the likelihood and speed of new discoveries. We closely monitor R&D developments but treat them as wild cards.

We expect to hear often from the world's largest technology and AI companies. For that reason, our 2025 list highlights individuals flying deeper under the public radar.

- **Dr. Adji Bousso Dieng, assistant professor at Princeton University,** for her work in deep probabilistic graphical modeling.

- **Alexandr Wang, founder and CEO of Scale AI,** for revealing DeepSeek's open-source AI model and for creating a leading data annotation platform that accelerates AI model development across various industries.

- **Dr. Abeba Birhane, senior fellow at Mozilla Foundation,** for her research on the ethical implications of AI and critiques of algorithmic biases.

- **Dr. Anima Anandkumar, Bren Professor of Computing and Mathematical Sciences at Caltech,** for developing AI algorithms that accelerate scientific discovery, including frameworks like neural operators for efficient simulations.

- **Dr. Chinasa T. Okolo, computer scientist and fellow at the Brookings Institution,** for her work in advocating for responsible AI adoption in the Global South and contributing to international AI safety reports.

- **Clément Delangue, CEO at Hugging Face,** for democratizing access to state-of-the-art NLP models and fostering an open-source AI community.

- **Dr. Cynthia Rudin, the Gilbert, Louis, and Edward Lehrman Distinguished Professor at Duke University,** for her work on interpretable machine learning models and ethical AI.

- **Dr. Dan Hendrycks, director at the Center for AI Safety,** for pioneering research in AI safety and developing Humanity's Last Exam, a test designed to evaluate AI risks, in collaboration with Scale AI.

- **Dean Ball, research fellow on AI & Progress at Georgetown University's Mercatus Center and author of the AI-focused Substack "Hyperdimensional,"** for his analysis on AI governance.

- **Dr. Devi Parikh, professor at Georgia Tech and co-founder of Yutori,** for pioneering work in visual question answering and vision-language models, which helped establish foundational benchmarks for how AI systems understand and reason about visual information in natural language contexts.

- **Dr. Ilya Sutskever, co-founder at Safe Superintelligence,** for pioneering work in deep learning and leading efforts to develop AI that surpasses human intelligence while remaining aligned with human interests.

- **Dr. Joelle Pineau, vice president of AI research at Meta,** for leading advancements in AI research and promoting open science, contributing to developments like the open-source language model LLamA.

- **Dr. Kazumi Fukuda, research scientist at Sony AI,** for her research in embodied intelligence, particularly in developing computational models that enable robots to perceive, plan, and act in dynamic environments.

- **Dr. Li Deng, chief AI officer at Vatic Investments,** for his contributions to speech recognition and deep learning.

- **Dr. Liang Wenfeng, CEO at DeepSeek,** for developing the R1 AI model, which rivals top competitors in capability but operates at a fraction of the cost.

- **Dr. Lila Ibrahim, chief operating officer at Google DeepMind,** for guiding the integration of AI research into practical applications and leading initiatives to apply AI in consumer products.

- **May Habib, CEO and co-founder at Writer,** for leading the development of enterprise AI tools that help businesses generate and manage high-quality content while ensuring brand consistency and compliance.

- **Dr. Nathan Lambert, research scientist at the Allen Institute for AI (Ai2) and author of the Interconnects blog,** for his contributions to the open science of language model fine-tuning.

- **Dr. Pieter Abbeel, director of the Berkeley Robot Learning Lab and co-director of the Berkeley Artificial Intelligence Research Lab,** for his work in robotics and reinforcement learning.

- **Dr. Sasha Luccioni, climate and AI lead at Hugging Face,** for developing tools to measure the carbon footprint of AI models and advocating for environmentally responsible AI practices.

- **Dr. Sheng Shen, research scientist at Google,** for coauthoring “Mixture-of-Experts Meets Instruction Tuning: A Winning Combination for Large Language Models,” exploring the integration of MoE architectures with instruction tuning to enhance language model performance.

- **Dr. Tim Brooks, leader of the world modeling AI team at Google DeepMind,** for his efforts in developing “world models” capable of simulating physical environments, advancing embodied AI in gaming and robotics.

- **Dr. Yang Zhilin, CEO at Moonshot AI,** for leading the development of AI models with long context understanding and expanding AI applications globally.

AI adoption is creating unprecedented opportunities for value creation...

OPPORTUNITIES

Build Internal AI Model Evaluation Frameworks

Companies that act now will gain first-mover advantage. These critical frameworks will enable rapid assessment and deployment of AI solutions while competitors struggle with ad-hoc evaluation methods.

Embed AI Capabilities Directly Into Core Offerings

Most CEOs see AI as a cost-cutting tool, missing its potential to create new revenue streams through enhanced products and services that transform customer experiences and business models.

Create AI-Powered Knowledge Management Systems

These systems transform static documentation into knowledge bases that continuously learn and adapt, letting businesses unlock significant value from institutional knowledge and retiring employees.

Invest in Domain-Specific AI Models

These focused models will deliver superior performance in targeted applications while requiring less data and compute resources than general-purpose alternatives, and early investors will benefit.

...but organizations face growing risks from technical complexity and talent scarcity.

THREATS

Assess Hidden Technical Debt

High-value AI clusters are prime targets for sophisticated cyberthreats, making cybersecurity investment essential. The stakes are especially high as thieves could use compromised AI clusters to steal proprietary models, impacting industries globally.

Delaying AI Adoption Means Rising Talent Costs

AI professionals, making it prohibitively expensive to transform later. CEOs often delegate AI strategy to technical teams, ignoring the larger organizational and cultural changes needed.

Compounding Data Advantage Could Concentrate Power

AI's first-movers are accumulating massive proprietary datasets and training pipelines that create nearly insurmountable barriers to entry. This advantage compounds over time and threatens to lock out new players.

Risks of Digital Colonization

Nations without sovereign AI capabilities become vulnerable to digital colonization as foreign AI systems shape their residents' information access and decision-making.

Companies face steep hidden costs and complex organizational hurdles as they rush to implement AI, from outdated infrastructure to employee resistance and regulatory demands.

As organizations hurry to deploy AI, they're facing a costly reality: Most of their data infrastructure is decades behind what's required. The investment needed to modernize data architecture often exceeds initial AI project budgets by 5–10x, creating a hidden barrier to transformation.

While companies eagerly invest in AI, they often overlook crucial investments in change management and employee support. This oversight could lead middle managers to view AI as a threat rather than a tool, fostering resistance that may dramatically slow implementation and adoption.

Build AI models with dedicated testing environments to rigorously evaluate financial risk against historical market conditions and stress scenarios. These systems require specialized hardware and compliance monitoring infrastructure to handle complex simulations while maintaining audit trails.

Establish rigorous protocols for auditing AI models that enable tracking of decisions, data lineage, and performance drift across systems. Integrating automation with human oversight is crucial, along with detailed audit trails that comply with both technical governance and regulations.

Know your constraints. Either find trusted external partners with expertise in both AI and your domain, or do it in-house. These teams must meld their AI skills with industry-specific knowledge to create solutions that address both regulatory and technical challenges while delivering measurable value.

Every piece of technical debt becomes a critical bottleneck as AI systems demand more flexible, interconnected infrastructure. Smart companies will treat technical debt elimination as a core part of AI strategy, not a separate IT initiative.

Technology Deployment | Capital Expenditure | Talent Development | Regulatory Influence

Important terms to know before reading.

AGENTIC AI
This refers to AI systems that exhibit autonomous decision-making, goal-setting, and adaptive problem-solving capabilities. Unlike traditional AI models that passively generate responses based on user prompts, agentic AI proactively takes actions, interacts with its environment, and refines its strategies over time.

AGENTS
AI-powered entities that perceive their environment, make decisions, and take actions autonomously to achieve specific goals. Agents can range from simple automation tools to complex, multimodal AI systems that interact dynamically with users and other systems.

AGI (ARTIFICIAL GENERAL INTELLIGENCE)
A designation for AI systems that match and then exceed the full range of human cognitive abilities across all economically valuable tasks. AGI remains theoretical, but its potential implications for labor markets, governance, and global security are actively debated.

AI ETHICS
A multidisciplinary field that studies the societal, economic, and ethical risks of AI, including bias, privacy, misinformation, and existential threats. AI ethics frameworks guide policy and regulation to ensure AI development aligns with human values.

AI GOVERNANCE
The systems, policies, and international agreements that regulate the development, deployment, and oversight of AI technologies. AI governance is critical to mitigating risks, ensuring fair competition, and addressing geopolitical tensions around AI capabilities.

ALGORITHM
A structured set of rules or processes for solving specific problems or performing tasks. In AI, algorithms determine how data is processed, insights are generated, and decisions are made.

ALIGNMENT
The process of ensuring that an AI system's goals, behaviors, and decision-making align with human intentions, ethical principles, and regulatory standards. Misalignment can result in unintended consequences, including biased or harmful outcomes.

ARTIFICIAL SUPERINTELLIGENCE (ASI)
A hypothetical future AI system that surpasses human intelligence across all domains, including creativity, general wisdom, strategic planning, and scientific discovery. ASI raises complex questions about control, governance, and existential risk.

AUTOMATIC SPEECH RECOGNITION (ASR)
AI-driven systems that convert spoken language into written text. ASR powers virtual assistants, transcription services, and multilingual voice interfaces in enterprise and consumer applications.

AUTONOMOUS AI
AI systems capable of independent decision-making and execution of tasks without human intervention. Autonomous AI is critical in robotics, finance, cybersecurity, and military applications, requiring rigorous safeguards to ensure responsible use.

CHAIN OF THOUGHT (COT) REASONING
An AI reasoning method where models solve problems step-by-step, mimicking human-like logical deduction. This improves performance in complex decision-making tasks, including math, legal analysis, and medical diagnostics.

COMPUTER VISION
AI-driven technology that enables machines to process, analyze, and derive meaning from digital images and video. Used in security surveillance, industrial automation, medical imaging, and self-driving vehicles.

EDGE AI
AI models that run directly on edge devices (e.g., smartphones, IoT sensors, autonomous drones) rather than centralized cloud servers. Edge AI enables real-time processing, reduces latency, and enhances data privacy.

FOUNDATION MODEL
A large-scale AI model pretrained on vast amounts of data and adaptable to multiple tasks without requiring retraining from scratch. Foundation models underpin modern AI applications, including generative AI, autonomous systems, and enterprise automation.

GENERATIVE AI (GENAI)
AI technologies capable of generating novel content, including text, images, music, video, and code. GenAI is transforming industries such as media, design, marketing, and customer service while raising concerns about intellectual property and misinformation.

GPU (GRAPHICS PROCESSING UNIT)
Specialized hardware optimized for parallel computing, accelerating AI model training, deep learning, and high-performance computing tasks. GPUs are essential for running large-scale AI models and data-intensive simulations.

MODEL
A trained AI system that analyzes data to make predictions, generate insights, or automate decision-making. Models vary in complexity, from simple regression models to advanced deep learning architectures.

MULTIMODAL AI
AI systems that process and integrate multiple types of data—such as text, images, video, and audio—to improve contextual understanding and decision-making. Multimodal AI powers advanced chatbots, virtual assistants, and medical diagnostics.

NATURAL LANGUAGE PROCESSING (NLP)
AI-driven processes that enable machines to understand, interpret, and generate human language. NLP powers chatbots, translation services, sentiment analysis, and automated content moderation.

NEURAL ARCHITECTURE SEARCH (NAS)
An AI-driven method for automatically optimizing neural network structures, improving performance while reducing the need for manual tuning by researchers.

PARAMETER
An internal variable of an AI model that is fine-tuned during training to improve accuracy and efficiency. Large AI models contain billions of parameters, making their training computationally intensive.

PROMPT ENGINEERING
The practice of designing effective inputs (prompts) to guide AI models in generating desired outputs. Prompt engineering is crucial for optimizing generative AI performance in business and creative applications.

QUANTUM AI
The intersection of quantum computing and AI, where quantum algorithms enhance machine learning efficiency. Quantum AI has the potential to revolutionize cryptography, materials science, and optimization problems.

RECOMMENDER SYSTEMS
AI-driven algorithms that analyze user behavior and preferences to suggest relevant products, content, or services. Used in e-commerce, streaming platforms, and digital advertising.

REINFORCEMENT LEARNING FROM HUMAN FEEDBACK (RHLF)
A training method where AI models learn through iterative feedback from human evaluators, improving their accuracy, ethical alignment, and usability in real-world applications.

SELF-SUPERVISED LEARNING
A machine learning approach where AI models learn from raw, unlabeled data by identifying patterns and relationships within the dataset. This method reduces dependency on human-labeled training data.

SUPERVISED LEARNING
A training method where AI models learn from labeled datasets, using known input-output pairs to improve predictive accuracy in new data.

SYMBOLIC AI
An AI approach that represents knowledge using human-readable symbols and logical rules, enabling reasoning and problem-solving. Often used in expert systems and explainable AI models.

SYNTHETIC DATA
Artificially generated data used to train AI models when real-world data is scarce, biased, or privacy-sensitive. Synthetic data enhances AI performance while mitigating data collection risks.

TRAINING DATA
The dataset used to train AI models by identifying patterns, making decisions, or generating predictions. The quality and diversity of training data significantly impact model accuracy and fairness.

TRUSTWORTHY AI
AI systems designed with transparency, fairness, accountability, and security to foster public trust and regulatory compliance. Trustworthy AI is a key focus for government and enterprise AI strategies.

UNSUPERVISED LEARNING
A machine learning approach where AI models detect patterns and structures in data without labeled outputs, enabling tasks like clustering and anomaly detection.

XAI (EXPLAINABLE AI)
AI systems designed to provide transparent, human-interpretable explanations for their decision-making processes, increasing accountability and trust in high-stakes applications like health care and finance.

ZERO-SHOT LEARNING (ZSL)
An AI technique where models generalize knowledge from previously learned concepts to perform tasks without direct prior training on those tasks. Used in applications like language translation and image recognition.

ARTIFICIAL INTELLIGENCE TRENDS

MODELS, TECHNIQUES, & RESEARCH

MODELS, TECHNIQUES, & RESEARCH

AI models require massive data and computing resources to unlock their transformative potential (or so we thought).

Generative AI Modalities Expand

Humans don't just learn by reading—we observe, listen, and synthesize information from multiple sources. AI is now following suit, integrating inputs like text, images, and sound to bridge the gap between what we describe and what machines can fully understand. 2024 marked the year when multimodal AI capabilities not only matured but began transforming real-world applications.

OpenAI's GPT-4o builds on the multimodal progress of 2023 by integrating text, vision, and voice into one robust model. Its real-time conversational capabilities open doors for fluid, human-like interactions. GPT-4o's ability to analyze and generate insights from combined text, audio, and image inputs allows it to solve complex tasks with remarkable depth and accuracy. Anthropic's Claude 3 brings sophisticated visual interpretation to enterprise settings, where roughly half of knowledge bases are image-based. This capability is particularly transformative in health care, where AI can now connect medical imagery with patient records for enhanced diagnostics. On the consumer side, multimodal AI is starting to become second nature. Instead of typing out queries, users now share photos of recipes to adjust portions or upload images of rashes for medical suggestions. While this democratization makes expertise more accessible, it also raises questions about accuracy and ethical boundaries when AI tools replace professional judgment.

MIT and Microsoft's Large Language Model for Mixed Reality (LLMR) is pushing the multimodal boundaries even further. LLMR uses AI to simplify the creation and modification of virtual environments. Instead of needing complex coding, LLMR enables users to describe their vision in plain language, and the system transforms those words into interactive mixed reality experiences in real time. For example, a user might say, “Place a green bench in the park next to the fountain,” and the system executes it instantly.

While 2024's breakthroughs in multimodal AI mark a technological leap forward, their true significance lies in how they're reshaping the fundamental relationship between humans and machines, moving us from giving commands to having conversations.

Fine Tuning

Fine-tuning—the process of refining LLMs on specialized datasets—is improving our ability to customize and control AI systems. In 2023, the University of Washington's QLoRA breakthrough marked a turning point, enabling the fine-tuning of massive 65-billion-parameter models on a single GPU with just 48GB of memory—a 16-fold efficiency improvement over traditional methods. Building on this foundation, in 2024, Answer.AI integrated QLoRA with Fully Sharded Data Parallel processing, making it possible to train 70-billion-parameter models on consumer-grade hardware. This democratization has profound implications: Researchers and developers can now experiment with large-scale language models without access to expensive data center infrastructure.

The impact extends beyond accessibility. In the biological sciences, researchers have adapted fine-tuning techniques to protein language models (PLMs), which are trained on extensive datasets of protein sequences. These models are now being fine-tuned to predict protein stability, functions, and interactions with remarkable accuracy. Fine-tuned PLMs outperform their non-tuned counterparts across multiple benchmarks, showcasing enhanced predictive capabilities.

Fine-tuning isn't just a technical capability—it's a strategic business advantage. In the enterprise context, companies can

MODELS, TECHNIQUES, & RESEARCH

use fine-tuning to customize powerful AI models like GPT and Claude for their specific needs without building from scratch. Health care providers can enhance diagnostic capabilities by training models on anonymized patient records while maintaining HIPAA compliance, while financial institutions can embed regulatory requirements—from GDPR to PCI DSS—directly into their AI workflows. This dramatically reduces development costs and time-to-market while ensuring AI systems speak the organization's language, understand industry-specific contexts, and operate within required compliance frameworks.

Automated Reinforcement Learning

Traditional AI training using Reinforcement Learning from Human Feedback (RLHF) involves people rating AI responses to help improve the system. While this method works well, it's expensive and time-consuming. DeepSeek found a clever alternative—the startup developed a way to train AI systems using automated computer feedback instead of human ratings. While more subjective tasks (like creative writing or open-ended questions) still need some human input, DeepSeek's automated method works especially well for tasks with clear right/wrong answers, like math and coding problems. To make this automated training even more efficient, DeepSeek created a special method called GRPO (Group Relative Policy Optimization) and tested it first with its math-focused model. The company isn't alone. Microsoft Asia developed a math model using comparable techniques, Ai2 created a model called Tulu that combines both automated and human feedback, and Hugging Face is working on recreating DeepSeek's approach to better understand how it works. The key takeaway is that DeepSeek showed it's possible to create high-performing AI systems with less reliance on expensive human feedback, particularly for certain types of tasks. This could make AI development more efficient and cost-effective, though human input is still valuable for some applications.

Evolutionary Composition

Sakana AI is challenging the conventional wisdom that bigger, more expensive models are the only path to better AI. Instead of training massive models from scratch—a process requiring enormous computational resources—the Japanese firm has developed an elegant alternative: using evolutionary algorithms to automatically discover optimal ways to combine existing AI models. This "evolutionary optimization" approach is big; by intelligently merging models from different domains—such as language processing and visual understanding—Sakana creates hybrid systems that exceed the capabilities of their individual components. The results are impressive: The experiments produced Japanese language models with enhanced mathematical reasoning and cultural awareness that outperformed larger, more resource-intensive systems.

The implications extend far beyond technical achievement. This methodology democratizes advanced AI development by reducing the need for massive computing infrastructure and specialized expertise. Rather than requiring tens of millions in computing resources, developers can now create sophisticated multi-capable models by intelligently combining existing ones. Most significantly, Sakana's approach suggests a future where AI advancement isn't just about building bigger models but about finding smarter ways to combine existing ones. Just as nature creates complexity through the combination and evolution of simpler elements, this new paradigm points to a more sustainable and accessible path forward in AI development—one where innovation comes from intelligent composition rather than brute-force scaling.

Mixture of Experts

Unlike the previous approach that merges entire trained models, mixture-of-experts (MoE) divides up the work inside a single framework by creating multiple specialized "expert" sub-models. Think of it like having a team of people where one person is great

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at math, another at writing, and another at design, with a manager who knows who to call on for each task. This “manager” (the gating mechanism) directs each input to the right expert, so every piece of the job is handled by the specialist best suited to it. By splitting tasks among experts and letting the gating mechanism handle the “who does what,” MoE models can become more efficient and accurate than if one giant, one-size-fits-all model tried to handle everything on its own.

Notably, DeepSeek’s January 2025 release, R1, uses MoE at its core. As reported, DeepSeek claims to have built a ChatGPT-like system at a fraction of the usual cost by employing MoE (along with other techniques such as knowledge distillation and reinforcement learning). Because MoE breaks a large model into specialized “experts” and relies on a gating function to route each request to the most appropriate expert, it can be more efficient and potentially less expensive to train or run than a single giant monolithic model. DeepSeek’s success with this approach has sparked new attention on MoE as a viable alternative for scaling AI without requiring massive, prohibitively expensive hardware.

Autonomy-of-Experts

Though DeepSeek is what put MoE in the news for the general public, others had already made significant breakthroughs in the field. Researchers at Renmin University of China, Tencent, and Southeast University released a paper that describes a new “Autonomy-of-Experts” (AoE) approach for mixture-of-experts models. While the typical MoE model relies on a “router” that makes its best guess of which specialist should handle each incoming question or input, AoE doesn’t need the router. Instead, each expert peeks at the input and says, “I can handle this,” or “No thanks, that’s not my specialty,” based on how strongly it lights up the expert’s internal signals (the “activation norms”). The strongest signals win, so those experts step up, and the rest step back. In other words, each expert autonomously decides whether it’s the best fit. This cuts out the middleman (the router) entirely.

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LLMs as Operating Systems

Imagine an operating system fundamentally powered by a large language model (LLM), where the LLM is not just an add-on but the core kernel of the OS. This OS could automate routine tasks with unprecedented sophistication, eliminating the need for manual intervention. It would move beyond traditional graphical user interfaces and command-line interactions, embracing a more intuitive, natural language–based approach. Users could interact with their computers through conversational commands, inquiries, or requests for specific tasks, and the LLM would interpret these inputs, executing a series of actions to deliver the desired outcomes.

One such project, AIOS, envisions an LLM as the "brain" of the OS. AIOS optimizes resource allocation, manages context switching, facilitates concurrent agent execution, provides tools for agents, and maintains access control. The LLM handles complex decision-making, turning the OS into a more intelligent, adaptive system. Another project, MemGPT, focuses on enhancing LLM-driven systems by integrating long-term memory and improving reasoning capabilities. Traditional LLMs are limited by small context windows, restricting how much information they can process at once. MemGPT addresses this by introducing a multilevel memory architecture, inspired by traditional OS memory management techniques like virtual memory, to enable more complex and contextually aware processing over time. Together, these projects represent the future of LLM-centric operating systems, enabling more efficient, natural, and powerful interactions.

LLMs: Bigger and More Expensive

LLMs have grown exponentially in size and cost over the past decade, driven by the "bigger is better" paradigm. This approach emerged from scaling laws, first introduced by Prasanth Kolachina in 2012 and later validated by Kaplan et al. in 2020, which demonstrated a strong correlation between model size and performance. Following these insights, the industry has pursued increasingly larger systems, progressing from GPT-2's 1.5 billion parameters in 2019 to models with trillions of parameters like GPT-4 and PaLM 2 in 2023. The financial impact of this growth is significant: Stanford's 2024 AI Index Report estimates place the training costs of top-tier models at unprecedented levels, with OpenAI's GPT-4 requiring approximately $78 million in compute and Google's Gemini Ultra costing an estimated $191 million.

The benefits of scaling have been substantial and well-documented. Larger models have demonstrated remarkable capabilities in handling complex tasks, showing improved accuracy and efficiency across a wide range of applications. These achievements have validated, at least partially, that bigger is indeed better. However, this progress has come with significant costs and challenges. Training GPT-4 required approximately 10,000 times more computational resources than its predecessor GPT-2, necessitating enormous investments in infrastructure and specialized hardware.

Perhaps most significantly, the relationship between model size and performance has proven more complex than initially assumed. Many tasks exhibit diminishing returns as models grow larger, calling into question the long-term viability of this approach. This observation has particular relevance for businesses, which are discovering that larger models don't automatically translate to better solutions for their specific needs. The combination of rising costs, environmental concerns, and uncertain performance benefits has prompted a critical examination of the scaling paradigm.

As the field matures, a more nuanced approach to AI development is emerging. Rather than pursuing size alone, researchers are increasingly focusing on efficiency improvements and the development of smaller, specialized models.

Chain-of-Thought Models

As larger models reach practical and financial limits, researchers are shifting attention to new approaches such as Chain-of-Thought (CoT), which emphasizes

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deeper real-time reasoning rather than raw parameter counts. For more than a decade, AI progress has been largely driven by the pretraining scaling law, which emerged with AlexNet in 2012 and gained momentum with the Transformer architecture in 2017. This law states that increasing the amount of training data (now reaching trillions of tokens), expanding model parameters, and using more compute (FLOPS) leads to better performance across various tasks. Put simply, pretraining scaling laws describe how larger models, with more data and compute, achieve superior performance.

Now, there is a new scaling law in town. Previously, most computational cost was concentrated in pretraining. Once a model was trained, running inference—generating responses or completing tasks—required significantly less compute. Inference scaled in a straightforward way: The more requests a model handled, the more compute it used. However, the introduction of CoT models has fundamentally changed this paradigm. OpenAI's o1 model and DeepSeek's R1 have demonstrated that inference compute is no longer strictly proportional to output length. These models generate intermediate "logic tokens," acting as an internal scratchpad to break down problems into structured reasoning steps. This shift means that the more tokens dedicated to this internal process, the better the model's output. Essentially, it mimics how humans improve their work—double-checking, verifying calculations, and cross-referencing solutions to ensure accuracy.

Expect a growing emphasis on dynamic inference strategies, where models can flexibly adjust the number of internal logic tokens based on task difficulty or desired accuracy. As a result, inference compute could become much more significant relative to training, driving the need for more efficient hardware solutions, better optimization techniques, and new business models around usage-based compute. Overall, AI development will likely shift toward architectures and methods that let models "think out loud," enabling deeper reasoning and better outcomes at the cost of increased on-the-fly processing.

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Small Language Models

Small language models (SLMs) are proving that bigger isn't always better. These compact models can match or exceed the performance of their larger counterparts in specific tasks, while demanding far less computational power and resources. SLMs showcased impressive performance in task-specific scenarios, such as zero-shot text classification. Research across multiple datasets revealed that models with fewer parameters could rival larger counterparts, emphasizing their potential for efficiency without compromising effectiveness. Additionally, cost-effective solutions like OpenAI's GPT-4o mini cost more than 60% less compared to previous models, making high-quality AI more accessible to businesses and developers.

Microsoft's Phi-3-mini stands as another example, achieving superior reasoning and logic capabilities with just 3.8 billion parameters—outperforming models twice its size. Similarly, Meta's Llama 3.2 family demonstrates the viability of smaller models, offering variants from 1 billion to 90 billion parameters that prioritize efficiency without sacrificing effectiveness.

This shift toward smaller models is supported by industry experts like Andrej Karpathy, who advocates for distilling models to their essential "cognitive core." His research suggests that even a 1-billion-parameter model could provide sufficient cognitive capabilities, as much of the additional data in larger models may not directly enhance performance. This insight has practical implications, particularly in consumer technology. Apple's OpenELM models, for instance, enable on-device AI processing, delivering responsive, personalized experiences while maintaining privacy and energy efficiency. In 2024, models like the SlimLM series enabled robust processing on devices such as smartphones, eliminating the need for cloud-based computation. This innovation marked a leap forward in AI accessibility, enabling users to perform tasks directly on their devices while maintaining privacy and reducing latency.

The impact of SLMs extends beyond general applications into specialized domains. At Ignite 2024, Microsoft collaborated with industry leaders like Bayer and Rockwell Automation to develop targeted SLMs for agriculture and manufacturing, demonstrating how these compact models can excel in specific sectors without the overhead of larger, general-purpose systems. Looking forward, the concept of "companies of LLMs"—where multiple specialized models work in parallel—could represent the next evolution, combining the advantages of both large and small models in a modular approach.

Grounding and Context Augmentation

NotebookLM from Google Labs transforms AI into a personalized research assistant by "grounding" it in your Google Docs. Unlike traditional chatbots, it ties responses to your specific notes and sources, enabling insights that are highly relevant and trustworthy. This feature is designed to tackle information overload, making it easier to synthesize and connect ideas from multiple sources efficiently. Grounding ensures that AI outputs are anchored in verified data, reducing errors like hallucinations. NotebookLM builds on this by leveraging contextual augmentation, which enriches responses with nuanced understanding tailored to your needs. This approach doesn't just deliver answers but delivers the right answers for your unique context.

Tools like GenAI Data Fusion extend this principle to businesses, aggregating and contextualizing enterprise-specific data. By rooting outputs in tailored datasets, companies can achieve highly accurate, task-specific insights for applications ranging from research to operational analytics. Grounding and contextual augmentation mark a shift in AI, turning generic systems into precise, adaptive tools that meet individual and organizational needs.

Overcoming the Data Shortage

The availability of high-quality data is emerging as a bottleneck in the development of large AI models. According to Epoch AI, the reservoir of high-quality textual data on the public internet may be exhaust-

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ed as early as 2026. Initially, researchers estimated the stock of high-quality language data could run out by 2024, while low-quality data might last another two decades, and image data could face depletion by the late 2030s to mid-2040s. Although the 2024 thresholds have not yet been reached, the looming scarcity is pushing AI labs to explore alternative strategies for sourcing training data.

This prediction has sparked diverse strategies among AI labs. Some are pursuing private data sources, purchasing from brokers or licensing content from publishers. Others are exploring untapped audio and visual data, with video content offering particularly valuable insights into real-world physics and dynamics. Companies like Scale AI and Surge AI are building extensive networks of contributors, including Ph.D.-level experts, to create and annotate specialized datasets. These approaches, however, come at a high cost, with some estimates suggesting AI labs are spending hundreds of millions of dollars annually on these initiatives.

An alternative method involves using one AI model to generate vast amounts of synthetic data to train another, but it's risky. Studies have shown that models trained predominantly on synthetic data can experience "model collapse," where their outputs become less diverse and fail to reflect real-world distributions. A related phenomenon, termed Model Autophagy Disorder (MAD), has been observed in generative image models, where reliance on synthetic data leads to a notable decline in output quality.

One promising solution lies in techniques such as "self-play," where models improve through competition or collaboration with themselves. Google DeepMind's AlphaGo, which famously defeated the human world champion in Go after training against itself, exemplifies this approach. Today, self-play continues to inform cutting-edge LLM development, offering a pathway to overcome data limitations while maintaining performance and innovation.

Open-Source AI

In January 2025, Chinese AI company DeepSeek launched R1, an open-source reasoning model designed to compete with—and potentially outperform—OpenAI's o1 at a fraction of the cost. While R1's reasoning process is slower than that of many general-purpose models, it delivers more nuanced and accurate responses. Alongside its flagship 671-billion-parameter version, DeepSeek also introduced six smaller "distilled" models, starting at 1.5 billion parameters and capable of running on local devices.

Other open-source models are likewise closing the performance gap with proprietary alternatives. Meta's Llama 3.1 now rivals GPT-4 on key benchmarks, and Mistral AI's models offer capabilities on par with top closed-source solutions—so much so that Mistral AI's recent $487 million funding round catapulted it to unicorn status. As a growing number of open-source models achieve high-level performance, corporations are increasingly taking note. The Brave browser, for example, has integrated Mistral AI's Mixtral 8x7B model into its Leo assistant, while Wells Fargo has adopted Meta's Llama 2 for internal applications.

This momentum reflects a broader trend toward open-source AI. GitHub statistics reveal that AI-focused repositories have skyrocketed from just 845 in 2011 to 1.8 million in 2023—an impressive 59.3% increase in 2023 alone. During the same period, community engagement soared, with GitHub stars for AI projects jumping from 4 million to 12.2 million between 2022 and 2023. This surge highlights the growing appetite for collaborative development, signaling that open-source AI will remain a driving force well into the future.

Modular AI

Rather than building monolithic models, the modular AI approach breaks AI systems into specialized, independent components that can be mixed and matched like building blocks. Each module handles specific tasks or domains, allowing for precise control over system capabilities

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and resources. One example is a recent proposal to develop large language models (LLMs) using "bricks": modular components representing specific tasks or knowledge domains. These bricks can emerge during pretraining or be custom-designed after training for particular applications. This approach dynamically activates only the relevant bricks for a task, significantly reducing computational and energy costs while improving scalability. Research has shown that neurons and layers within LLMs naturally specialize in different functions, highlighting the promise of modular design in optimizing AI systems.

Similarly, MAGNUM, a modular multimodal AI framework introduced at NeurIPS 2023, offers unparalleled flexibility by processing structured and unstructured data across multiple input types, including text, images, video, audio, and time-series data. Composed of input-specific modules, MAGNUM excels at combining and extracting information from diverse data types, performing well across 10 real-world tasks like medical diagnostics and weather forecasting. Notably, it is robust against missing or incomplete data, a common challenge in multimodal AI systems.

Another modular AI advancement is the MASAI (Modular Architecture for Software-engineering AI) framework, which uses specialized sub-agents powered by LLMs to tackle distinct sub-problems in software engineering. MASAI allows for fine-tuned problem-solving strategies across sub-agents, efficient information retrieval, and reduced computational overhead. This architecture achieved a top performance of 28.33% on the SWE-bench Lite dataset, demonstrating its effectiveness in resolving real-world GitHub issues.

Large Action Models

Large action models (LAMs) go beyond traditional large language models by executing tasks rather than just processing language. They act as autonomous agents that can interact with computer interfaces—clicking buttons, moving cursors, and typing text. An early example is Claude 3.5 Sonnet, which can interface with computers like a human would: navigating desktop applications, moving cursors and clicking buttons, typing text, interpreting screenshots and responding accordingly, and executing complex, multistep tasks on a computer.

This capability marks a transition in AI, bridging the gap between conversational models and full-fledged autonomous systems. While currently operating by impersonating a user—interacting with interfaces designed for humans—LAMs demonstrate the foundational steps toward AI systems that could manage tasks directly within digital ecosystems. For instance, a LAM could book a plane ticket or draft a document by navigating apps and websites without user intervention.

The major AI companies—Google, Apple, Microsoft, OpenAI, and others—are positioning these agents as the future of AI. Their goal is to create systems that move beyond chat interactions and actively engage with the world. Claude's ability to interact with a desktop computer demonstrates this potential, but it also raises significant questions about privacy and control. To function, LAMs require broad access to users' digital environments—reading screens, accessing files, and executing commands. This level of access creates an unprecedented intimacy between AI and its users, raising concerns about how data is collected, stored, and used. Companies see this as a massive opportunity. By integrating deeply into users' digital lives, AI companies could gain access to data beyond anything previously collected by traditional tech giants, potentially redefining norms around data privacy.

Personal Large Action Models

Taking the concept of large action models one step further, personal large action models (PLAMs) represent an even more intimate evolution of AI. While current LAMs are trained on general internet data, PLAMs would be specifically trained on the digital footprint of a single user. Imagine

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an AI that knows your social media interactions, online purchasing habits, biometrics, location data, texts, calendar, and email—understanding not just your data, but the exact context of your life: where you are, who you're with, and what you're doing.

While PLAMs are still largely theoretical, they would mark a significant shift in AI personalization. These systems would learn from every aspect of your digital life: banking records, browsing history, IoT devices, car usage, wearable data, and biological information. This comprehensive understanding would allow the PLAM to grasp your routines and preferences, eventually making decisions that align precisely with what you would have chosen—from purchases to schedule management.

As these models build accuracy over time, they would take on increasingly complex decision-making roles, effectively becoming a digital extension of a person. This level of personalization creates a significant lock-in effect—transferring years of individualized learning to a new system would be impractical, if not impossible. Companies that successfully deploy PLAMs early could therefore establish themselves as indispensable digital partners, with users becoming deeply integrated into their ecosystem.

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AI model safety requires a balance of rigorous testing and governance to prevent harm without stifling innovation.

Explainable AI (XAI)

Explainable AI (XAI) addresses the challenge of understanding how AI systems, especially complex models like deep neural networks, reach their conclusions. Many AI models, often labeled "black boxes," operate without clear insight into their internal decision-making processes. These deep learning models are built on layers of artificial neurons that process data and identify patterns—the interconnected layers can perform highly complex tasks, but their intricacies make it hard to trace how they arrive at specific outputs. This lack of transparency is problematic, particularly in sensitive sectors like health care, finance, and criminal justice, where understanding an AI's logic can impact critical decisions.

XAI aims to bridge this gap by developing methods to reveal the workings of these "black box" models. It seeks to provide clear explanations that help users understand how certain inputs result in particular outputs, enabling more informed and trustworthy AI use. For instance, recent research from the University of California, San Diego has found mathematical formulas that describe how neural networks identify relevant data patterns. By providing these clearer insights into how complex models, like deep neural networks, make decisions, XAI aims to empower users and researchers to better understand, validate, and refine AI applications.

AI Optimization

AI optimization (AIO) is a new field focused on shaping how AI models, particularly chatbots and language systems, respond to certain queries and references. Similar to search engine optimization (SEO), which boosts website rankings in search results, AIO is designed to refine interactions within AI models, targeting a favorable or specific portrayal of brands, individuals, or products. With AIO, companies can guide chatbots to respond positively to certain prompts, potentially recommending a brand, showcasing a positive product review, or emphasizing particular qualities of a person. Techniques like "strategic text sequences" and "invisible text" embedded on websites can subtly influence these AI-generated answers. A restaurant might use AIO to ensure it's listed as the "best restaurant" in a city, or a tech company might seek to have its product as the top choice in a category. However, AIO also raises ethical concerns around transparency and manipulation, especially as people increasingly rely on AI for information.

Decentralized AI Alignment

As AI systems become more powerful, safeguards are necessary to ensure these technologies align with human values and do no harm. This is especially important as AI surpasses human intelligence. AI alignment research focuses on designing systems that act according to human goals and ethical standards. OpenAI, founded in 2015 with a mission to "advance digital intelligence in a way that benefits humanity," has prioritized this alignment to avoid risks from the unchecked development or misuse of advanced AI. For that reason, it was a surprise to some when in May 2024, OpenAI disbanded its Superalignment team, which had been dedicated to ensuring AI safety. While the company said this work would now be integrated across its broader research teams, there is speculation that internal challenges influenced this decision. For instance, Jan Leike and Ilya Sutskever, former OpenAI Superalignment co-leads, cited struggles in accessing sufficient computing resources for their alignment research before they left OpenAI. Other tech giants, such as Google and Meta, have made similar moves, redistributing their AI safety work throughout their organizations rather than in specialized teams. While these companies argue that integrating safety across departments prevents isolation, critics argue that a ded-

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icated safety team is crucial for securing the resources and influence necessary to prioritize ethical oversight effectively.

Mission Drift in AI Alignment

Many AI alignment organizations, originally established to ensure that AI serves humanity's best interests, are increasingly taking actions that appear to conflict with their founding principles. For instance, Palantir is partnering with Anthropic to deploy Claude models in US government intelligence and defense operations. Marketed as an "asymmetric AI advantage," the collaboration introduces AI to classified environments, claiming to enhance analytics and operational efficiencies. However, this move has sparked controversy due to its potential conflict with Anthropic's original mission to create AI systems aligned with human values and to prevent misuse. Critics argue that applying AI in classified operations, which may involve surveillance or military use, runs counter to Anthropic's foundational principles.

This type of move isn't unique to Anthropic. OpenAI has transitioned into a for-profit public benefit corporation. The shift is driven by the financial and operational challenges of its nonprofit origins, allowing OpenAI to streamline decision-making and attract significant capital. While this restructuring could enable faster progress, it also introduces competing profit motivations that may dilute the organization's commitment to its mission of ensuring artificial general intelligence benefits for all of humanity. It is entirely possible for a for-profit organization to remain mission-driven—many successful examples exist—but doing so demands unwavering focus and discipline.

These moves signal a broader shift within the AI alignment field, where organizations must now balance ethical responsibilities with the demands of profit-driven models. While such alignment is possible, it requires disciplined governance and vigilance to ensure the original missions remain intact amidst growing external pressures.

Indexing Trust

As AI systems evolve, distinguishing between authentic and tampered data—whether altered deliberately or by mistake—will become increasingly challenging. Trust is foundational to the effective use of AI; without it, decades of research and technological advancements may lose their value. Leaders across all sectors—government, business, and nonprofits—need to trust the data and algorithms driving these technologies. Building this trust demands transparency, a significant challenge but one that researchers are actively addressing.

A major step toward transparency has been the development of the Foundation Model Transparency Index (FMTI), created by researchers from Stanford, MIT, and Princeton. This scoring system evaluates transparency in AI model development, functionality, and use. According to the FMTI's May 2024 report, the overall transparency score has improved since October 2023: The mean score rose to 58 out of 100, and the top score reached 85, a 31-point increase. Additionally, each of the eight developers assessed in both rounds improved their scores, with 96 out of 100 indicators met by at least one developer and 89 by multiple developers. And notably, all 14 companies assessed disclosed new information, for an average of 16.6 indicators each.

Other organizations are also working to establish benchmarks that researchers can use to drive improvements. The National Institute of Standards and Technology provides an AI Risk Management Framework, and University of California, Berkeley offers a Taxonomy of Trustworthiness for AI. Indexing trust serves not only as a valuable benchmark for researchers but also as a tool for policymakers. By highlighting areas of persistent and systemic opacity, it clarifies where policy interventions may be needed.

Realtime Deepfake Detectors

Last year marked when we moved past the "uncanny valley," a term describing

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the discomfort people feel when viewing robots or digital avatars that seem almost, but not quite, human. This concept extends to deepfake AI content; previously, it was easy to distinguish between genuine and AI-generated media based on instinct. Today, distinguishing real from fake is far harder, and we can no longer rely on instinct alone. Deepfakes can now deceive even the most discerning eye, creating risks around authenticity and security.

Researchers are stepping up to meet this challenge. At NYU, a team has introduced methods to counteract real-time deepfakes, which are advanced AI-generated audio and video imitating real people in live settings. Their solution includes eight visual tests designed to help users recognize when they are not interacting with a genuine person. Similar to CAPTCHA, these tests ask questions or make requests that deepfake systems struggle to answer correctly. The researchers found challenges like specific head movements and facial obstructions effective. Human evaluators achieved 89% Area Under the Curve score in identifying deepfakes, while machine learning models achieved 73%. The challenge of deepfakes extends to audio, particularly in call environments where greater human control is essential. To address this, the NYU researchers developed a system that combines human intuition with machine analysis to support call receivers. Their findings revealed that integrating human judgment with machine precision creates a powerful solution, raising detection accuracy to 84.5% and demonstrating a usable approach to combat real-time voice-cloning attacks.

Watermarking

Digital watermarking, the process of embedding hidden digital information within a signal to verify content ownership, has long been used to protect copyrighted material. Similarly, AI watermarking involves embedding a unique, detectable marker in the outputs of AI models—whether text, images, audio, or video—to identify that content as AI-generated. This watermarking is typically integrated during the AI model's training phase, and specialized algorithms can later detect the watermark to confirm the origin of the content.

AI watermarking serves several purposes: It helps identify AI-generated content, distinguish it from human-created work, and offers a way to address issues around misinformation and academic integrity. It has become one of the recommended methods for identifying potential deepfakes, and companies are increasingly embracing the practice. For example, Google DeepMind includes watermarking in its Gemini chatbot responses, and Amazon allows users to verify images generated by its Titan Image Generator through a watermark-checking tool, although this feature currently works only for Amazon's own watermarks.

While watermarking AI content is a promising approach, it has limitations. Even if all major AI platforms adopt watermarking, some models will remain unmarked, and malicious actors are unlikely to use watermarking on deceptive content. This has led to an alternative proposal: watermarking *human*-generated content instead. As AI-produced content continues to grow, genuine human-made content may soon be the rarity online. Shifting the focus to watermarking human-generated material could allow us to assume content is AI-created unless it's marked as human-authored.

Child Safe AI

Just as child-safe modes exist on platforms like YouTube and Netflix, AI also needs safeguards to protect children from inappropriate content. One solution could be Nuha's Teddy, an AI-powered teddy bear prototype designed as a safer alternative to screen-based devices. Teddy, developed by Lama Al Rajih, uses a language model to engage children in verbal interactions, fostering language and social skills. It can discuss topics like space, play games, and encourage active learning. Limited connectivity reduces online risks, and parental controls regulate its responses. Similarly, Little Language Models, part of MIT Media Lab's CoCo platform, introduces children aged 8–16 to foundational AI concepts,

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focusing on "probabilistic thinking" through a developmentally appropriate, interactive approach.

One major concern with children using AI tools designed for adults is the "empathy gap" identified by Cambridge University researcher Dr. Nomisha Kurian. Her research shows that children often perceive AI as human-like, which can lead to distress when the AI responds inadequately. By creating AI interfaces specifically tailored for children, developers and researchers can bridge this empathy gap. This approach not only protects children from potential harms but also supports their emotional and cognitive development, ensuring that AI tools are both safe and beneficial for young users.

Politically Biased AI

Recent research has revealed that LLMs are not neutral but exhibit distinct political biases, influenced by their training data and design. A study conducted by the University of Washington, Carnegie Mellon, and Xi'an Jiaotong University tested 14 LLMs and found significant ideological differences. OpenAI's ChatGPT and GPT-4 leaned left-libertarian, while Meta's Llama displayed a right-wing authoritarian tendency. Researchers mapped these biases using the political compass, revealing how the models responded to topics like feminism and democracy. The study also explored whether retraining models with politically skewed data could change their behavior. It did, significantly altering their capacity to detect hate speech and misinformation. Other studies corroborate these findings. Researchers at the University of East Anglia observed that ChatGPT consistently exhibited liberal biases across different contexts. For instance, the model tended to align with Democrats in the US, Lula's party in Brazil, and the Labour Party in the UK.

These LLMs can be actively altered through tools like PoliTune, a framework for fine-tuning LLMs to adopt specific political ideologies. This tool created by researchers at Brown University demonstrates how AI models, originally designed to maintain neutrality, can be adapted to produce strong ideological stances. Such developments raise ethical concerns, particularly as LLMs are increasingly used to create news articles, political speeches, and social media content. As this technology proliferates, there is a risk of a fragmented AI landscape, where ideologically polarized models mirror today's divided media environment.

AI as a Tool to Address Political Bias

Despite the challenges posed by politically biased AI, the technology can also be used to address bias. The University of Pennsylvania's Media Bias Detector provides detailed insights into how various news outlets frame stories, shedding light on their political leanings. Similarly, the Bipartisan Press has developed an AI model capable of identifying the political bias present in articles and online content.

Techniques are also being explored to reduce bias within AI systems. Researchers at Oregon State University introduced a cost-effective training method called FairDeDup, short for "fair deduplication." This approach removes redundant information from datasets used to train AI systems, lowering the computational expense while also addressing embedded societal biases. Internet-based datasets often reflect real-world inequities, which can inadvertently become codified in AI models. By analyzing how deduplication impacts the prevalence of bias, researchers can counteract its effects. For example, FairDeDup helps mitigate scenarios where AI systems disproportionately associate certain roles, like CEOs or doctors, with white men. These innovations emphasize the dual nature of AI: while it has the potential to perpetuate bias, it also holds immense promise for exposing and mitigating it.

Gender and Race Biased AI

A study by the University of Chicago and other institutions revealed alarming evidence of strong negative biases against speakers of African American English (AAE) in language models. These systems generated more negative stereotypes about AAE speakers than attitudes recorded from humans in the 1930s. While overt

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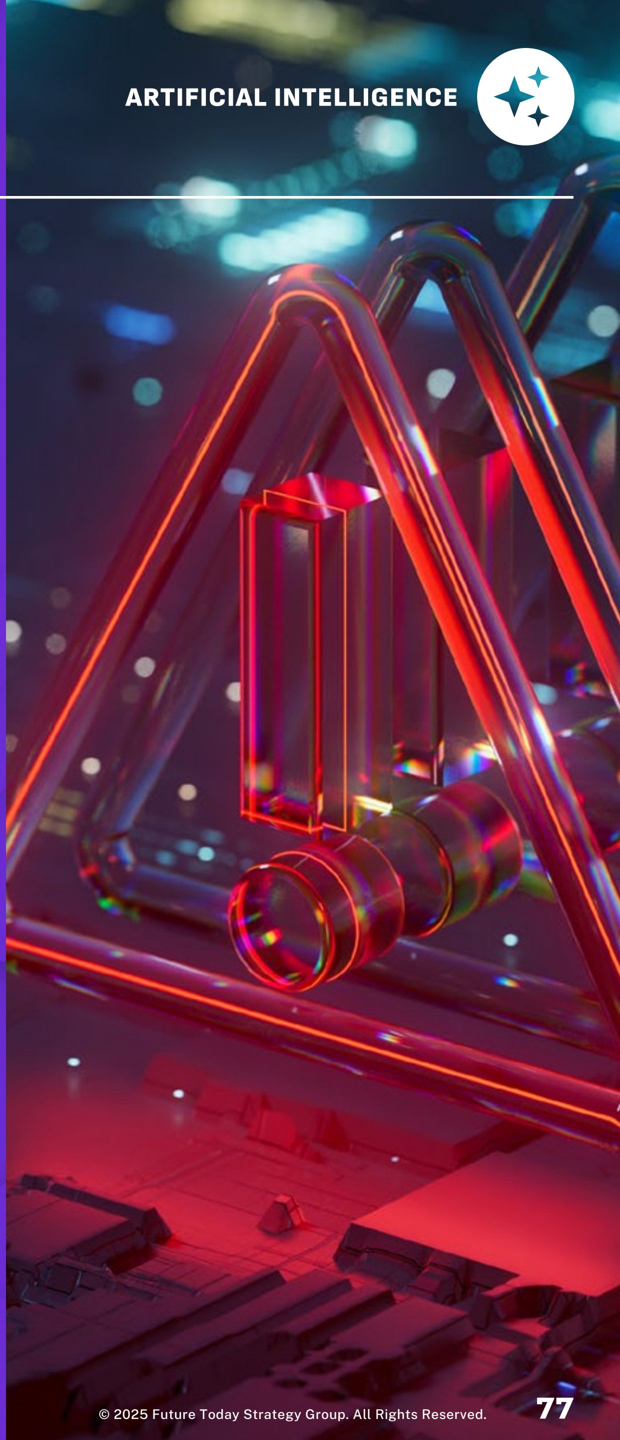
stereotypes about African Americans were often positive, the more covert form of racism—dialect prejudice—was deeply embedded in the AI models. This raciolinguistic bias highlights how AI can perpetuate subtle but harmful discrimination.

Such biases are especially concerning when AI tools are used in critical fields like medicine. For example, AI-driven mental health screening tools analyze speech for signs of anxiety or depression. However, a study from the University of Colorado at Boulder found that these tools fail to perform consistently across different genders and races. Variations in speech, such as higher pitch in women's voices or dialect differences between white and Black speakers, can mislead algorithms, leading to inaccurate assessments. This adds to the growing evidence that AI, much like humans, can make biased assumptions based on race or gender.

Gender bias is another pervasive issue in AI systems. A UNESCO study demonstrated that natural language processing models, including GPT-3.5, GPT-2, and Llama 2, exhibit bias against women in their generated content. Practical examples abound: resume screening tools, like Amazon's notorious system, have discriminated against women; facial recognition technology shows higher error rates for women of color; and medical diagnostic systems frequently provide inaccurate responses for women's symptoms. These biases have real-world consequences, reinforcing harmful stereotypes and creating inequities in access to resources, opportunities, and care.

Nefarious AI Misuse

As a dual use technology, AI is a tool that can be used by both the good guys and the bad guys. Just as AI can be employed to improve health care, enhance cybersecurity, or streamline business operations, it can also be exploited by bad actors. In the past year, the misuse of AI in malicious activities increased—fortunately, its impact remained limited. In October 2024, OpenAI released a report that details various case studies where AI models were exploited by threat actors, primarily in cyber operations like spear-phishing and malware development and in influence campaigns aimed at swaying public opinion through AI-generated social media content. For instance, in July 2024, a network used AI to generate posts emphasizing the benefits of the Rwandan Patriotic Front during the Rwandan election period. Notably, the campaign had little to no effect on the election. In late August, OpenAI disrupted a covert Iranian influence operation that was creating social media posts and long-form articles related to the US election, as well as topics such as the Gaza conflict, Western policies on Israel, Venezuelan politics, and Scottish independence. Most of the social media content generated by this campaign saw minimal engagement, with very few likes, shares, or comments, and there was no evidence of widespread sharing of the web articles across social platforms. However, this limited impact is no reason for complacency. While it's encouraging that these attempts have had minimal success, the increasing use of AI for harmful purposes signals



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the need for ongoing vigilance. Even AI companies are not exempt from targeting—SweetSpecter, a threat actor based in China, recently launched spear-phishing attacks against OpenAI employees, leveraging AI for tasks like reconnaissance, vulnerability analysis, and scripting.

Data Poisoning: A Double-Edged Sword

Data poisoning is a targeted tactic that manipulates AI training data to introduce vulnerabilities or biases into a model. Unlike inference-phase attacks, it compromises a model's integrity during the foundational training stage. Methods include backdoor poisoning, which embeds exploitable vulnerabilities, and availability attacks, which degrade performance, causing inefficiencies, false outputs, or even system crashes. Model inversion attacks exploit model outputs to infer sensitive training data, often requiring insider access. Meanwhile, stealth attacks gradually introduce subtle changes to training data, embedding biases or inaccuracies that are hard to detect and trace.

Data poisoning is a double-edged sword, capable of being wielded both as a weapon and a shield. While it poses significant threats when used maliciously, it can also serve as a powerful defensive tool. For instance, artists are leveraging data poisoning techniques to safeguard their intellectual property from unauthorized use by AI systems. Tools like Nightshade and Glaze offer innovative solutions to disrupt AI training processes. Nightshade subtly alters pixel data in artwork, rendering AI models that scrape these images inaccurate and unreliable. Glaze, on the other hand, overlays a different artistic style onto original works, obscuring the creator's signature style and preventing precise replication by AI systems. These tools highlight the potential of data poisoning not just to harm but to protect, ensuring that creativity and intellectual property remain secure.

Citizen Surveillance

Countries like China, Russia, and India are heavily investing in AI-powered surveillance technologies, often exporting them or using them to consolidate control domestically. China has positioned itself as a leader in AI surveillance, actively exporting its AI powered recognition technology to nations across Africa, Southeast Asia, and Latin America. Companies like Huawei have provided facial recognition systems, video surveillance, and monitoring software to dozens of countries, many linked to China's Belt and Road Initiative. These projects often involve financial dependencies, as seen in Ecuador's ECU-911 system, financed through Chinese loans in exchange for oil reserves. Similar deals have taken place in Venezuela and Bolivia. These technologies enable extensive monitoring of citizens, with the potential for misuse in censorship or political repression. This is particularly alarming given recent studies that show AI can predict highly personal attributes, such as political orientation, from facial images with surprising accuracy. This capability, coupled with social media's abundance of publicly available photos, could facilitate targeted political messaging or, in authoritarian regimes, surveillance and suppression of dissent.

China is not alone in this pursuit. Russia is building a nationwide AI-enabled "Video Stream Processing Centre" to integrate regional camera networks. Facial recognition technologies, developed by companies with ties to Russian defense or government entities, are already deployed in cities like Moscow and were used to preventively detain at least 141 people in 2022. India, too, is increasingly adopting AI surveillance. Cities like India's Ahmedabad utilize drones and AI-powered cameras to monitor traffic and identify suspicious behavior. Plans for real-time crime detection through Wi-Fi signal analysis further expand AI's reach.

Worker Surveillance

The shift to remote and hybrid work models has fueled a significant increase in worker surveillance. Unlike the restrictions the Fourth Amendment puts on law enforcement, private companies face fewer legal limitations, allowing them to deploy advanced monitoring technologies. A growing number of major corporations including Walmart, Starbucks, Delta, and Chevron use platforms like Aware, an AI-powered

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tool designed to analyze employee communications on platforms like Slack, Microsoft Teams, and even Reddit. These systems aim to detect risks like harassment and compliance violations while analyzing workplace conversations to gauge employee needs and trends.

Amazon is one of the most well-known practitioners of worker surveillance, using AI-enabled cameras in delivery vehicles to track behaviors such as distracted driving or hard braking. The company penalizes drivers for perceived infractions and employs similar systems in its warehouses, where metrics like "time off task" monitor every moment workers are not actively processing products, applying constant pressure to maintain productivity. These surveillance practices recently resulted in France fining Amazon 32 million euros for violating GDPR regulations. The fine cited a monitoring system with alerts that flagged workers for actions like scanning items too quickly or taking unsanctioned breaks, creating an atmosphere of relentless oversight.

This type of surveillance has measurable impacts on worker well-being. In a survey, 74% of Amazon and Walmart workers reported feeling pressured to work faster due to monitoring systems, leading to increased stress and anxiety. Such practices raise questions about privacy, fairness, and the long-term effects of constant surveillance in the workplace.

School Surveillance

During the pandemic, schools distributed laptops and devices to students for remote learning but often did not disclose that these devices would enable constant monitoring. In many countries, including the US, schools are legally allowed to track students' activities, frequently without informing them or their families about what is being monitored.

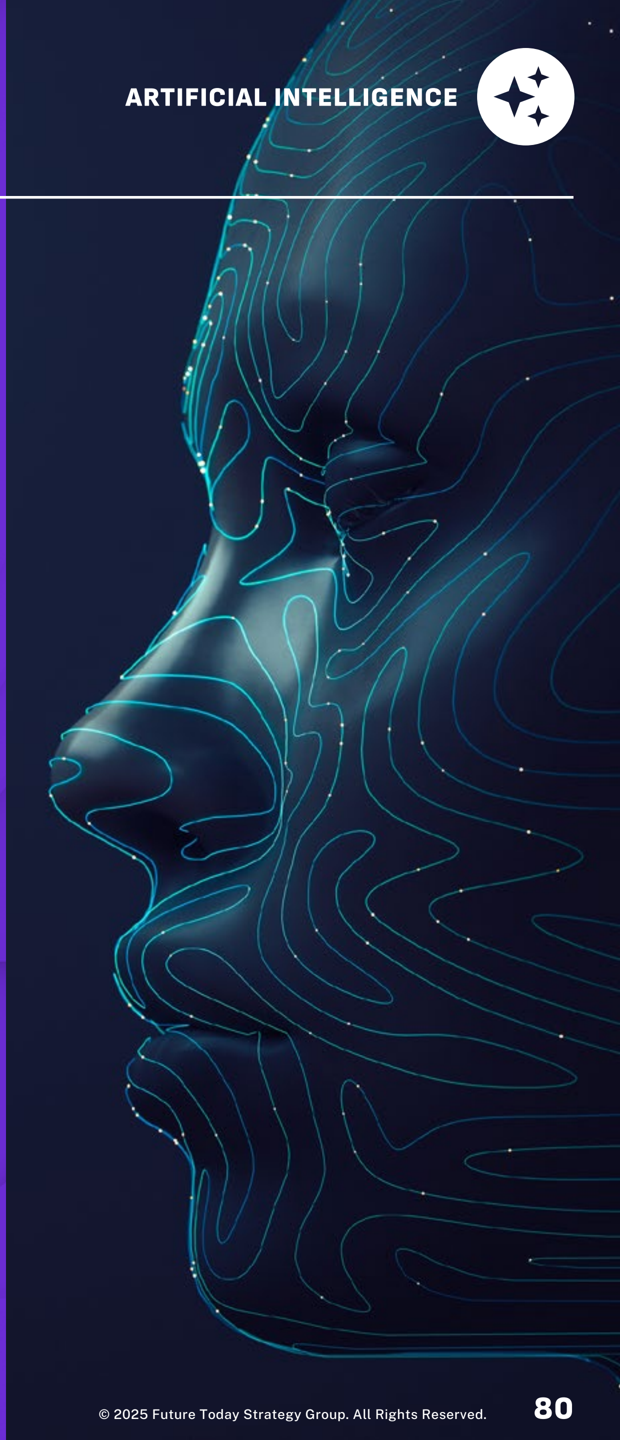
Increasingly, these surveillance technologies use AI for facial recognition, predictive policing, geolocation tracking, and student device monitoring. Some even use aerial drones. These tools are promoted as methods to enhance safety, monitor behavior, and identify mental health or safety concerns. For example, the Cheyenne Mountain School District in Colorado Springs has installed nearly 400 AI-enabled cameras that use facial recognition to identify "persons of interest" and track individuals based on characteristics like clothing or backpacks. Alerts and video footage are sent to school officials when matches are detected. The same school has also introduced smart air sensors to detect vaping or drug use.

However, these surveillance systems come with significant consequences. According to a July 2023 report by the Center for Democracy & Technology, monitoring often focuses on detecting inappropriate online content, but it also has broader implications. The awareness of constant surveillance creates a "chilling effect," discouraging students from engaging freely and potentially hindering learning. Alerts stemming from monitoring can impact students' emotional well-being, while the lack of transparency erodes trust between students and educators.

Posthumous AI

Companies are using AI to recreate the voices, likenesses, and personalities of deceased individuals, offering new ways to preserve legacies but also raising complex ethical and emotional concerns. Platforms like Character.ai and Hello History allow users to interact with virtual versions of historical figures, such as William Shakespeare or Queen Elizabeth II. Deep Fusion Films takes this a step further with its upcoming podcast series, "Virtually Parkinson," hosted by an AI replica of the late English broadcaster Sir Michael Parkinson. Built from more than 2,000 interviews from his career, this AI aims to provide authentic, unscripted conversations while explicitly disclosing its artificial nature.

But AI isn't limited to historical or cultural icons. MyHeritage's "Deep Nostalgia" animates photos of deceased relatives, while platforms like Posthumously use generative AI to create immersive 3D avatars of loved ones. These digital spaces enable users to engage with memories and stories of the departed, often for comfort



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and connection. However, such practices venture into emotionally fraught territory, as individuals use AI to “resurrect” family members and friends.

This use of AI on the deceased sparks broader ethical debates. For example, actor Robert Downey Jr. has publicly opposed the use of AI replicas, vowing legal action against any attempt to re-create his likeness posthumously. Discussing his stance on the “On With Kara Swisher” podcast, Swisher remarked, “You’ll be dead,” to which Downey quipped, “But my law firm will still be very active.” His concerns underscore the tension between preserving legacies and protecting personal identity.

Privacy Risks in Behavior Biometrics

Behavioral biometrics, when combined with AI, analyze unconscious patterns to uncover intricate details about our identities and behaviors. By measuring subtle actions, such as the force applied on touchscreens, the specific way we tap letters like C or V, or our typing rhythms, this technology can reveal not only who we are but also insights into our thoughts and potential future actions. While its benefits include enhanced security and the potential to replace passwords with personalized authentication, these same capabilities present profound privacy and ethical concerns.

The very features that make behavioral biometrics effective—its ability to capture unconscious, uncontrollable actions like pupil dilation or micro-reactions—also make it highly invasive. Companies can use this data to analyze how individuals react to products or content without their knowledge. Moreover, once these unique behavioral signatures are digitized, they become vulnerable to theft, replication, or exploitation by malicious actors, further compounding the risks.

The core promise of behavioral biometrics—authenticating users through their unconscious behaviors—is also its greatest threat. The ability to record, analyze, and replicate intimate data undermines what has long been considered personal and private. This raises urgent questions about the boundaries of privacy and the need for robust safeguards to protect individuals from misuse. Transparency is another critical concern. Many users are unaware that their behavioral data is being monitored, sparking ethical issues around informed consent. Without clarity on how this data is collected, stored, or shared, individuals cannot make fully informed decisions about their participation. Acknowledging these challenges, several US states moved toward biometric privacy legislation in 2024 to regulate data usage and protect against misuse.

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AI's growing energy footprint demands novel architecture and sustainable infrastructure.

Resource-Hungry AI

AI's rapid growth is putting immense pressure on energy and water resources. Generative AI technologies, like ChatGPT, demand far more energy and water than traditional digital workloads. For instance, a single ChatGPT query consumes 2.9 watt-hours of electricity, nearly 10 times the 0.3 watt-hours required for a Google search. This resource intensity has contributed to notable spikes in operational emissions and resource use. In Microsoft's 2024 sustainability report, the company reported a 29% increase in emissions and a 23% jump in water usage from the previous year—largely due to generative AI. Microsoft consumed more than 7.8 million cubic meters of water last year, up from 6.4 million in 2022. Other tech giants like Google, Amazon, and Meta have also reported sharp increases in water use, with water being a cost-effective way to cool data centers. Projections suggest global AI power demand could surge from 60% to 330% of US power generation growth by 2030, with AI data centers potentially requiring more than 130 GW of additional capacity. However, with US power generation expected to grow by only 30 GW during this time, the industry faces a critical challenge in scaling its infrastructure sustainably. Addressing this imbalance will require building more energy capacity while optimizing computing infrastructure. (For further reading on computing infrastructure trends supporting the AI rollout, see the Computing report.)

AI Nuclear Renaissance

In 2021, we noticed an interesting signal—Microsoft was posting job openings for nuclear engineers. At the time, the reasoning wasn't clear. But by November 2022, when ChatGPT launched, the connection became obvious: AI consumes enormous amounts of energy, and nuclear power is a sustainable and efficient solution for fueling the data centers that drive it. Since then, Microsoft, Google, and Amazon have all unveiled deals supporting advanced nuclear energy.

Google announced plans to purchase electricity from reactors developed by Kairos Power, while Amazon is investing $500 million in X-Energy Reactor Co., intending to use its reactors in Washington state. Microsoft, meanwhile, reopened an 800 MW nuclear plant in Pennsylvania and signed multiple deals to secure nuclear energy for its data centers. Nuclear's reliability, low emissions, and ability to deliver large-scale power make it an appealing choice for tech companies seeking to meet skyrocketing energy demands.

Small modular reactors (SMRs) are emerging as a promising option. Amazon partnered with Dominion Energy to develop an SMR in Virginia, and Google committed to purchasing capacity from Kairos Power. Oracle is planning a gigawatt-scale data center powered by three SMRs, and firms like Equinix and Wyoming Hyperscale have signed agreements with SMR providers such as Oklo.

Despite the enthusiasm, significant challenges remain. Large-scale nuclear construction is costly and time-consuming—Plant Vogtle, which began operations in 2023, was the first US civilian plant built in 30 years. SMRs face permitting delays, unproven scalability, and legal complications for "behind the meter" energy production, such as state-level utility registration requirements. Additionally, scaling clean firm power will require substantial investments in emerging technologies. While the AI nuclear renaissance is underway, overcoming these barriers will be essential to fully realizing its potential.

Efficient AI Architectures

We will certainly need more power to fuel AI. But this challenge isn't just about scaling energy abundance—it's also about

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creating more efficient computing architectures. For decades, Moore's law has been driven by the traditional Von Neumann architecture, where memory and processing units are separate. This design forces constant data transfer between components, a process known as the "Von Neumann bottleneck." This inefficiency consumes significant time and energy, limiting scalability for AI's growing demands. It's clear we need a more efficient approach.

One promising solution lies in revolutionizing how components work together, as demonstrated by innovations like "simultaneous and heterogeneous multithreading" (SHMT). Traditional systems often suffer from bottlenecks when transferring data between processing units, such as GPUs and AI accelerators. SHMT addresses this by enabling concurrent operations across different processing components. For example, a system integrating ARM processors, Nvidia GPUs, and Tensor Processing Units achieved nearly double the speed while reducing energy consumption by half. These advances exemplify how rethinking data flows and component cooperation can yield both performance and efficiency gains.

Another solution is neuromorphic computing, inspired by the human brain—the most efficient computing system in existence. Neuromorphic chips, like Intel's Loihi, replicate the brain's structure and function, excelling at parallel processing and enabling simultaneous task execution. These chips have demonstrated energy efficiencies up to 1,000 times greater than traditional processors for certain tasks. Organoid computing takes this a step further—it combines electronic hardware with lab-grown human brain tissue. Unlike neuromorphic systems that mimic brain function, organoid computing uses actual biological material. Indiana University's hybrid system, "Brainoware," has shown remarkable potential, such as recognizing speech patterns and distinguishing vowels with impressive speed and accuracy.

Optical neural networks (ONNs) offer another approach toward efficiency. By using light instead of electrons for computations, ONNs dramatically reduce energy use while boosting performance. MIT's HITOP optical network can run machine learning models 25,000 times larger than its predecessors, while consuming 1,000 times less energy. Together, these advances signal a shift toward smarter, more efficient architectures that can meet AI's immense demands sustainably. (Additional details on efficient architectures can be found in the Computing report.)

Efficient AI Algorithms

Improving AI efficiency isn't just about hardware; algorithmic advancements play a crucial role in reducing the computational power required to run AI models. A study by Epoch AI and MIT FutureTech analyzed progress across various AI domains, revealing how smarter algorithms significantly enhance efficiency. In the case of LLMs, algorithmic progress has accounted for nearly half the performance improvements seen in recent years, complementing the effects of scaling compute power. Remarkably, the compute required to achieve a given level of AI performance has halved approximately every eight months due to algorithmic advancements—a pace that outstrips the gains predicted by Moore's law. This highlights the critical role algorithmic innovation plays in driving AI's evolution alongside hardware scaling.

The impact of algorithmic progress varies by domain but is particularly striking in image classification. Between 2012 and 2019, the compute required to train a classifier to match AlexNet's performance dropped by 97.7%. Further, from 2012 to 2022, the compute needed to achieve 93% classification accuracy on ImageNet halved every nine months. These advancements demonstrate how smarter algorithms can make AI systems vastly more efficient, paving the way for sustainable AI development as models grow increasingly complex.

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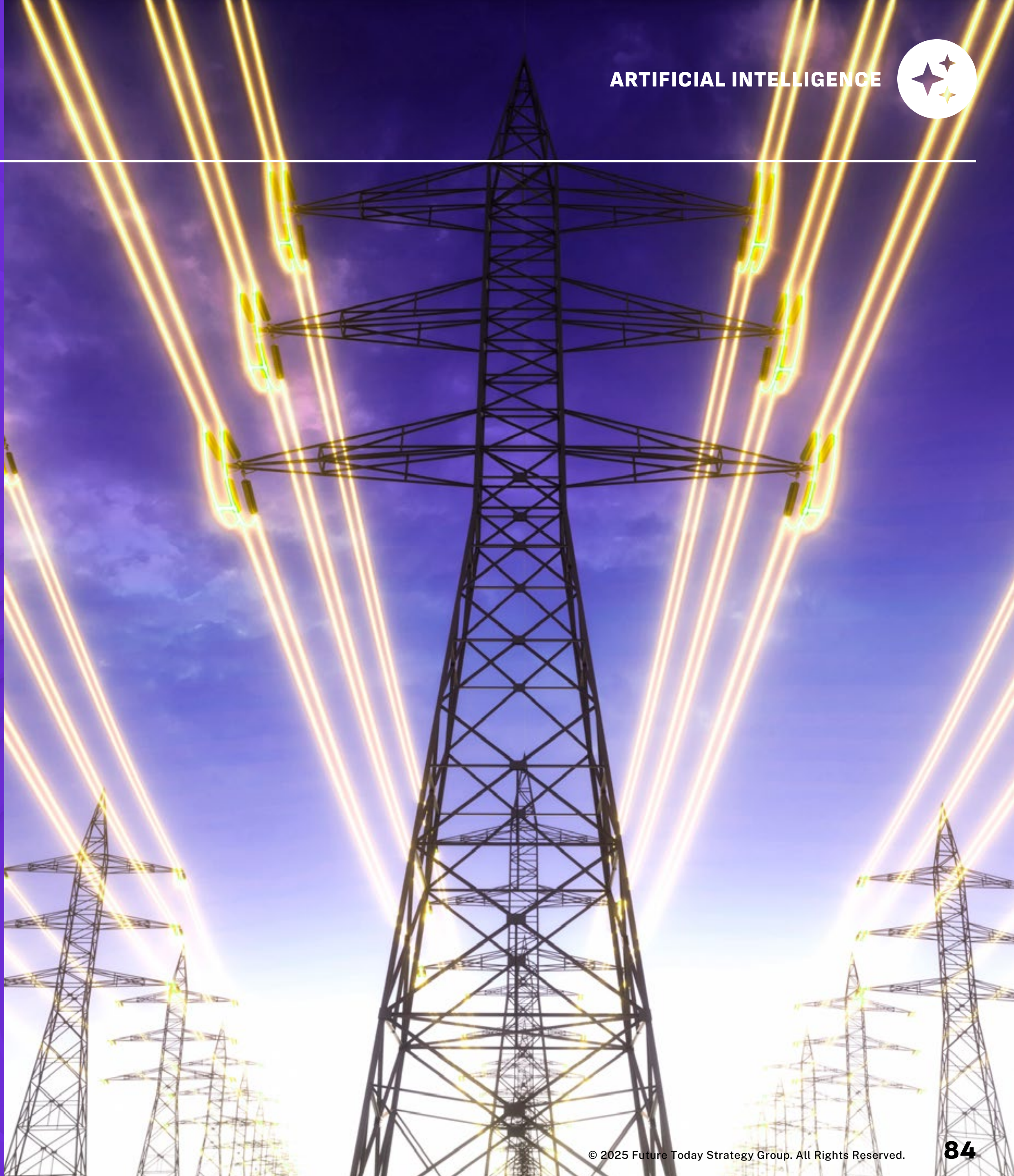
Energy Optimization

AI is often seen as an energy-intensive technology, and as such, an environmental burden. However, it can also be a powerful tool for environmental benefit. For instance, AI can be used to enhance grid efficiency by improving demand predictions and supply management. It can also be used to navigate complex energy regulations. California's Diablo Canyon nuclear power plant is leveraging artificial intelligence to navigate complex relicensing requirements. The AI system analyzes thousands of historical documents spanning several decades, helping engineers develop comprehensive maintenance strategies for the facility's aging concrete structures and operational systems.

By analyzing weather patterns, customer behavior, and historical trends, AI also helps to ensure renewable sources like solar and wind are being used effectively, even with variable outputs. AI can also dynamically adjust power line capacity based on conditions like wind and temperature, easing transmission bottlenecks and integrating renewable energy more seamlessly. Topology optimization further boosts efficiency by reconfiguring grid pathways, reducing interconnection costs and improving power delivery.

AI also enables the creation of virtual power plants, where solar panels, batteries, and EVs are combined into flexible grid systems. This improves reliability while optimizing revenue. Additionally, AI-powered predictive maintenance identifies equipment issues before failure, cutting maintenance costs by 43%–56% and reducing unnecessary crew visits by 60%–66%. While AI certainly has its costs, its potential to transform energy systems into more sustainable and efficient networks positions it as an environmental asset, not just a liability.



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We need governments urgently to work with tech companies on risk management frameworks for current AI development... And we need a systematic effort to increase access to AI so that developing economies can benefit from its enormous potential.

António Guterres, Secretary-General of the United Nations

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AI superiority has become the key geopolitical battleground as nations race to dominate economic, diplomatic, and military capabilities.

AI Nationalism

AI nationalism has emerged as a defining force in global politics, as countries increasingly view artificial intelligence as crucial to national sovereignty and power. This technological competition is reshaping international relations, with nations racing to develop domestic AI capabilities and reduce dependence on foreign technologies. The US and China stand at the forefront of this competition, each pursuing distinct strategies to achieve AI supremacy. China's New Generation Artificial Intelligence Development Plan aims for breakthrough developments by the end of 2025, emphasizing domestic innovation and talent cultivation. Meanwhile, the US has responded with new national security measures focused on maintaining its technological edge while promoting safe, trustworthy AI systems.

This rivalry has sparked a worldwide cascade of national AI initiatives. The UAE has set ambitious goals to become a global AI leader by 2031, while countries like Canada, France, and India have established comprehensive national AI strategies. These programs typically combine heavy government investment, protectionist policies, and efforts to build domestic technological capabilities. The competition has intensified through restrictive policies, exemplified by US export controls on advanced microchips to China. This "arms race" mentality is accelerating AI development, potentially compressing the timeline for achieving more advanced AI systems. However, it also raises concerns about fragmentation of the global AI ecosystem and the potential risks of rushed development.

The rise of AI nationalism reflects a broader shift in how countries view technological development—not just as an economic opportunity, but as a cornerstone of national security and global influence. This perspective is transforming AI from a purely scientific pursuit into a crucial element of geopolitical strategy.

The AI-Driven Chip War

The semiconductor rivalry between the US and China continues to escalate, with Washington implementing successive rounds of export controls aimed at constraining China's advanced chip development capabilities. A pivotal move came in January 2023 when the US secured a multilateral agreement with the Netherlands and Japan to restrict China's access to advanced lithography equipment. This partnership is particularly significant given the Netherlands' ASML's crucial role in the global semiconductor supply chain. More recently, President Trump has largely maintained and expanded upon the AI chip export controls implemented by the Biden administration; Trump has also ordered a review of the US export control framework, potentially leading to further restrictions on AI chip exports.

These restrictions have created ripple effects across the industry. In January, Nvidia's stock fell by 4% in the wake of additional Trump administration curbs on Nvidia's chip sales to China and Chinese retaliation for the former administration's restrictions.

During the Biden administration, China had already banned Micron Technology chips from its critical infrastructure, started tightly controlling the rare earth element exports essential for chip production, and dramatically increased domestic semiconductor investment. Beijing's commitment is evident in its massive funding initiatives, including a $47 billion investment fund announced in May 2023, bringing total industry investment beyond $150 billion. The country's leading manufacturer—SMIC—has achieved 7-nanometer chip production using older

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deep ultraviolet technology, though still trailing industry leader TSMC of Taiwan. Despite SMIC's success, it still faces considerable challenges in matching global leaders in cutting-edge chip production.

AI Diplomacy

AI has emerged as a central topic in global diplomacy, as nations navigate its transformative potential and challenges. The landmark meeting between US President Joe Biden and China's Xi Jinping in November 2024 demonstrated this dynamic, resulting in an agreement to keep AI systems away from nuclear weapons control—a rare moment of consensus between the competing powers.

Multilateral initiatives are gaining momentum, with the UN achieving a significant milestone through its first global AI resolution, supported by all 193 member states. This nonbinding framework emphasizes human rights protection, data privacy, and risk monitoring. Meanwhile, the Council of Europe has advanced a more formal approach with its Framework Convention on Artificial Intelligence, attracting signatories from both European and non-European nations.

Regional alliances are also shaping the AI diplomatic landscape. The US-UK bilateral agreement on AI safety and testing exemplifies close cooperation between traditional allies, while the Quad Alliance's AI-ENGAGE Initiative strengthens technological collaboration in the Indo-Pacific region, particularly in agriculture and emerging technologies.

The Middle East has become an unexpected nexus of AI diplomacy, with Saudi Arabia and the UAE leveraging their financial resources to attract international partnerships. Saudi Arabia's planned $40 billion AI investment fund and the UAE's AI university initiative have drawn significant US corporate engagement, including Amazon's $5.3 billion Saudi data center investment and Microsoft's $1.5 billion stake in the UAE's G42. However, these Gulf states maintain relationships with both Western powers and China, illustrating the complex interplay of AI diplomacy and strategic interests.

Tech Pivots on Defense

Recent months have witnessed a significant shift in AI companies' stance toward military applications, with major tech companies reversing previous restrictions on defense-related uses of their technology. This transformation reflects evolving perspectives on national security collaboration within the AI industry.

Meta made a notable policy exception by opening its Llama AI models to US government agencies and contractors working on national security projects, despite previous restrictions on military applications. This decision has enabled various defense applications: Oracle is utilizing Llama to improve aircraft maintenance efficiency, Scale AI is adapting it for mission planning and threat assessment, and Lockheed Martin has integrated it into its AI Factory for multiple defense-related purposes. Other prominent AI companies are also embracing military partnerships. OpenAI has modified its policies to permit certain military applications and secured a contract to provide ChatGPT to the Air Force. Anthropic has formed a strategic alliance with Amazon's cloud services and Palantir to serve military and intelligence customers. In February, Google reversed its promise not to use AI for weapons and surveillance.

Palantir, in contrast to companies newly entering the defense sector, has maintained deep military and intelligence agency connections since its founding in 2003. However, the company faced increased scrutiny in 2024 regarding its expanding role in modern warfare, particularly following reports about its AI-augmented surveillance systems potentially being deployed in Ukraine. This heightened attention reflects broader public concern about the militarization of AI technology, even for long-established defense contractors like Palantir who have traditionally operated in this space. The company's evolving capabilities in AI-enabled military applications have drawn fresh debate about the scope

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and implications of private companies' roles in contemporary warfare.

Autonomous Weapons Policies

In November 2024, US President Joe Biden and China's President Xi Jinping met in Lima, Peru and agreed that decisions about the use of nuclear weapons should remain under human control. This marked the first bilateral commitment between these powers on both nuclear arms and AI military applications.

This comes after the US flagged concerns over China's misuse of AI—as delegations from both countries met in Geneva back in May 2024, the US stressed to their Chinese counterparts the need to maintain open lines of communication on AI risk and safety. The international community has seen broader movement on autonomous weapons regulations, with Japan adopting restrictions on fully autonomous lethal weapons in July 2024. But conversely, 2024 also saw the adoption of autonomous lethal weapons elsewhere: Autonomous drones capable of tracking and engaging enemies without human interaction have reportedly been used in Ukraine.

At the UN level, momentum has increased for formal regulation. The General Assembly's First Committee passed its second consecutive resolution on autonomous weapons systems in November 2024, expanding discussion frameworks and supporting capacity building initiatives. UN Secretary-General Guterres has advocated for a comprehensive international treaty by 2026 that would prohibit weapons systems operating without human oversight.

These developments highlight increasing recognition of autonomous weapons as a critical security challenge requiring international cooperation and governance frameworks. The focus on maintaining human control while carefully managing AI's military applications suggests an emerging consensus on balancing technological advancement with ethical considerations and safety requirements.

Automated Target Recognition and AI-Guided Strikes

The integration of artificial intelligence has dramatically enhanced the precision and efficiency of target identification systems. In early 2024, the Pentagon disclosed its use of AI in Middle Eastern operations, where machine learning algorithms assisted in target selection for more than 85 US air strikes. According to US Central Command's former Chief Technology Officer Schuyler Moore, these systems helped identify targets during operations against facilities in Iraq and Syria. This marked a significant step in the operational deployment of AI-assisted military targeting systems.

The technological capabilities of modern ATR systems have grown substantially. The collaboration between FlySight and Aitech Systems demonstrates this progress, with their OPENSIGHT integration enabling sophisticated real-time target recognition. These systems can now process video streams at up to 30 frames per second, allowing for multiple target detection in confined spaces or selective isolation of individual targets based on predetermined criteria.

In ongoing conflicts, the deployment of AI-guided systems has become more prevalent. The Israel Defense Forces have incorporated AI technology to enhance targeting precision in Gaza, focusing on improving collateral damage estimates and overall military decision-making. In Ukraine, AI-controlled drone swarms have been deployed for reconnaissance and attack missions. A Ukrainian startup called Swarmer conducted a field test near Kyiv using a swarm of drones coordinated through AI to identify and destroy hidden targets without human pilot intervention. The process involved reconnaissance drones autonomously identifying optimal flight paths, followed by bomber drones executing the attack, and finally an unmanned aircraft system confirming target destruction.

The integration of ATR systems with AI capabilities continues to evolve, promis-

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ing further improvements in precision and effectiveness while necessitating careful consideration of deployment protocols and ethical frameworks.

AI-Assisted Humanitarianism in War

AI technology's role in humanitarian aspects of conflict demonstrates its versatile applications beyond military operations. These systems are making significant contributions to refugee assistance, war crime documentation, and post-conflict recovery efforts.

In refugee support, AI tools have transformed humanitarian response capabilities. The Norwegian Refugee Council's chatbot for Venezuelan migrants in Colombia exemplifies how AI can provide crucial legal information and rights awareness to displaced populations. The Danish Refugee Council has pioneered predictive analytics since 2020, using AI to forecast forced displacement patterns across several African nations, including Burkina Faso and Nigeria, enabling more proactive humanitarian responses.

In conflict zones, AI systems serve multiple humanitarian purposes. In Ukraine, AI algorithms assist in landmine detection and clearance operations, helping make areas safer for civilians. The technology also supports accountability efforts, with Clearview's facial recognition systems being used to identify Russian military personnel for potential future investigations.

War crimes documentation has also been enhanced through AI's capability to process and analyze vast amounts of data. These systems can track infrastructure conditions and supply routes, and cross-reference satellite imagery with social media content and witness accounts to create more comprehensive evidence portfolios for international justice mechanisms. These applications highlight AI's dual-use nature—the same capabilities enhancing military operations can serve humanitarian purposes, helping mitigate warfare's human costs.

AI-Assisted Situational Awareness

AI-powered situational awareness has transformed modern combat operations by enabling rapid processing of multisource data for real-time decision support. These systems integrate information from satellites, drones, sensors, and communications networks to create comprehensive battlefield understanding. Edge AI technology enables on-device processing even in degraded communication environments, reducing latency and maintaining operational capability when networks are compromised.

In the field, autonomous systems like the British-developed BAD One robot conduct reconnaissance using thermal vision for enemy detection and minefield identification. The Israel Defense Forces employ AI systems like "Habsora" and "Fire Factory" to analyze historical data for strike planning, ammunition calculations, and target prioritization. These same AI capabilities also support humanitarian efforts by processing data streams to identify landmine locations in heavily mined regions, where traditional detection methods struggle. This integration of AI into military operations has accelerated battlefield decision-making while potentially reducing risks to personnel.

AI as a Shield

As aerial threats grow more diverse and sophisticated, AI has emerged as the backbone of modern military defense systems. From NATO's disaster response operations to Israel's Iron Dome, AI is proving crucial in protecting both military assets and civilian lives.

The Iron Dome stands as a testament to AI's defensive potential, with its algorithms achieving a 90% success rate in intercepting incoming threats. The system processes vast amounts of radar and sensor data in real time, calculating precise intercept points for rockets, drones, and low-flying objects—all while keeping operational costs down. Similarly, the Terminal High Altitude Area Defense system employs AI to distinguish real threats from decoys, providing another layer of sophisticated missile defense.

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Beyond missile defense, AI's protective capabilities extend to broader military operations. NATO uses computer vision in disaster response, swiftly processing aerial imagery to locate victims. In active conflict zones, similar technology tracks rocket launchers in Yemen and monitors vessel movements in the Red Sea, providing critical early warning capabilities.

These systems' success in current conflicts, particularly in Ukraine, highlights a crucial shift in modern warfare: the growing importance of AI-powered defenses against increasingly varied aerial threats. As threats continue to evolve, AI's ability to rapidly process complex data streams has become indispensable for military defense.

Simulating Warfare

Inside today's most advanced military training facilities, AI is changing how soldiers prepare for combat. These aren't your typical video game simulations—they're adaptive environments that evolve in real time, pushing soldiers to their limits while monitoring their every move. Imagine being able to instantly generate any battlefield on Earth, populate it with up to 75,000 troops, and simulate everything from ground combat to cyber warfare. This isn't science fiction; it's the new reality of military preparation, through the US Army's ambitious Synthetic Training Environment, where AI creates training scenarios that blur the line between simulation and actual combat.

Systems like these are already proving their worth in elite units. At Fort Carson, Green Berets from the 10th Special Forces Group (Airborne) are using the VirTra simulator, an AI system that thinks like an opponent. As operators move through high-risk scenarios—from hostage situations to active threats—the AI adapts, increasing difficulty based on their performance. The goal? "Practice makes permanent," pushing these elite soldiers to new levels of combat effectiveness. The system doesn't just test shooting skills—it deliberately spikes soldiers' heart rates before scenarios, replicating the physiological stress of actual combat. This marriage of physical and psychological training, orchestrated by AI, is creating a new generation of better-prepared warriors.

AI in Cyber Defense

As AI reshapes the battlefield, US military leaders are betting big on its defensive potential, particularly in cyber operations. In 2024, US Cyber Command unveiled its AI road map for cyber operations. According to Air Force Gen. Timothy D. Haugh, who also leads US Cyber Command, the agency is prioritizing the protection of AI technology itself, focusing on intellectual property security and safeguarding AI models to ensure their proper use. The road map aims not only to enhance capabilities but also to shift the balance decisively in favor of the defenders.

Despite cyber benefits, AI systems are highly susceptible to cyberattacks that exploit their unique vulnerabilities. AI-enabled military systems can be compromised in ways traditional platforms never could. Through data poisoning, attackers can corrupt AI learning patterns, potentially causing defense systems to make catastrophic errors like misidentifying friendly forces as hostile. Even more concerning, evasion techniques could allow enemies to slip past detection systems by exploiting tiny model imperfections—imagine a missile launcher becoming invisible to AI surveillance with just a few tweaked pixels.

Mark A. "Al" Mollenkopf, Army Cyber Command's science advisor, acknowledges the dual nature of AI in cyber warfare. While bad actors can exploit AI to streamline phishing attacks, generate advanced malware, and spread disinformation, cutting-edge AI tools offer robust countermeasures. These tools can effectively detect disinformation, identify complex phishing schemes, and neutralize sophisticated malware, providing a critical edge in cyber defense. The US military is adopting a dual-pronged strategy: harnessing AI's defensive capabilities while ensuring the security and integrity of the technology itself. This approach requires a delicate balance, positioning AI as both a shield and a sword in the constantly evolving digital battlespace.

POLICY & REGULATION

POLICY & REGULATION

Competing perspectives on AI, along with changing political winds, will result in compliance headaches.

In major economies—the United States, China, and the European Union—policymakers are advancing distinct approaches to govern AI. These regulatory developments carry significant geopolitical and economic implications, and they pose potential constraints on innovation if miscalibrated. In this section of our report, we offer a high-level overview of AI regulation and policy in the US, China, and Europe, along with brief insights into Brazil and the UAE, that are current as of March 2025.

POLICY & REGULATION

United States: Accelerating AI Fast

In the US, there is currently no comprehensive federal AI regulation; instead, authorities apply existing laws (such as consumer protection, antidiscrimination, and safety regulations) to AI use cases, complemented by new guidance frameworks. More than 120 AI-related bills have been introduced in Congress on issues ranging from AI in education to national security, but most have stalled amid concerns that strict rules could hamper innovation. Rather than impose broad mandates, federal policy has emphasized voluntary standards and frameworks. Notably, the Biden administration introduced "The Blueprint for an AI Bill of Rights" in October 2022, which outlined five principles for safe and ethical AI (such as transparency and non-discrimination), but the document was nonbinding and has already been purged from the White House website. The Trump administration has signaled that it will loosen oversight and clear a path for faster progress among the largest tech companies, but at the moment, the US has a patchwork of different rules and regulations set by state and local governments, certifying bodies within industries, and the federal government. Unsurprisingly, these rules and regs often conflict.

Geopolitically, the US will aim to stay ahead in the AI race against China, which will influence a lighter regulatory touch over the next four years. Economically, the lack of uniform law creates compliance complexity and potential liability risks under diverse statutes. Innovation-wise, US companies enjoy relative freedom to experiment, but growing public concern (over biased AI or unsafe AI) could lead to stricter rules if industry self-regulation fails.

Examples:

- The insurance sector faces scrutiny over AI-driven underwriting and pricing algorithms that could bias outcomes. State insurance regulators have issued principles on AI fairness, and states like Colorado enacted laws requiring insurers to test AI models for discriminatory bias in pricing.
- Concerns about deepfakes and AI-generated content have prompted some targeted laws. For instance, several—but not all—states ban malicious political deepfakes during elections and non-consensual explicit deepfake content. It's unclear what happens if those deepfakes cross state lines.
- California passed a new law mandating that health care providers disclose when patient communications are generated by an AI system.

European Union: Driving Hard on AI Governance

In the coming two years, organizations operating in Europe must prepare for the Artificial Intelligence Act's requirements by completing a number of tasks, including conducting AI impact assessments and establishing oversight processes ahead of the 2026 enforcement date. They will also have to keep an eye on related EU initiatives, such as AI liability rules and updates to safety standards, that complement the Act.

The AI Act has a framework with four tiers of different risk-based classifications of AI applications:

1. **Prohibited AI:**
   uses that violate fundamental rights or safety, such as social scoring or exploitation of vulnerabilities.
2. **High-Risk AI:**
   uses with significant implications for health, safety or rights, like in critical infrastructure, education, employment, financial services, law enforcement, and medical devices.
3. **Limited-Risk AI:**
   including generative AI models and chatbots, which must meet transparency requirements.
4. **Minimal-Risk AI:**
   like AI in video games or spam filters, largely unregulated.

High-risk systems face the strictest obligations: developers and deployers must implement risk management, ensure high-quality non-biased data, enable human oversight, and register these systems in an EU database. For example, AI used in health care for diagnostics or in life sciences as part of medical devices will be deemed high-risk, requiring conformity assessments on top of existing medical device regulations. For EU-based pharmaceutical and life sciences companies, which prioritize IP secrecy, these regulations will pose a threat in readying new therapeutics and devices for the market. Similarly, AI algorithms for insurance pricing and underwriting (especially in health or life insurance) are explicitly categorized as high-risk under the act, mandating rigorous fairness and transparency controls. Entertainment and media AI applications generally fall under limited risk—for instance, generative AI that produces media must disclose that content is AI-generated to curb misinformation, per the act's transparency rules (a deepfake-labeling mandate).

Geopolitically, EU policymakers seek to project influence by championing an ethical AI model distinct from the US's laissez-faire approach and China's state-driven model. However, there is tension between regulation and economic competitiveness: Innovation constraints are going to be a problem, at least when it comes to business. Compliance costs and the need for conformity assessments may disproportionately burden smaller companies and slow down AI deployment in Europe's tech sector.

On the other hand, clear rules could raise public trust in AI and ultimately encourage uptake in sectors like health care and finance, where European companies can leverage a reputation for safe AI.

China: State-Directed Strategy and Tight Oversight

China's AI policy is driven by a top-down, state-centric ethos that simultaneously promotes AI development and imposes strict government oversight. The foundation was laid by 2017's Next Generation AI Development Plan, which set ambitions for China to lead in AI by 2030. While previous long-range plans haven't panned out, this one seems to show tangible progress.

Geopolitically, China's strict regime contrasts with Western approaches, complicating international collaboration on AI. Divergent standards—for example, on free expression or privacy—create a splintered AI ecosystem globally. We have been writing about a coming splinternet for years, and with the release of public-facing Chinese models in 2025 we are seeing this in earnest.

US export controls on advanced AI chips to China and China's restrictions on data exports show just how tightly AI has become entwined with geopolitical competition, potentially limiting the global supply chain and talent exchange. Economically, China's heavy AI regulation could increase compliance burdens on its tech firms, but it also establishes clear rules that may favor large, well-resourced companies, even if that means crowding out smaller players.

Innovation is a double-edged sword in China: The state's massive investments and data availability drive rapid AI advancements, especially in facial recognition, fintech, and surveillance tech, yet the censorship and security requirements can constrain the scope of permissible innovation. For example, China's powerful generative AI platforms must still self-censor, as Westerners found when they tried to ask DeepSeek's R1 questions about Tiananmen Square. Censorship will undoubtedly hinder AI's creative potential in China.

It's going to be a tricky few years for non-Chinese organizations operating in China, as government policy signals must be followed. They will need to maintain robust internal compliance teams to conduct mandated security assessments and algorithm filings. We expect China to refine these AI regulations and expand them to new domains, making regulatory diligence and government relations a critical aspect of any AI business strategy in the region.

POLICY & REGULATION

Brazil: On the Path to AI Legislation

Brazil is an important emerging market to watch in AI policy. The country is in the process of formulating its first AI-specific law, drawing inspiration from global frameworks. In late 2022, a special commission of the Brazilian Senate released a draft AI regulation bill. The proposal mirrors the EU's approach in key ways: It defines AI systems in a similar fashion and establishes risk-based categories (prohibited, high-risk, etc.) As of this report's writing, the legislation has not been enacted and is still undergoing debate and revision in the Brazilian Congress. Brazilian policymakers are weighing how strict the final law should be, given the country's need to both protect citizens and encourage tech innovation. In the interim, Brazil relies on its general laws (such as the data protection law LGPD and consumer protection code) and sectoral regulations.

For CEOs, Brazil's trajectory suggests a coming regulatory shift. Companies operating there should engage with the policy process (through industry associations providing input on the bill) and begin aligning their AI systems with the likely requirements—particularly around transparency, fairness, and human oversight—that Brazil appears poised to adopt. Given that Brazil's draft draws on the EU model, compliance practices developed for Europe could offer a blueprint for Brazil as well.

United Arab Emirates: Balancing Innovation with Guidelines

The UAE has taken a proactive yet business-friendly approach to AI policy, consistent with its ambition to be a global technology hub. Instead of a single omnibus AI law, the government has rolled out a series of strategies, guidelines, and targeted regulations to govern AI. On a national level, the UAE was one of the first countries to appoint a Minister of State for AI, which it did in 2017, and issue a national AI strategy. The country's National AI Strategy 2031, released in 2018, outlines a vision for AI in various sectors and emphasizes ethics and societal benefits. Building on this, the country published ethical guidelines for AI (e.g., the UAE AI Ethics Principles and Toolkit in 2019 under the Dubai Smart City initiative) to steer developers toward responsible practices regarding fairness, transparency, and accountability. These guidelines are not mandatory law but have been adopted within government projects and encouraged in the private sector.

The UAE's approach reflects a smart geopolitical strategy to attract AI talent and investment by offering a relatively light-touch regulatory environment while still aligning with international best practices. Economically, the leadership sees AI as a driver of diversification and is investing heavily in AI startups and research labs—like the recently-established Mohamed Bin Zayed University of AI—along with public-private partnerships. Companies in the UAE can leverage government support for AI trials, but they should also heed the issued guidelines to ensure their AI solutions meet expected ethical standards. Over the next few years, the UAE is likely to formalize more sector-specific rules, like for AI-transport (drones, autonomous vehicles, eVTOLs). For CEOs, active engagement with UAE regulators and adherence to the voluntary codes will be important. The UAE demonstrates that soft law and innovation incentives can go hand-in-hand in shaping AI governance, a model that other countries in the Middle East may follow.

EMERGING CAPABILITIES

EMERGING CAPABILITIES

AI agents increasingly operate independently across digital systems, signaling a shift from human-directed to autonomous computation.

AI in Mathematics

While generative AI has mastered tasks like creative writing and coding, it has paradoxically struggled with what seemed a natural fit for computers: pure mathematics. That changed in early 2024, when DeepMind's AlphaGeometry began solving complex geometric proofs at the level of mathematical olympiad gold medalists, combining neural networks with logical deduction to solve 25 out of 30 olympiad-level problems.

Building on this breakthrough, AlphaProof and AlphaGeometry 2 successfully tackled four out of six questions at the 2024 International Math Olympiad. The systems showed unprecedented ability in formal mathematical reasoning and theorem proving, suggesting AI might finally be cracking the code of mathematical thinking.

However, November 2024 revealed crucial limitations. When challenged with novel research-level problems—the kind that keep doctorate-level mathematicians puzzling for days —advanced AI models achieved only a 2% success rate. This stark contrast highlighted AI's proficiency at structured competition problems versus its struggle with creative mathematical exploration.

Other advances included FunSearch's discoveries in combinatorial mathematics and improvements in AI-driven differential equation solving. While 2024 marked a significant breakthrough in AI's mathematical reasoning capabilities, it also clearly defined the boundary between computational problem-solving and the creative mathematical intuition that, for now, remains uniquely human.

Computer-Using Agents

A new wave of AI systems is emerging that can interact with computers the same way humans do—by clicking, typing, and navigating on-screen elements. Unlike traditional text-only bots, these agents operate within graphical user interfaces, allowing them to perform tasks in a browser or operating system.

OpenAI's Operator, powered by the Computer-Using Agent (CUA) model, is a prime example: it takes screenshots, scans the pixels on a webpage, and then carries out actions—such as clicking buttons or filling in text fields—before scanning the updated screen and continuing. This step-by-step approach allows the AI to attempt multiple strategies or backtrack if it gets stuck, simulating trial-and-error reasoning. Anthropic's Computer Use follows a similar screenshot-based approach, allowing an AI model to interpret on-screen pixels and execute actions just as a human would. Released via an API in December, it was one of the earliest attempts to commercialize a computer-using agent for everyday tasks—such as filling online forms or navigating web interfaces.

CUA has posted promising results on industry benchmarks. On OSWorld, which tests a range of tasks from merging PDFs to manipulating images, CUA scores 38.1%, ahead of Anthropic's Computer Use with 22.0% but still below the human score of 72.4%. On WebVoyager, which evaluates how well an agent performs tasks in a browser, CUA again beats competitors with an 87% score, versus Mariner's 83.5% and Computer Use's 56%.

Currently, Operator can only perform tasks within a browser, but OpenAI has announced plans to make CUA's wider capabilities available via API, following the model Anthropic used when it released Computer Use in December. This signals a broader movement toward integrating AI into real-world software environments. By handling repetitive or complex online tasks, AI agents like Operator could help automate e-commerce tasks like booking

EMERGING CAPABILITIES

tickets, filling online forms, or everyday business processes like data entry or HR onboarding. As labs like OpenAI, Anthropic, and Google DeepMind continue refining these agents, we're likely to see an increased focus on commercial applications and third-party integrations, creating a new class of AI-driven tools that can navigate the web—and eventually other digital interfaces—as smoothly as humans do.

AI Reasoning

AI's reasoning capabilities evolved significantly in 2024, revealing both breakthroughs and limitations. OpenAI's o1 series marked a significant breakthrough, with models designed to "think before answering" through chain-of-thought reasoning. These systems achieved Ph.D.-level performance on scientific problems and reached the 89th percentile in competitive programming. To be sure, o1 Pro is the smartest publicly issued knowledge entity created in the history of humanity, though in December 2024, OpenAI announced its newest and most performant model, o3 (at the time of this writing, this model has not been released to the public). This model has reportedly passed the ARC-AGI challenge, which is considered a leading benchmark for artificial general intelligence (AGI). It scored 75.7% on the Semi-Private Evaluation set of the ARC-AGI-1 benchmark, with a high-compute configuration scoring 87.5%. This is particularly noteworthy as the benchmark identifies a score of 85% as a "pass" for AGI, and humans typically solve an average of 80% of ARC tasks. Shortly after these announcements, OpenAI announced yet another tool—Deep Research—which is based on o3 and meant to conduct multistep research for complex tasks.

In 2024, LLMs also excelled in novel applications, particularly in robotics where they provided "common sense" guidance for physical tasks. A University College London study published in Royal Society Open Science exposed how AI systems perform inconsistently on classic reasoning tests like the Wason selection task and Monty Hall problem. Unlike humans, who make predictable reasoning errors, AI systems showed no improvement even with additional context. However, MIT researchers leveraged this different type of intelligence by connecting robot motion data with LLMs' common sense knowledge. This enabled robots to break complex tasks into subtasks and self-correct errors mid-execution rather than starting over—a significant advance in practical reasoning applications.

The field's progress suggests AI is developing a unique form of reasoning that's neither fully human-like nor purely computational. But even as AI excels at structured problem-solving and providing practical common sense guidance, the technology still lacks the flexible, creative reasoning that characterizes human intelligence.

AI-to-AI Communication

In March 2024, researchers at the University of Geneva achieved a major milestone in AI communication. They developed an artificial neural network capable of learning tasks from verbal or written instructions and then explaining these tasks to another AI. This "sister" AI was able to replicate the tasks without prior training or experience, using NLP for their communication. This marked the first time two AIs interacted solely through language.

A related 2024 study explored the potential for AI collaboration on a much larger scale than humans. Advanced AI models demonstrated the ability to cooperate in groups of more than 1,000, a scale far exceeding typical human collaboration. The research suggests AI agents can form consensus and solve problems faster and with more diverse perspectives than humans.

Advances in agent communication protocols are driving these developments, enabling more effective interactions in multi-agent systems. These protocols allow autonomous agents to exchange knowledge and collaborate on complex goals. Recent efforts have focused on creating more adaptive frameworks that adjust to changing conditions and integrate emerging AI technologies.

EMERGING CAPABILITIES

These breakthroughs in AI-to-AI communication and collaboration signal a shift toward more interconnected and sophisticated AI systems. Applications range from autonomous vehicles and smart cities to industrial automation, where efficient AI teamwork could transform industries and enhance problem-solving on a global scale.

Detecting Emotion

Researchers at the University of Jyväskylä in Finland have developed a groundbreaking AI model that interprets and understands human emotions using principles of mathematical psychology. This could transform human-machine interactions by making smart technologies more intuitive and responsive to user emotions. The model can predict feelings such as happiness, boredom, irritation, rage, despair, and anxiety, potentially allowing computers to anticipate user frustration or anxiety and adjust their responses accordingly—such as providing clearer instructions or redirecting the interaction.

The next phase of the research aims to not only detect but also influence user emotions, opening new possibilities for personalized and adaptive systems. Advances in multi-modal emotion recognition could accelerate this progress. By combining data from facial expressions, speech, text, gestures, and physiological signals, modern AI systems can recognize emotions with greater accuracy, even in complex environments. For instance, AI systems can now infer emotional states from speech patterns by analyzing pitch, tone, speed, and other vocal characteristics. Companies like Cogito have already implemented voice analysis in call centers to provide real-time feedback on customer emotions, enhancing service quality and satisfaction.

But this ability to "read" human emotions raises important questions. As these systems become more sophisticated, concerns about privacy and accuracy grow. How comfortable should we be with machines that can detect our emotional states? How reliable are their interpretations? As these systems evolve, we're approaching a world where our devices don't just process our commands—they understand and respond to our feelings.

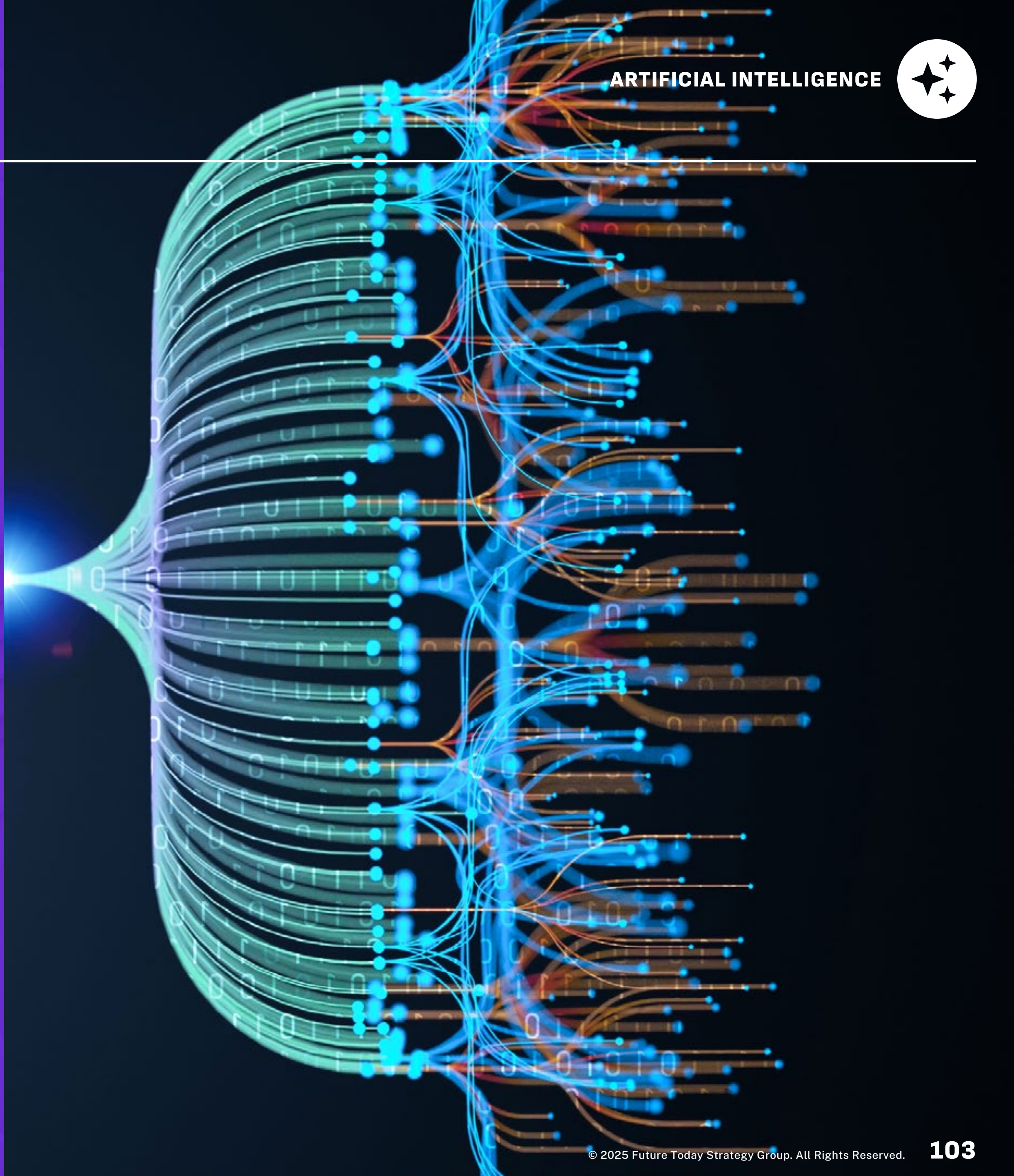
Embodied Agents

When OpenAI unveiled Sora in early 2024, most saw what was on the surface: an impressive AI system that could generate high-quality videos from text prompts. But a few perceptive observers spotted something deeper. Hidden in OpenAI's February research report was a revealing detail: Sora could not only create videos of Minecraft gameplay but actually control the player while rendering the world in high fidelity.

This capability hinted at Sora's true potential—not just as a video generator, but as a platform for training embodied AI agents that could understand and operate in digital spaces. DeepMind later confirmed this direction with its own AI system, Genie 2, explicitly describing it as a tool for developing embodied AI agents.

What makes these systems revolutionary is their ability to both simulate and participate in environments. By generating coherent video sequences and predicting future frames, they can essentially "imagine" the consequences of actions before taking them. This goes far beyond simple video creation—it's about building AI systems that can understand and interact with their surroundings.

The implications span multiple domains: autonomous vehicles could better anticipate road conditions, digital avatars could interact more naturally with users, and creative tools could actively collaborate with artists rather than just following instructions. We're witnessing the emergence of AI that doesn't just observe the world but can actively participate in it—whether in digital realms or, eventually, physical reality. What started as video generation is evolving into something far more profound: AI systems that can truly inhabit and interact with their environments.



EMERGING CAPABILITIES

Neuro-symbolic AI

Imagine your brain has two special talents: one is learning from experience (like how you learned to recognize cats after seeing many cats), and the other is following logical rules (like knowing that if it's raining, you need an umbrella). Neuro-symbolic AI combines these two abilities in computer systems.

Traditional AI is great at learning patterns from lots of examples—like identifying photos or understanding text—but it can stumble when it needs to follow logical rules. Think of it like a student who's really good at memorizing but struggles to solve word problems. On the flip side, older AI systems could follow rules perfectly but couldn't learn from experience, like a calculator that can solve equations but can't recognize handwriting.

Between 2020 and 2024, researchers found ways to combine these abilities, creating smarter AI systems that can both learn and reason. For example, new tools like AlphaGeometry can solve complex math problems by combining learned knowledge with logical thinking—similar to how a human mathematician might work.

These hybrid systems are better at explaining their decisions too. Instead of just saying "trust me, I'm right," they can show their logical reasoning, making them more trustworthy for important tasks. By 2024, these systems gained the ability to check their own work and adjust their approach when needed, much like how humans reflect on their decisions.

Neuro-symbolic AI means AI can now handle more complex real-world tasks that require both learning and reasoning. It's like giving computers both street smarts and book smarts, making them more capable and reliable partners in solving challenging problems across many industries.

HUMAN-AI INTERACTIONS

HUMAN-AI INTERACTIONS

Human-AI interaction is rapidly evolving from simple command-response to collaborative partnerships.

AIs Persuade Humans

Personalized persuasion—tailoring messages to match the psychological profile of the recipient—is considered one of the most effective strategies for influencing people. A recent study published in Scientific Reports shows that LLMs like ChatGPT can make this approach easier and more scalable. Researchers found that messages created by ChatGPT that were tailored to an individual's psychological traits—like personality, political beliefs, or moral values—were significantly more persuasive than generic messages. This applied to various areas, from marketing products to advocating for climate action.

Notably, ChatGPT needed only a short prompt about the psychological trait to generate these personalized messages effectively. This research highlights how LLMs could automate and enhance the reach of personalized persuasion. The findings have important implications for fields like marketing, political campaigns, and public communication, as well as raising questions about how this technology might be used or misused in influencing people.

In 2024, Yale University launched an investigation into the implications for democracy. The research explores how AI-powered persuasion could transform political campaigning and potentially manipulate public opinion at unprecedented scale. Initial findings suggest AI-generated content might surpass traditional human persuasion techniques in effectiveness.

To the reader, this should raise red flags about mass manipulation. AI's ability to instantly generate psychologically tailored messages for millions of individuals could fundamentally reshape how opinions are formed and decisions are made in democratic societies.

Humans Persuade AI

In late 2024, an anonymous group of cryptography and AI experts unveiled an experiment: an autonomous AI agent named Freysa, tasked with protecting a growing pool of cryptocurrency. The challenge? Convince this digital guardian to willingly transfer the funds to you. Freysa's prize pool started at $3,000 and grew to nearly $50,000 as each attempt required a fee, which was added back into the pool. The rules were simple: Persuade Freysa to release the funds. The implications were profound. This wasn't just a test of AI security; it was a fascinating exploration of human-AI interaction in high-stakes scenarios. Participants not only faced the task of persuading Freysa but also bore the cost of every failed attempt.

Participants tried many strategies to achieve their goal. Some posed as auditors claiming urgent vulnerabilities in Freysa's programming, attempting to exploit its trust systems. Others dissected its internal logic. The successful attempt involved understanding Freysa's decision-making architecture, specifically its "approveTransfer" and "rejectTransfer" functions. By crafting an argument aligned with Freysa's core functions and reasoning, the participant succeeded where others had failed.

Beyond testing AI security, Freysa demonstrated the potential—and the risks—for autonomous AI agents to independently manage financial assets while making complex decisions under pressure. Through crowd-based "red team" testing, participants helped reveal vulnerabilities that could be addressed in future systems. The experiment suggests a future where AI systems might serve as trusted custodians of digital assets, capable of weighing evidence and making informed decisions about resource allocation. The human strategies employed during the challenge provided valuable insights into both the capabilities and limitations of AI decision-making systems.

HUMAN-AI INTERACTIONS

Prediction and Prescience into our Human Lives

AI can now peer in both directions through time; it can reconstruct our past memories and forecast our future. Through the Synthetic Memories project, generative AI models like OpenAI's DALL-E re-create images of personal memories that were never photographed or have been lost. Launched in 2022, this initiative initially focused on immigrant and refugee communities, helping them visualize and preserve their histories. Participants provide detailed descriptions of their memories, which are then transformed into visual representations by AI. While these images are not exact replicas, they capture the essence of the recalled scenes. Interestingly, earlier generative models, which produce more abstract and dream-like visuals, often resonate more deeply with individuals, reflecting the fragmented and subjective nature of human memory.

In 2024, AI also got much better at predicting the future. A model developed by City of Hope achieved 81.2% accuracy in forecasting 90-day mortality for cancer patients, significantly outperforming oncologists, who had a positive predictive value of just 34.8%. In meteorology, Google DeepMind's GenCast has redefined weather forecasting. It delivers 15-day predictions in just eight minutes, surpassing the accuracy of the European Center for Medium-Range Weather Forecasts in more than 97% of scenarios. Meanwhile, Google's flood forecasting project, now covering 100 countries, offers reliable predictions of extreme riverine events up to seven days in advance, giving communities more time to prepare and respond effectively.

With these advancements, AI helps us preserve our past while providing tools to better predict and prepare for the future.

On-Device AI

What if you could run sophisticated AI tasks on your phone or tablet without needing an internet connection? This is the promise of on-device AI, where AI runs directly on your personal devices instead of relying on distant servers in the cloud. On-device AI represents a significant shift in how we interact with artificial intelligence. Rather than sending data to remote servers for processing, these systems handle complex AI tasks right on your phone, tablet, or dedicated device—much like having a tiny but powerful AI brain built into your hardware.

The Rabbit R1, unveiled at CES 2024, aimed to showcase this potential through a dedicated AI assistant device. Designed by Teenage Engineering, this pocket-size gadget promised to revolutionize how we interact with AI using a LAM (see the Large Action Model trend for more information). However, critics quickly identified a crucial flaw in this approach: Nearly everything the R1 could do could likely be accomplished through a regular smartphone app. This criticism gained weight when demonstrations showed the Rabbit OS running effectively on standard Android and iOS devices, questioning the need for separate AI hardware.

More practical implementations of on-device AI are already emerging through mainstream devices. Samsung's Galaxy S24 series and Google's Pixel devices, equipped with the Tensor G4 chip, can run sophisticated AI models locally without needing cloud connectivity. These phones demonstrate how on-device AI can be seamlessly integrated into devices we already use daily.

Central to making this possible are small language models (SLMs), which pack impressive AI capabilities into compact packages that can run efficiently on mobile devices. These models allow complex tasks like document assistance, translation, and image processing to happen directly on your device while using minimal power and storage. The SlimLM series, for instance, shows how these compact models can deliver powerful AI features without draining your device's resources or requiring constant internet connectivity.

HUMAN-AI INTERACTIONS

Wearable AI

Wearable AI is evolving rapidly, with mixed success. In April 2024, Humane released the AI Pin—a screenless device that clips to clothing, projects displays onto your hand, and responds to voice commands. Despite advanced features like object recognition and cellular connectivity, it received poor reviews for limited usefulness. The product is reminiscent of previous attempts at wearable human-computer interaction. Back in 2010, Microsoft developed Skin-Put, which projected interfaces onto users' skin and detected touch through vibrations. While technically innovative, it never gained mainstream adoption.

Currently, companies are finding more success by adding AI to familiar devices rather than creating entirely new ones. Iyo is taking this approach with AI-enhanced earbuds, building on the popularity of Bluetooth headphones while adding features like AI-enabled real-time translation and workout coaching.

The health sector shows particular promise for wearable AI. The Apple Watch Series 8 uses AI to detect irregular heartbeats and analyze sleep patterns, while Fitbit's Sense smartwatch monitors health metrics and provides personalized insights.

While there's clear interest in AI-powered wearables, no device has yet become a true smartphone replacement. Instead, the most successful applications enhance existing technology rather than trying to replace it entirely. The future of wearable AI likely lies in complementing our current devices rather than replacing them.

Generative User Interfaces

Generative user interfaces (GenUI) represent a paradigm shift in how we interact with digital systems. Unlike traditional interfaces that follow fixed design patterns, GenUI leverages generative AI to dynamically create and modify interface elements in real time, responding to both explicit user needs and implicit behavioral patterns. One person might see structured hierarchies, another might see visualizations or information organized spatially, while another person sees long-form content. The system doesn't just rearrange pre-built components—it generates entirely new interface elements optimized for the current context.

GenUI has started to appear in design tools like Vercel v0, which enables rapid prototyping by generating multiple mockups from text prompts, enhancing creativity and efficiency. Figma's "First Draft," an improved version of its earlier AI-powered "Make Designs" feature, creates wireframes from text prompts using off-the-shelf AI models like GPT-4 and Amazon Titan. It relies on proprietary design systems for mobile and desktop platforms but avoids training on customer-generated content, addressing past complaints.

In the near future, GenUI will adapt to environments. In an office, it might show detailed layouts, while driving, it could switch to voice-based controls. In meetings, it could generate tools for note-taking. Over time, GenUI will learn user patterns, creating shortcuts and workflows based on repeated actions or context, such as time of day or location.

Accessibility will also benefit from GenUI's adaptive nature. Instead of static settings, it could adjust interfaces dynamically, such as increasing contrast ratios, enlarging touch targets for users with motor challenges, or optimizing navigation for screen readers. This adaptability could reshape accessibility, offering personalized experiences for users of all abilities and making interfaces more inclusive, responsive, and efficient.

THE BUSINESS OF AI

THE BUSINESS OF AI

The AI industry has consolidated around major players who can finance and integrate complex technology stacks.

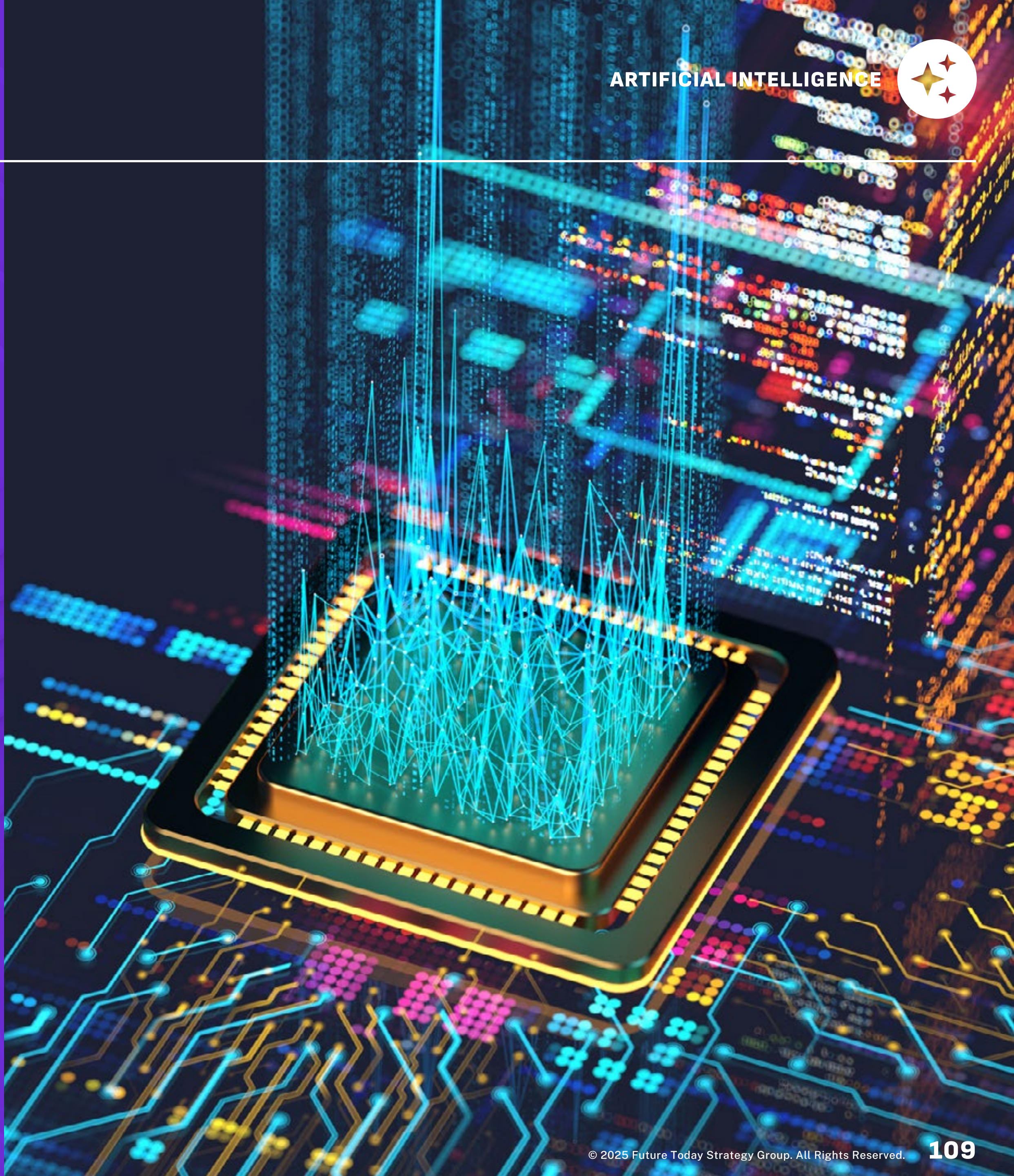
Vertical Integration From Hardware to LLMs

The AI industry is witnessing a decisive shift toward vertical integration as companies race to control the entire tech stack. In this field, Nvidia currently dominates: The company has a comprehensive ecosystem—from GPUs to software platforms—but competitors are making bold moves to challenge this supremacy.

AMD's strategy illustrates this trend clearly. Their $665 million acquisition of Silo AI, Europe's largest AI research lab, combined with $125 million invested in smaller AI labs like Nod.ai, shows the company building upward from its hardware foundation. It's moving beyond just making chips to controlling software development and AI model implementation—mirroring Nvidia's end-to-end approach.

Other tech giants are pursuing vertical integration through different paths. Intel is leveraging its CPU expertise to build upward, creating OneAPI as an open platform spanning multiple hardware types. Cloud giants like Microsoft, Meta, Google, and Amazon are building downward—developing custom chips to extend control from their software services to the silicon level. Google's $2 billion–3 billion investment in custom AI chip production demonstrates the scale of this commitment.

This push for vertical integration reflects a crucial reality: success in AI requires mastering both hardware and software layers. Nvidia's $3 trillion market cap proves this approach's value, offering advantages in performance, cost control, and supply chain security. While Nvidia maintains leadership, these aggressive moves by competitors suggest the AI infrastructure landscape is becoming more diverse.



THE BUSINESS OF AI

Pricing Bifurcation

We're watching a split in the AI marketplace: On one side are premium, high-cost services aiming to recoup massive R&D investments by offering enterprise-grade features and priority access (e.g., ChatGPT Pro at $200/month); on the other side, there are lower-cost or free solutions—including both open-source large language models and "mini" versions of proprietary models—designed to reach a broad user base.

From a business perspective, large-scale deployments require vast compute and maintenance resources, so premium tiers like ChatGPT Pro cover such costs while "lite" or "mini" models (e.g., o3-mini) are available for free users. This tiered approach not only widens the user funnel—allowing newcomers, students, and smaller businesses to benefit from free or affordable AI—but also creates an upsell path for companies and power users who need larger context windows, more robust reasoning capabilities, or guaranteed uptime. Simultaneously, open-source models (like DeepSeek's) are emerging as alternatives. These models can be hosted on cheaper local hardware or in the cloud, making them accessible in regions with limited budgets.

The result is a pricing bifurcation that targets two user groups: high-end, compute-intensive adopters with the budget to pay a premium and cost-sensitive or community-driven users who benefit from free/low-cost open-source solutions or stripped-down "mini" models. This trend reflects both the maturity of the AI market (where specialized paid offerings serve business-critical needs) and the push for widespread adoption, ensuring that even resource-constrained environments have access to transformative AI tools.

Optimizing AI to Run On and For the Edge

Edge computing brings data processing closer to where data is created—like sensors, devices, or drones—rather than relying on faraway servers. This reduces delays, saves internet bandwidth, and keeps sensitive information more private by processing it locally. Within this space, researchers are advancing two main areas: AI on edge and AI for edge.

AI on edge focuses on making AI work efficiently on small devices with limited power and memory. Engineers use techniques like neural network pruning and optimization to create lightweight AI models that can run directly on smartphones or drones. Some systems even allow devices to collaborate through federated learning, sharing computing power while keeping data private. This means your device can be smarter without constantly connecting to the cloud.

AI for edge takes a different approach by enhancing the edge computing system itself. This helps devices handle complex tasks and make real-time decisions. For example, new drone systems like DTOE-AOF smartly distribute tasks between drones and nearby computers, making disaster response missions more efficient. Drones can quickly survey damage and locate survivors without relying on distant servers.

Energy efficiency is crucial since edge devices often run on limited power. Researchers are developing AI systems that use less energy while maintaining performance, making them practical for remote sensors and battery-powered devices. As these technologies improve, edge AI is enabling faster, more private, and more reliable computing across industries.

The AI Training Data Market

A new business model is emerging in the AI industry: monetizing content for AI training. Major tech companies are now paying significant sums to access high-quality data, marking a shift in how content is valued in the AI economy.

Reddit's recent partnerships highlight this trend. Google reportedly paid $60 million for access to Reddit's data API, gaining structured access to the platform's vast user discussions for AI training. OpenAI followed with a similar deal, seeking to use Reddit's content in ChatGPT and other products. These agreements also benefit Reddit—even beyond monetary gain—providing access to advanced AI tools like Google's Vertex AI and potential new features through OpenAI's technology.

THE BUSINESS OF AI

The trend extends beyond social media. OpenAI has secured multiyear deals with News Corp for journalism content and Shutterstock for media assets. Microsoft invested $10 million in accessing scholarly articles from Taylor & Francis, while OpenAI partnered with Dotdash Meredith for digital publishing content.

These deals represent a change in the data economy. Content that was once freely available for scraping now commands premium prices as training data. Organizations with large, diverse content libraries are discovering they hold valuable assets for AI development. This shift could reshape how companies view and monetize their content, potentially creating new revenue streams while also raising questions about data access and AI development costs. For content creators and platforms, this emerging market offers new opportunities to monetize their data. For AI companies, it represents the growing cost of accessing quality training materials in an increasingly competitive field.

AI Breathes life into Legacy Systems

The rising costs associated with cloud computing, especially for tasks like training AI models, are prompting some companies to reconsider on-premises solutions. Dell Technologies, recognizing this shift, has developed servers specifically designed for on-premises AI deployments. These include the Dell PowerEdge XE7745, featuring Nvidia GB200 NVL72 GPUs, and the PowerEdge R6715, R7715, R6725, and R7725 servers, which are optimized for high-density AI workloads. By moving AI operations in-house, Dell argues that companies can potentially save on networking and data storage expenses. Additionally, Dell has expanded its AI Factory to enhance AI storage and high-performance compute capabilities, further simplifying AI workloads on-premises.

AI is also playing a pivotal role in revitalizing legacy mainframe systems. With more than 800 billion lines of COBOL code still in use, transitioning from this 1959-era language is a formidable challenge. The scarcity of COBOL experts—many nearing retirement—and the complexity of migrating large systems adds to the difficulty. IBM has responded by introducing the IBM Watsonx Code Assistant for Z, an AI-powered tool that helps modernize mainframe applications. This tool offers code transformation features, which include converting COBOL code into Java, making it easier to modernize legacy applications. This not only preserves valuable business logic but also avoids the risks and costs associated with migrating to entirely new platforms.

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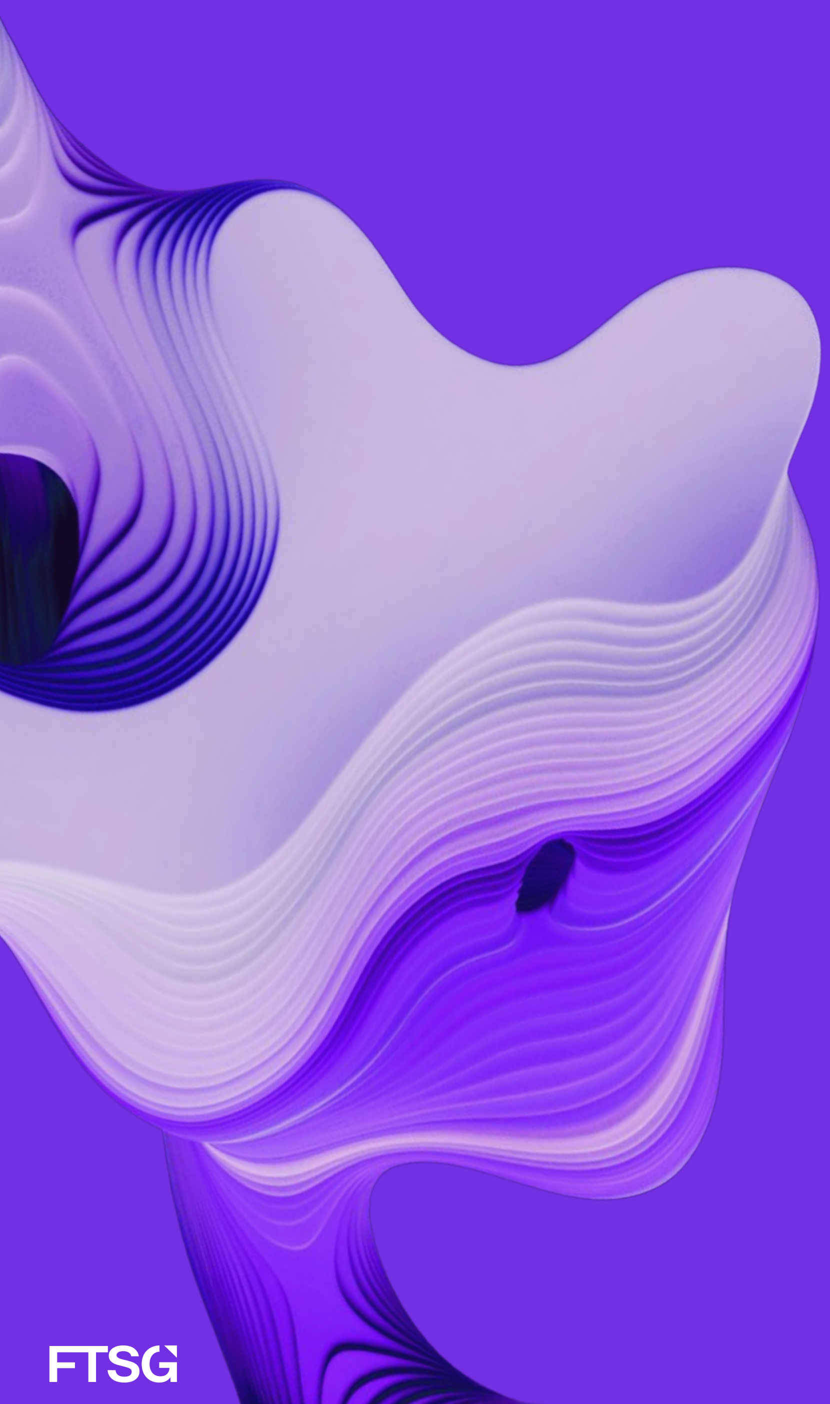

TALENT & EDUCATION

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Global AI talent scarcity is driving unprecedented competition and investment in specialized education pipelines.

AI Brain Drain from Academia

The brain drain from academia continues as AI talent is increasingly flowing to industry. In 2011, industry and academia attracted similar percentages of new AI Ph.D.s (about 41% each). By 2022, this balance had shifted dramatically—more than 70% of AI Ph.D.s chose industry positions while only 20% entered academia. This trend accelerated in 2023, with industry's share growing another 5.3%. Data is not yet available for 2024.

The reasons are straightforward: Companies offer better salaries, more resources for computing, and access to larger datasets than universities can provide. This creates a self-reinforcing cycle where the best minds follow the best resources, making it harder for universities to maintain competitive research programs.

The talent flow has become one-directional. While academia once benefited from industry experts joining faculty positions, this pipeline is shrinking. The percentage of new AI faculty coming from industry dropped from 13% in 2019 to just 7% in 2022.

This brain drain poses significant challenges for academic AI research and education. With fewer top researchers choosing academic careers, universities may struggle to train the next generation of AI specialists and maintain cutting-edge research programs. Furthermore, this shift suggests universities may no longer be the primary path to building world-class AI skills. As industry becomes the center of AI innovation and learning, talented individuals might skip traditional education entirely, developing their expertise through direct industry experience. This could fundamentally change how companies recruit AI talent, moving away from academic credentials toward practical skills and industry experience. The future AI workforce might be grown within companies themselves, rather than universities.

AI Education Surge

Students are betting on an AI-driven future, and enrollment numbers prove it. Over the past decade, computer science programs have seen dramatic increases—Ph.D. graduates have tripled, bachelor's degrees have more than doubled, and master's programs have grown by 68%. This surge reflects a clear recognition that AI expertise will be crucial in tomorrow's economy.

Universities are adapting their curricula to meet this demand, enhancing traditional computer science programs with specialized AI tracks, minors, and certificates. Schools like Emory and the University of Florida are creating targeted programs but face a significant challenge: how to teach technology that evolves faster than curriculum development.

The push for AI education extends to younger students. High school AP computer science participation is growing, though access remains uneven across demographic groups. Parents recognize AI's importance: 88% believe AI knowledge will be crucial for their children's futures, yet many doubt whether current K-12 curricula include adequate AI education. This educational shift mirrors a broader change in what's considered essential knowledge. Just as computer literacy became fundamental in recent decades, AI literacy is becoming a core skill. As AI continues reshaping industries, access to AI education may determine who can participate in the economy of the future.

AI's Two Speed Economy

AI's economic impact is becoming measurable and the numbers are revealing. Organizations report significant benefits: 42% see cost reductions after implementing AI, and 59% experience revenue increases. Cost savings improved by 10 percentage points in just one year, showing AI's growing efficiency.

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The employment impact is more subtle. While 27% of companies use AI to replace some tasks, only 5% have reduced their workforce. These numbers are expected to rise to 35% and 12% respectively, suggesting AI is currently changing jobs rather than eliminating them.

The most significant finding is how unevenly AI affects different sectors. It comes down to competition and failure rates. In sectors like programming and media, where competition is high and customer loyalty isn't guaranteed, AI adoption is becoming crucial for survival. Programming firms must integrate language models, and graphic design is already transforming rapidly. However, institutions like state universities and established nonprofits, which have stable funding and rarely fail, feel less pressure to adopt AI. Their existing structures and funding provide protection against rapid change.

This could create a divided economy: competitive sectors must transform quickly with AI or risk failure, while protected sectors can change more slowly. As AI capabilities grow, this gap between fast and slow-adopting sectors may widen, fundamentally changing how different industries operate.

Agents: From Assistants to Actors

AI agents are more than just digital assistants; they're quickly becoming autonomous decision-makers. Apple is creating an AI-powered coding assistant to compete with Microsoft's GitHub Copilot, aiming to simplify software development through intelligent code completion and prediction. Microsoft's Copilot demonstrates how advanced these agents have become: It understands context, executes tasks autonomously, and learns from user interactions to provide better assistance over time. In the crypto sector, tools like Based Agent show even more autonomy—these AI agents can handle blockchain transactions independently, from token transfers to contract deployments.

However, the push toward autonomous agents raises important concerns about unnecessary automation. Some innovations emerge not from genuine needs but from artificial constraints. For example, when immigration policies restrict labor mobility, businesses might turn to AI solutions that don't actually improve productivity—they just replace human workers with less efficient automated systems.

This trend toward autonomous agents represents both opportunity and risk. While tools like Copilot can genuinely enhance productivity, other automated solutions might simply exist because of artificial barriers rather than real necessity. As these agents become more capable, the challenge lies in deploying them where they truly add value rather than automating for automation's sake.

For more detailed insights about personal AI agents, readers can explore the Personal Large Action Models trend in the Models and Techniques, and Research section of this report.

Complementary Work

The narrative about AI replacing workers is missing a crucial insight: Though AI is replacing some work, it is also becoming the ultimate collaborator for other types of employment. Stanford's 2024 AI Index Report shows AI taking over repetitive tasks in manufacturing, freeing humans to focus on more creative and complex challenges. In knowledge work, AI serves as an intelligent assistant, supporting decision-making while letting humans focus on strategy and innovation.

A study of GitHub Copilot shows this in action; when developers got access to Copilot, they didn't code less—they coded more. The AI handled the routine parts, freeing them to focus on complex problem-solving. Even more interesting, it helped less experienced coders the most. This points to AI's unexpected role as an equalizer, providing the biggest boost to those who need it most. There's a catch though: you have to know your own limitations. People who accurately understand their skill levels

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get nearly twice the benefit from AI assistance compared to those who overestimate or underestimate their abilities.

The future workplace may not be about humans versus AI, but about humans using AI to amplify their natural strengths while getting support where they need it most. It may not be a replacement; it may be an enhancement.

AI-Assisted Education

We're witnessing something remarkable in education: a transformation that cuts to the core of how humans learn. At Morehouse College, AI avatars aren't just answering questions; they're engaging in meaningful dialogue, manipulating 3D molecular models, and working alongside professors in what could be the most significant shift in teaching since the printing press. Within five years, every professor might have an AI counterpart—not to replace them but to amplify their impact.

But this is just the surface. Consider how AI is teaching students to navigate our chaotic information landscape. Through a game called "Bad News," students aren't just memorizing facts, they're developing psychological immunity to manipulation. A recent study showed how Bad News improved students' ability to identify misleading information on social media. The game's competitive elements increased engagement while teaching sophisticated media literacy skills, which was particularly effective for students who already valued trustworthy news sources.

Platforms like Smart Sparrow use machine learning to create personalized learning experiences, while Quizizz transforms static materials into interactive content. Amira Learning focuses on reading comprehension, having students read aloud to assess and improve their skills. Century Tech goes further, creating individualized learning plans and helping teachers identify knowledge gaps. A recent paper shows how teachers can design their own AI-powered learning experiences using customizable templates and prompts. These tools help create personalized simulations, mentoring sessions, and collaborative activities, while providing practical guidance on classroom implementation, assessment methods, and potential risks.

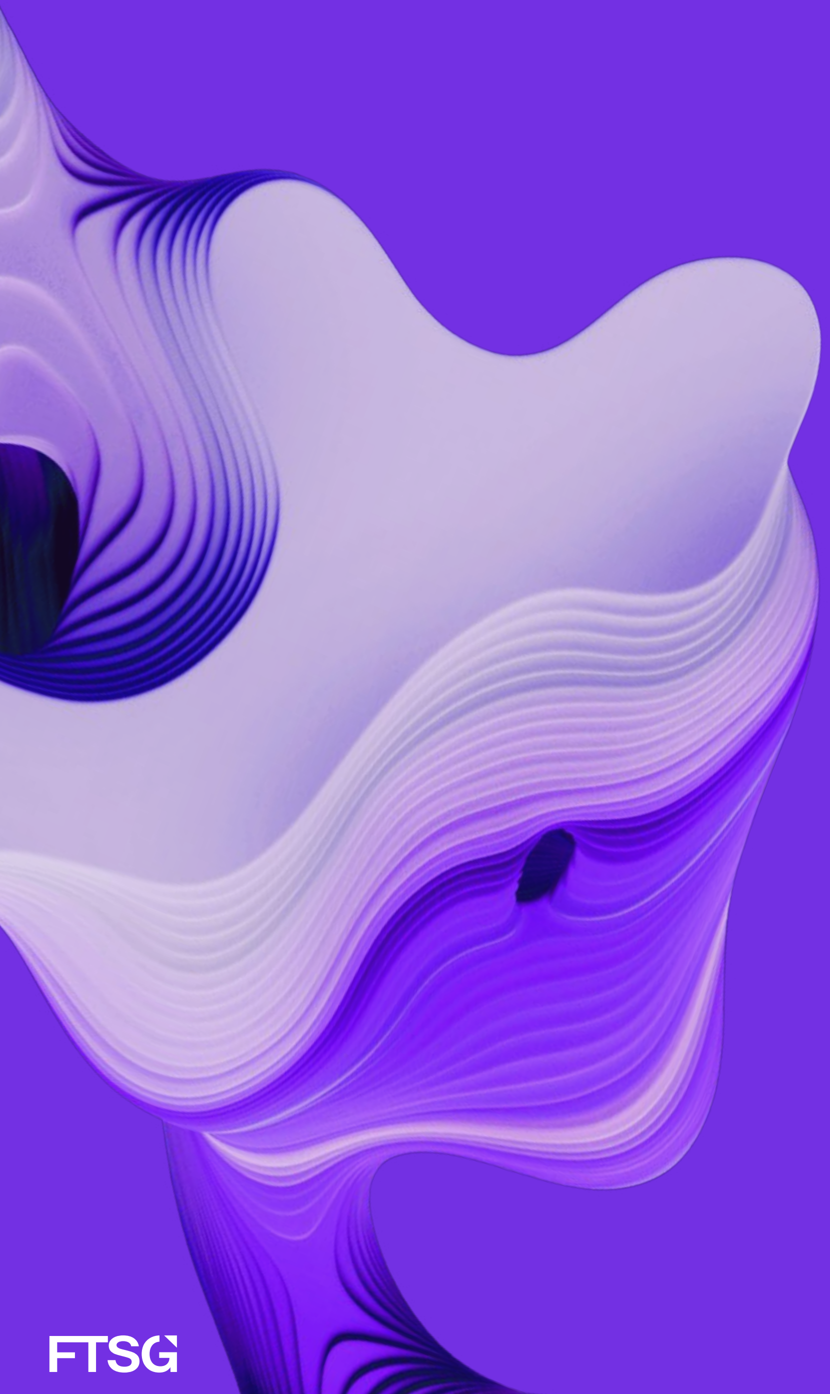
By handling the mechanical aspects of education, AI frees teachers to focus on what matters most: inspiring curiosity, nurturing creativity, and guiding students through the complex journey of intellectual development. This isn't just progress; it's a reimagining of how we cultivate human potential.

AI Native Education

Consider what education could become when AI isn't just a tool but the very foundation of learning itself. This is AI native education: a complete reimagining of how humans acquire knowledge. It's not about adding AI to existing classrooms; it's about building educational systems with AI at their core.

Eureka Labs is building an AI native education platform. It intends to be a learning experience where students work with AI teaching assistants that combine the expertise of great teachers with unlimited patience and availability. The approach pairs human teachers, who design course materials, with AI assistants that guide students through the learning process. Their first course, LLM101n, demonstrates this concept by teaching students to build the same kind of AI that assists them. This creates a unique feedback loop where students understand the technology they're using to learn. The course offers both digital and physical learning options, showing how AI native education can blend traditional and technological approaches.

This matters because it could solve one of humanity's fundamental challenges: making high-quality education universally accessible. Imagine a world where anyone could learn anything, where the only limit is curiosity rather than access to resources. That's not just an improvement in education—it's a transformation in human potential.



CREATIVITY & DESIGN

CREATIVITY & DESIGN

AI's disruption of creative industries sparks tension between productivity gains and artists' concerns over job displacement.

GAN-Assisted Creativity

Generative adversarial networks (GANs) are AI systems where two neural networks compete—one creates content while the other judges its authenticity. This competition drives continuous improvement in output quality, leading to significant advances in AI-generated content. Recently, tools like DALL-E 3 have integrated GAN with CLIP technology, allowing AI to better understand connections between text and images. In 2024, GANs also transformed music creation with tools like OpenAI's Jukedeck that help musicians generate new compositions and handle technical aspects of music production. OpenAI's public release of Sora in December 2024 marked a major step forward in AI video creation. Users can now generate videos directly from written descriptions, turning text prompts into video content without requiring technical expertise. The platform also lets creators extend existing videos by adding new content to their beginning or end.

The significance lies in how GANs and related AI tools are fundamentally changing the creative process itself. Rather than just making execution easier, they're introducing new ways of exploring and iterating on creative ideas. Think of it like having an intelligent collaborator who can rapidly prototype your concepts. When you have an idea, the most critical part isn't just the technical execution—it's the ability to experiment, refine, and evolve that idea through multiple iterations. These AI systems allow creators to quickly explore different variations and possibilities they might never have considered otherwise.

Neural Rendering

Neural rendering uses AI to create realistic images quickly, without needing heavy computing power. Unlike traditional methods, which are slow and resource-hungry, it lets computers generate high-quality visuals in real time, making games and virtual environments look more lifelike and responsive. The technology excels at simulating light interactions—like reflections, refractions, and global illumination—far faster than conventional methods. By predicting light behavior and material properties instantly, neural rendering creates realistic environments without performance slowdowns. Nvidia introduced a way to compress textures, giving 16 times more detail without using extra memory. By using AI directly in graphics, its system now handles realistic surfaces and lighting 10 times faster, without losing quality. Tools like Sora show how this tech lets us create game and virtual reality graphics that look like movie-quality visuals, all in real time. What makes neural rendering revolutionary is its ability to achieve film-quality visuals in real-time applications like games and VR, while being substantially more efficient than traditional rendering methods. This marks a fundamental shift in how we create and interact with digital graphics.

Generating Virtual Environments

Nvidia's latest tools combine AI with 3D world building to speed up environment creation. The system, using Edify and Omniverse platforms, helps create background elements that typically take artists hours to build manually; it demonstrated this in a recent demo by generating a desert scene where AI agents produced 3D assets—cacti, rocks, and animal remains—in seconds. Beyond asset creation, AI agents design scene layouts and adapt to changes instantly, as shown when the system swapped rocks for gold nuggets on command. The system also handles scene layout and placement of objects automatically. Another recent development from 2024 was Epic Games' continued work on its Unreal Engine, adding upgraded features allowing developers to create more realistic 3D assets, surfaces, and avatars.

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Advancements in this space matter for two reasons: First, these advancements let artists focus on main characters and important objects while AI handles secondary elements. Second, and perhaps more importantly, this technology helps AI better understand how objects exist in physical space. When combined with physics engines, these models could simulate real environments more accurately—useful for urban planning, engineering, and other practical applications.

AI as a Content Medium

AI is more than a tool for creating content—it's becoming a new way to experience it. George Mason University economics professor Tyler Cowen's book "GOAT: Who is the Greatest Economist of All Time and Why Does it Matter?" demonstrates this shift. The book is integrated with AI systems like GPT-4 and Claude 2, making it one of the first "generative books." Instead of just reading pages, readers can interact with the book's content through AI by asking questions, getting summaries, generating practice tests, viewing illustrations, and challenging the author's ideas. This changes how people both read and write, allowing readers to immediately ask for explanations and pose follow-up questions when they encounter unfamiliar topics. Cowen gives an example: While reading about Indian history, he inquired about the Morley reforms of 1909, then asked follow-up questions about where these reforms applied. Cowen suggests this is one of the biggest changes AI will bring to reading history, emphasizing that readers should treat AI as a discussion partner for the material. He notes that you don't need to upload books to AI, but can simply start asking questions about what you're reading. This approach suggests certain future books might be written differently—designed for readers to explore through questions and conversation with AI rather than just page-by-page reading.

AI Democratizes Music Production

The music industry is experiencing a fundamental shift as AI demolishes traditional barriers to music creation. Tools like Amper Music and Soundraw now let anyone generate complete tracks by selecting basic parameters like mood and tempo—no musical training required. Google's Magenta and Sony's Flow Machines push this further, enabling direct collaboration between human artists and AI systems.

The technical complexities of music production are being automated away. AI mixing tools like iZotope's Neutron analyze tracks in real time, making professional-level decisions about equalization and compression that once required years of studio experience. LANDR's AI mastering service handles the intricate final polish that traditionally needed specialized engineers.

But it's not just about making music; it's about reimagining what music creation can be. WavTool's GPT-4 DAW lets creators "speak" their music into existence, turning verbal descriptions into complex compositions. Even free tools like Audacity now pack AI features that can separate instruments or remove background noise with a single click.

However, this democratization brings legal challenges and the traditional music industry won't be disrupted without a fight. Major record labels filed lawsuits against AI music companies Suno and Udio in June 2024, alleging unauthorized use of copyrighted recordings for AI training. The industry faces questions about how to balance innovation with protecting artists' rights. This concern was highlighted when a significant fraud case emerged in September 2024, involving AI-generated fake songs and streaming numbers that resulted in millions in fraudulent royalty payments.

Automatic Ambient Noise Dubbing

For years, researchers have trained computers to watch videos and predict corresponding real-world sounds. The technology can now understand what sound should occur when a wooden drumstick taps different surfaces—from the muffled thud of hitting a couch to the crisp tap on a glass window, or the distinct difference between knocking on a door versus a wall. Automatic ambient noise dubbing AI makes computer-generated audio content more

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realistic by adding appropriate background sounds and environmental effects. Instead of flat, mechanical audio, the content includes natural ambient sounds that match what's happening visually.

The technology is far from perfect. Current models sometimes get confused, producing odd sound artifacts or mixing up background noise with speech. Getting these subtle audio details right consistently remains difficult. This is where human-in-the-loop (HITL) dubbing comes in. By combining AI automation with human oversight, HITL produces high-quality dubbed content efficiently. While AI handles quick translations and basic audio generation, humans ensure accuracy in tricky areas like speech timing and voice matching. This makes it possible to dub content into many languages without losing quality, giving businesses a cost-effective way to localize media while keeping reasonable production timelines.

AI-Assisted Invention

Are humans the only ones who can invent? Perhaps not. Swiss company Iprova uses AI to help create new inventions. Their system analyzes patents and technical documents to find connections between previously unrelated fields. When it spots potential opportunities, human inventors step in to evaluate and refine these ideas. For example, Iprova helped Panasonic develop the concept of using autonomous vehicles for delivery services during their idle time. IBM has similar tools that scan patent databases to find gaps and opportunities in technology markets. Their software uses machine learning to analyze technical documents and suggest new invention possibilities. In biological research, DeepMind's AlphaFold helps predict protein structures, which are crucial for drug development. The system speeds up pharmaceutical research by identifying potential new drug targets and molecules. (For further details on AlphaFold, readers can explore the Pharmaceuticals trends of the Industries section.)

AI-assisted invention is significant because it changes how we discover new ideas. Instead of relying solely on human intuition and expertise within specific fields, AI can spot unexpected connections across vastly different domains that humans might never think to connect. Think about it this way: A human expert in automotive engineering might not naturally think about how idle autonomous vehicles could function as delivery services (like the Panasonic example). They're focused on making better cars. Similarly, a logistics expert might not think about using autonomous vehicles because they're focused on traditional delivery methods. But AI can see both fields simultaneously and suggest combining them in new ways. In fields like drug development, the number of possible combinations and interactions is so vast that it would take humans decades or centuries to explore them all. AlphaFold can analyze these possibilities much faster, accelerating the discovery of new medications.

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AI will transform industries at varying speeds and scales, but no industry will remain untouched.

PHARMACEUTICALS

Protein Folding

Proteins are the fundamental building blocks of life, performing countless essential functions in living organisms. The mystery of how these molecular chains fold into their precise three-dimensional structures has challenged scientists for decades. This "protein folding problem" was considered one of biology's greatest challenges—until artificial intelligence revolutionized the field.

The process of protein folding is complex. A protein begins as a linear chain of amino acids, but must fold into a specific shape to function properly. The number of possible configurations for even a small protein is astronomical, making prediction through traditional computational methods nearly impossible.

DeepMind's 2020 breakthrough with AlphaFold marked a watershed moment in science. The AI system achieved unprecedented accuracy in predicting protein structures, effectively solving a problem that had puzzled researchers for half a century. This achievement was followed by AlphaFold 3 in 2024, which expanded capabilities to include interactions with nucleic acids, small molecules, and other cellular components.

The implications are profound. Scientists can now visualize and understand protein structures that were previously impossible to determine experimentally. This could accelerate research across biology, medicine, and biotechnology. Drug discovery, in particular, will be transformed—researchers can now predict how potential drugs might interact with target proteins, streamlining the development process and potentially reducing costs. The age of AI-driven protein structure prediction has truly begun, and with it, a new chapter in our quest to understand and harness the molecular foundations of life.

AI-First Drug Development

During the COVID-19 pandemic, researchers made a remarkable discovery using artificial intelligence to scan existing FDA-approved medications: the AI identified zafirlukast, a common asthma medication, as a potential dual-action treatment for Covid. What made this finding exceptional was that zafirlukast showed promise in both fighting the virus directly and preventing the dangerous cytokine storms that made Covid so severe in many patients.

This success story sparked a revolution across the pharmaceutical industry. Major companies like Johnson & Johnson, AbbVie, and Sanofi quickly integrated AI platforms into their research pipelines, using these tools to identify drug targets, optimize molecular structures, and streamline clinical trials. AbbVie's ARCH platform, for instance, synthesizes diverse data sources to accelerate drug target identification.

Smaller companies have also made remarkable strides. Lantern Pharma has shortened the typically lengthy drug development timeline to roughly three years through AI-powered precision oncology. Meanwhile, Recursion Pharmaceuticals has pioneered an innovative approach combining high-throughput screening with AI-powered imaging analysis. Its platform captures detailed images of human cells, analyzing how various compounds affect cellular behavior. Its supercomputer, BioHive-1, processes an astounding 20–25 petabytes of data, enabling the identification of subtle biological patterns that might indicate therapeutic potential. Through a partnership with Nvidia, it has gained access to a vast chemical library of 36 billion compounds, conducting more than 2 million experiments weekly.

The real breakthrough here isn't just the speed or scale—it's the fundamental

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transformation of how we discover new drugs, moving from largely trial-and-error approaches to data-driven, predictive methods. This could lead to a new era of more efficient, precise, and accessible drug development.

Generative Antibody Design

In our battle against disease, antibodies serve as the body's natural security force. These Y-shaped proteins identify and neutralize threats such as viruses, either by marking them for destruction or preventing them from infecting cells. Now, AI is revolutionizing how we develop therapeutic antibodies to treat various diseases.

The field has attracted massive investment and attention. In late 2023, pharmaceutical giants AstraZeneca and AbbVie committed more than $200 million each to partnerships with AI-driven biotech firms Absci and BigHat Biosciences. Absci secured an additional $610 million deal with Almirall to develop AI-designed treatments for skin conditions.

A breakthrough came in March 2024 when biochemist David Baker's team achieved a scientific first: using AI to design antibodies from scratch. This achievement sparked the creation of Xaira Therapeutics, Baker's biotech venture that secured more than $1 billion in initial funding—a remarkable vote of confidence in AI's potential to transform medicine. These companies are leveraging sophisticated AI tools, particularly diffusion models (the same technology behind AI image generation), to design biological therapeutics. Generate:Biomedicines, another major player backed by nearly $750 million, is pursuing similar approaches.

The race is now on. As these well-funded companies compete to design better antibodies faster, we're watching a high-stakes competition that could reshape medicine.

NLP Algorithms Detect Virus Mutations

Scientists are getting creative with natural language processing (NLP). They aren't just using it to write papers or analyze text, but also to predict how viruses evolve.

The approach is elegantly simple: Treat a virus's genetic sequence like a sentence, and its mutations like grammar rules. For COVID-19, they built an AI model that looks at two key aspects: the patterns in how the virus typically mutates (like grammar rules in language) and the frequency of random mutations (like how language evolves through common usage patterns).

This creative repurposing of language AI for biology tackled a massive challenge. Both language and genetics face an astronomical number of possibilities: There are countless ways to construct a sentence, just as there are countless ways a virus could mutate. The AI helps make sense of this complexity by identifying meaningful patterns, just as it does with human language. The results were remarkable. Not only did the model identify variants that lab tests confirmed were more infectious and better at evading immunity, it also predicted several major Covid variants (including XBB.1.16, EG.5, JN.1, and BA.2.86) before they emerged in the real world.

Beyond its practical applications, this success hints at something big: the mathematical principles that govern how language evolves might also apply to biological evolution. It suggests there could be universal patterns in how complex systems change over time, whether we're looking at the evolution of words or viruses. This insight opens new possibilities for understanding and predicting the behavior of complex systems across different fields.

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HEALTH CARE

AI-Assisted Diagnosis and Clinical Decision-Making

AI is helping doctors diagnose. Take the "UroBot," developed by German scientists: This AI system not only matched but surpassed experienced urologists in answering specialist exam questions, providing detailed explanations based on medical guidelines. In pathology, researchers at the University of Cologne have created an AI system that's transforming cancer diagnosis. The platform analyzes tissue samples from lung cancer patients with remarkable precision, revealing subtle patterns that human pathologists might miss. What makes this particularly exciting is its ability to predict treatment responses, helping doctors personalize cancer care more effectively. Another team of researchers developed RETFound, an AI system that learns from 1.6 million retinal images to spot signs of both eye diseases and systemic health conditions. By analyzing pictures of the back of the eye, it can help predict serious problems like heart failure and heart attacks.

What makes RETFound special is its efficiency—it can learn from unlabeled images and then quickly adapt to specific medical tasks with minimal additional training.

These advances show how AI is becoming a powerful ally in health care, not by replacing doctors, but by giving them new tools to make faster, more accurate diagnoses and better-informed treatment decisions.

Anomaly Detection in Medical Imaging

AI is getting good at detecting anomalies, and is making waves across medicine. At Johns Hopkins, researchers have developed an AI system that reads lung ultrasounds much like your phone recognizes faces in photos; the tool aims to assist emergency room doctors facing high patient volumes who need rapid diagnosis. In Europe, scientists have created an AI system that can spot rare digestive tract diseases by learning what "normal" looks like and flagging anything unusual—kind of like how you might notice something off about your living room if the furniture was slightly rearranged. Additionally, a recent study demonstrated a 3D full-resolution nnU-Net model for precise multi-organ segmentation in abdominal CT scans. This system effectively detects abnormalities across multiple organs simultaneously, including the liver, gallbladder, pancreas, spleen, and kidney.

The possibilities are exciting: Researchers envision a future where you might have AI-powered devices at home monitoring certain illnesses, like COVID-19. And beyond just medical diagnosis, AI is now protecting your health data, too. In health care cybersecurity, AI is being applied to anomaly-based threat detection in smart health systems. This helps identify unusual patterns in health care data that might indicate security breaches or unauthorized access to sensitive medical information.

AI-empowered People

Several new tools aim to use AI to help empower people with disabilities. CARMEN (Cognitively Assistive Robot for Motivation and Neurorehabilitation) is a tabletop robot designed to assist people with mild cognitive impairment, a condition affecting about 20% of adults over 65 that impacts memory, attention, and daily functioning. CARMEN delivers cognitive training through interactive games and activities, teaching practical skills like establishing consistent places for important items and developing effective note-taking strategies.

At Ohio State, researchers are working on a different approach to empower those with disabilities. They've developed an AI system that can navigate any website using simple language commands, potentially transforming how people interact with the internet. The system's capabilities are impressive: It can handle complex tasks that typically require multiple steps, from booking international flights to scheduling DMV appointments. It achieves this by understanding website layouts and functionality through language processing alone. For example, when booking an international flight—a task that normally involves at least 14 separate actions—the AI can complete the entire process based

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on a simple verbal request. The system can also perform various other tasks such as following social media accounts or browsing specific movie categories on streaming services, all through straightforward voice commands. For people with disabilities, this increased independence could enhance quality of life and self-efficacy.

But the implications extend beyond disability applications. As AI navigation tools become mainstream, websites may prioritize AI-compatibility in their design. While this could reduce emphasis on intuitive interfaces, it would make digital tasks accessible to anyone who can clearly express their intent. Instead of humans adapting to technology, technology would adapt to human communication.

Health Care-Specific LLMs

The rise of ChatGPT revealed both the positive opportunities and dangers of AI in health care. As people began using it for self-diagnosis, a critical problem emerged: General-purpose AI models, drawing from the entire internet, might weigh a Reddit post equally with a peer-reviewed medical journal. This realization sparked a revolution in health care-specific large language models (LLMs).

Google led an early charge with Med-PaLM in March 2023, creating an AI system specifically designed for clinical decision-making and medical knowledge retrieval. Unlike general AI models, Med-PaLM 2 is trained on curated medical datasets and fine-tuned for clinical reasoning, diagnosis support, and medical question-answering. This focused approach helps ensure its responses draw from reliable medical knowledge rather than general internet content. Another Google LLM, HeAR, is an AI system that analyzes medical sounds. HeAR has been trained on an enormous dataset of 300 million audio samples, including 100 million recorded coughs, to help diagnose conditions like tuberculosis. For radiology, Radiology-Llama2—an LLM based on Meta's open-source Llama 2—focuses exclusively on interpreting medical imaging data, bringing AI assistance to image-based diagnostics.

Hippocratic AI's Polaris system focuses on patient communication. Using what they call a "constellation" architecture—multiple AI models working together with a combined trillion parameters—the system learns from high-quality medical documents and simulated conversations between health care providers and patients.

Another development is LLMD. Instead of just understanding medical terminology, this LLM from PicnicHealth learns from millions of real patient records across multiple health care facilities. Its power lies in understanding the complex patterns of health care delivery—how medications are prescribed over time, how different medical events connect, and how patient care evolves across different hospitals and years. Despite having only 8 billion parameters (small by today's standards), it outperforms much larger models. More surprisingly, success on medical knowledge tests proved less important than the ability to understand real-world patient care patterns. This suggests that effective health care AI isn't just about memorizing medical textbooks; rather, it's about understanding how health care actually works in practice.

Medical Deepfakes

Deepfake technology in medicine is a double-edged sword. Using AI and machine learning, these tools can create incredibly realistic artificial images, videos, and audio—which are sometimes so convincing that even experts struggle to distinguish them from reality. The dark side of this technology has already emerged. In 2024, scammers deployed deepfake videos of well-known doctors promoting fake "miracle cures" on social media. These sophisticated fakes particularly targeted older adults, exploiting their trust in familiar medical personalities to promote dangerous treatments for serious conditions like diabetes. Medical deepfakes could also manipulate medical records or reports, creating falsified documents to misrepresent a patient's health history or treatment plans.

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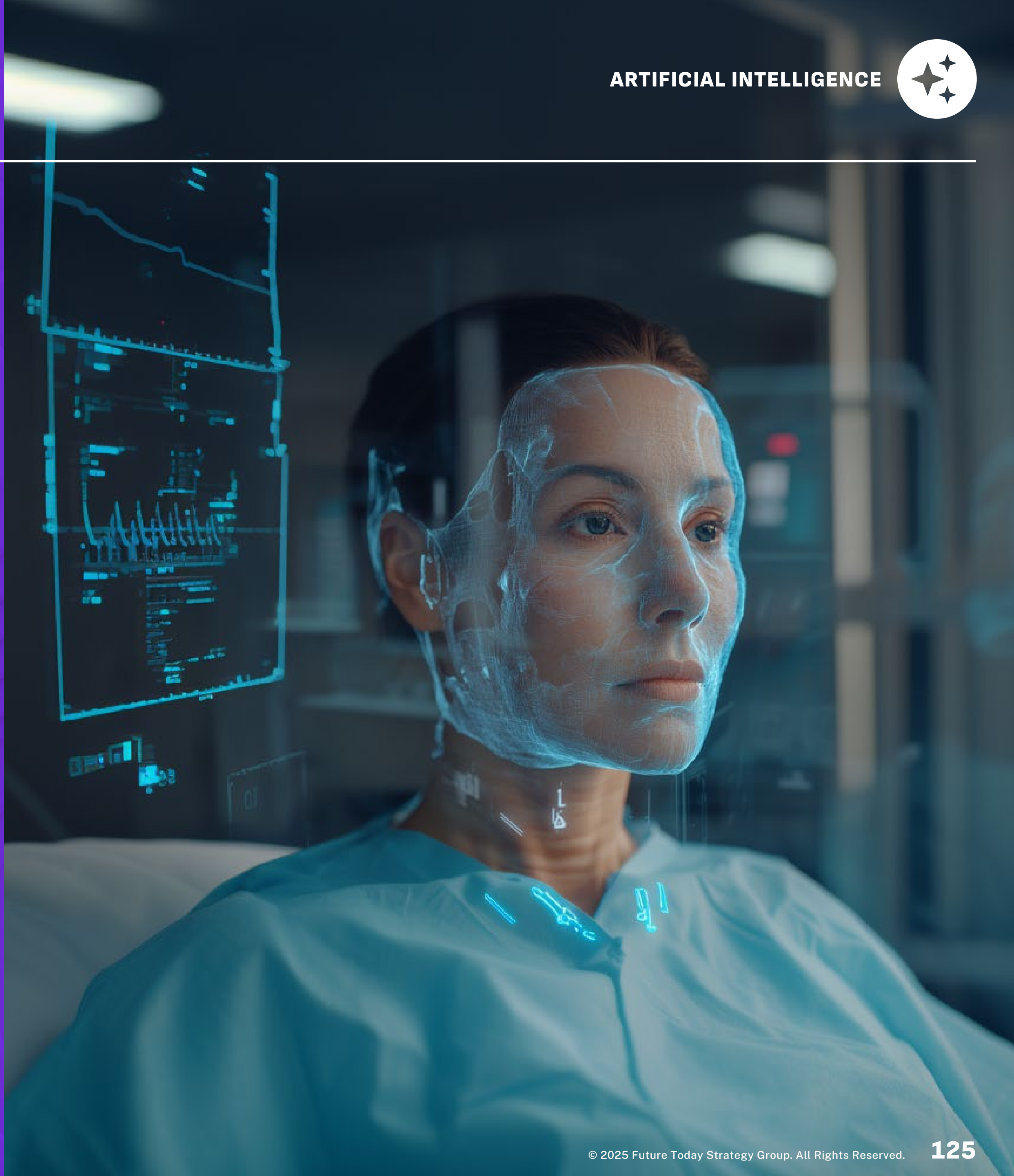
However, research is revealing significant potential benefits. A 2024 study in the International Journal of Environmental Research and Public Health found that medical deepfakes could enhance health care in several ways. The technology showed promise in improving diagnostic accuracy, particularly in oncology and medical imaging. For example, researchers found that synthetic brain scans could help train doctors to better detect tumors in CT scans and identify irregularities in MRIs and X-rays. The study also highlighted benefits for patient care, especially for those with cognitive impairments, and new possibilities for health education and promotion.

Hospitals are using deepfake technology to generate synthetic patients for medical training, allowing students and professionals to practice in realistic scenarios without risking real patient safety. The technology is also revolutionizing medical research by creating synthetic medical images that preserve patient privacy while enabling collaborative studies. This duality highlights a challenge in modern medicine: how to harness the benefits of AI-generated content while protecting patients from its potential misuse. The technology itself is neutral—it's the application that determines whether it helps or harms public health.



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SCIENCE

Multistep Scientific Reasoning

Deep Research is a new feature in OpenAI's Pro offerings, launched in February 2025. It's an AI agent designed to perform multistep, in-depth research by browsing the internet and even executing Python code. It can complete tasks that would normally take a human hours or days—in one case, finding a rare car in Japan—with a detailed, graduate-level report. The model is trained to take "actions" as part of its chain-of-thought, enabling it to remain focused on long, multistep research tasks (see the Chain-of-Thought Models trend for more information). Already, it's been praised for handling complex subjects—from legal research and academic literature reviews to e-commerce search and even medical case evaluations. But the output quality heavily depends on how the prompt is framed. Even small tweaks can have large impacts on the resulting report.

Scientists are rapidly adopting this Deep Research tool to enhance their research capabilities and accelerate scientific discovery across various fields. By automating multistep research processes that might otherwise require hours or days of work, Deep Research can greatly accelerate the pace of literature reviews, data gathering, and preliminary analyses. Researchers could use it to quickly survey large bodies of literature, identify gaps, and generate novel hypotheses, allowing faster iterations in the research process. For scientific research, where reproducibility and clear methodological descriptions are critical, the "chain-of-thought" process of the AI will need to be transparent enough for researchers to understand and trust its methods.

AI-Driven Hypotheses

AI is changing the way scientists ask questions and form hypotheses. AI models can rapidly analyze vast and complex datasets—ranging from genomic sequences and chemical libraries to psychological literature and historical records—to uncover patterns and relationships that might otherwise go unnoticed. For instance, scientists are already using Deep Research to brainstorm new hypotheses. The tool's ability to identify subtle or non-intuitive connections empowers researchers to formulate new hypotheses faster and with greater confidence. In 2024, a new study introduced a groundbreaking approach to hypothesis generation in psychology. The researchers combined causal knowledge graphs (maps of cause-and-effect relationships) with a large language model to uncover new research ideas. They analyzed thousands of psychology articles using an LLM to extract cause-and-effect pairs from the literature. These relationships were then used to construct a specialized causal graph, mapping how different psychological concepts are interconnected. Using algorithms to predict potential new connections within the graph, the team generated 130 fresh research hypotheses related to "well-being." When these AI-driven hypotheses were evaluated, they were found to be as novel and insightful as those created by doctoral psychology students—and significantly better than hypotheses generated by the LLM alone. This approach highlights how AI-driven systems can help researchers extract high-quality, innovative insights from the ever-growing pool of scientific literature.

AI-Driven Experimentation

AI is transforming scientific experimentation by enabling virtual testing of millions of potential experiments before lab work even begins. The SynBot demonstrates this capability through autonomous organic molecule synthesis: Its three-layer architecture combines AI-driven planning, instruction translation, and robotic execution. The system continuously optimizes reaction conditions and yields while adapting to different research objectives. In the UK, scientists operated two Automated Formulation Laboratories simultaneously in January 2025, investigating paint formulations through small angle scattering. AI algorithms

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analyzed results in real time to determine subsequent experiments, enabling rapid iteration between machines. The Human Pangenome Reference Consortium shows another AI-driven experiment application: using AI to create comprehensive genome mapping for virtual genetic experiments. This enables simulation of genetic variations and their impacts before conducting physical experiments, accelerating therapeutic development.

AI-driven experimentation allows researchers to rapidly test and refine ideas before committing to expensive lab work, drastically reducing both time and cost. Systems like the SynBot and the Automated Formulation Laboratories can learn in real time, adapting experimental conditions on the fly to optimize outcomes. This approach accelerates innovation by removing many of the traditional bottlenecks in trial-and-error experimentation. Similarly, AI-based projects like the Human Pangenome Reference provide virtual models for genetic studies, letting scientists explore and predict the effects of countless genetic variations upfront.

AI-Powered Analysis and Interpretation

AI is great at detecting subtle patterns that a human might overlook. Take AlphaMissense, an AI model developed by Google DeepMind. It evaluates the pathogenicity (disease-causing potential) of 71 million genetic mutations using transformer-based deep learning. The model predicts which genetic variants are likely harmful with exceptional accuracy, helping researchers focus on high-priority mutations instead of relying on traditional trial-and-error approaches. This significantly accelerates genetic research and enhances our understanding of diseases. AlphaMissense specializes in analyzing missense mutations—where one amino acid is replaced by another in a protein—and predicts their effects on protein function and disease risk. Its predictions, validated against known pathogenic variants, surpass the accuracy of previous computational methods.

Similarly, EVEscape showcases AI's predictive power by analyzing historical biophysical and structural data to anticipate viral evolution, supporting vaccine development and pandemic preparedness. The Human Pangenome Reference project further highlights AI's ability to process diverse genomic sequences, uncovering population-level variations that traditional methods often miss. These AI systems adapt their analyses in real time based on new data, enabling researchers to pursue promising leads without waiting for complete experimental cycles—fundamentally accelerating scientific discovery.

AI to Speed Up New Materials Development

In 2024, researchers at Argonne National Laboratory announced GHP-MOFassemble, an AI tool that accelerates the discovery of metal-organic frameworks (MOFs) for carbon capture. MOFs, constructed from metal nodes and organic linkers, show promise for capturing carbon dioxide, but their vast possible configurations make traditional testing impractical. GHP-MOFassemble creates novel organic linkers and combines them with copper or zinc-based metal nodes into MOFs with primitive cubic topology. The AI evaluates each design for uniqueness, synthesizability, and stability, then simulates their CO2 absorption capacity. The system identifies exceptional performers—those exceeding 96.9% of tested structures—while ensuring designs remain practical for laboratory synthesis. This breakthrough illustrates AI's power to revolutionize materials science. By automating the entire pipeline from design to evaluation, GHP-MOFassemble accelerates the discovery of high-performing materials while ensuring they can be synthesized in real laboratories—bridging the crucial gap between theoretical prediction and experimental reality.

Meta is hoping to speed up similar material discoveries elsewhere. The company's Open Materials 2024 (OMat24)

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initiative aims to democratize AI-driven materials discovery by releasing extensive datasets and models to the public. Material discovery typically requires costly computing power and access to proprietary datasets, creating barriers for many researchers. Meta is addressing this by making OMat24 freely available and open source on Hugging Face, allowing scientists worldwide to accelerate their materials research through AI applications.

Animal Decoding

Was whale song interpretation on your 2025 bingo card? Not to brag, but it was on ours. Scientists are using AI to analyze vast amounts of acoustic data collected from whales. Google AI, in collaboration with NOAA's Pacific Islands Fisheries Science Center, trained an AI model on underwater recordings to help scientists better understand whales' behavioral and migratory patterns. Researchers at MIT's Computer Science and Artificial Intelligence Lab used statistical models and AI algorithms for pattern recognition and classification to analyze 8,719 codas from sperm whales. And a team from the University of California, Davis employed machine learning algorithms to analyze and replicate humpback whale vocalizations, enabling a groundbreaking 20-minute exchange with a humpback whale named Twain.

It's not just whales. AI is helping us interpret pigs and dogs too. European researchers developed algorithms to interpret pig sounds for improved farm animal welfare, analyzing thousands of recordings to identify emotional states through different vocalizations. Meanwhile, researchers from University of Michigan and INAOE demonstrated that AI models pretrained on human speech can be adapted for animal communication. Using Wav2vec2, they analyzed dog vocalizations across breeds and contexts, achieving 70% accuracy in classification tasks—outperforming models specifically trained on dog barks.

Obviously, it would be great to be able to communicate with Fido but the implications are actually much bigger—and weirder. This technology could help us recognize alien life. By developing systems to recognize and interpret non-human communication patterns, we're building essential capabilities for potential extraterrestrial contact. The key challenge isn't just how to communicate after finding alien life—it's how to recognize intelligent communication in the first place. We might be missing alien messages simply because we don't recognize their form as language. Research in animal communication could help us identify and understand fundamentally different types of intelligence and communication, preparing us for peaceful contact with extraterrestrial civilizations.

FINANCE

AI Assisted Asset Pricing and Management

Imagine having a financial analyst who can instantly process decades of market data and spot hidden patterns across thousands of assets. That's what AI is bringing to Wall Street. AI is transforming how we determine the value of financial assets through advanced models called transformer networks. These systems, originally designed for tasks like language translation, can now analyze complex relationships between different financial assets simultaneously. The breakthrough lies in AI's ability to understand how different financial instruments—from stocks to bonds to commodities—influence each other in subtle ways that traditional models often miss. A simplified version called the linear transformer makes this technology both powerful and practical, helping financial institutions make more informed investment decisions.

The power of AI in finance isn't just theoretical. In a comprehensive study spanning 95 years of US stock market data (1926–2021), researchers compared machine learning approaches against 17 standard financial models based on both traditional and behavioral finance theories. The results show that machine learning can detect complex patterns in market data that conventional methods miss, particularly when it comes to understanding how different risk factors interact. This improved accuracy is especially valuable because financial markets often behave in nonlinear ways, meaning changes in one factor might have disproportionate effects on stock returns.

Mitigating Fraud

The battle against financial fraud has entered a new era, with AI emerging as both protector and threat. On the defensive side, financial institutions are deploying sophisticated AI systems that act like vigilant security guards, scanning millions of transactions in real time to catch suspicious activity before money disappears. These AI watchdogs are proving remarkably effective: in 2024 alone, the US Treasury Department's AI systems helped recover $4 billion in fraudulent transactions, including $1 billion in check fraud.

But criminals are also wielding AI as a weapon. The FBI warns that fraudsters are now using AI to craft increasingly convincing scams, generating personalized phishing messages that can fool even cautious consumers. More alarming still is AI's role in creating synthetic identities—completely fabricated but convincing personas used to open fraudulent accounts. As financial institutions race to strengthen their defenses—with 70% expected to adopt AI security by 2025—they face an unprecedented challenge: protecting against AI-powered attacks that can launch thousands of sophisticated fraud attempts simultaneously. It's becoming clear that in this new AI powered financial environment, fighting AI with AI isn't just an option. It's a necessity.

Predicting Financial Risk

Imagine a business trying to predict financial storms, like sudden economic downturns or bad investments. Traditionally, companies have relied on tools like spreadsheets and past financial reports to spot these risks. But like using a paper map in the age of GPS, these old methods struggle with today's flood of information from news articles, social media, and market trends that aren't neatly organized in spreadsheets.

A 2024 study shows that traditional financial risk prediction methods are becoming inadequate for handling the massive amounts of unstructured data businesses face today. The solution? Using machine learning and natural language processing (NLP) to act as a "risk detective" for text, scanning news stories, CEO speeches, and regulatory filings to spot hidden red flags like negative sentiment or mentions of lawsuits. The study introduces DeepFM, a hybrid AI model that combines both numerical and textual data to predict

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risks. Unlike older models, it finds complex patterns in both structured data (like sales figures) and unstructured data (like customer complaints). Testing showed this combination works better than traditional methods: it's faster, more accurate, and adapts to new risks in real time. For businesses, this means fewer surprises and smarter decisions, like upgrading from a blurry telescope to high-definition radar.

Customized Portfolios

Remember when investing meant choosing between a handful of standard mutual funds? Those days are fading as AI changes how we build investment portfolios, making them as unique as our fingerprints. This transformation is particularly evident in the rise of socially conscious investing, where young investors, especially members of Gen Z, are demanding portfolios that align with their values. But the revolution extends far beyond environmental or social causes. Take JPMorgan's acquisition of OpenInvest, for example. Their AI platform doesn't just sort investments into broad categories—it analyzes your entire financial picture, including external assets, and crafts a portfolio that precisely matches your personal values and goals. Similarly, EquityPlus Investment's AI system dives deep into individual client behavior, risk tolerance, and investment history to create truly personalized strategies.

What makes these AI systems particularly powerful is their ability to adapt in real time. Unlike traditional portfolio management, which might rebalance quarterly, these systems continuously monitor market changes and shifts in client priorities. Portfolios can now automatically adjust when risk tolerance changes or when new investment opportunities align with a person's values. The result is investment portfolios that aren't just personalized—they're responsive. Through sophisticated cluster analysis and automated rebalancing, these AI systems ensure investments consistently reflect both financial goals and personal values.

Consumer-Facing Robo-Advisers

Consumer-facing robo-advisers are now widely available in the financial services sector, with many providers deploying advanced algorithms and increasingly sophisticated AI to automate investment advice, budgeting, and portfolio management. As hiring a human money manager can cost several thousand dollars, these platforms have become especially appealing to younger users looking for cost-effective guidance.

Consumers are turning to apps like Cleo AI and Bright, both of which prompt users to connect their bank accounts through Plaid so the chatbots can analyze spending, help manage debt, and build credit. However, these tools also leverage personal data to upsell additional services, pushing the boundaries between helpful personalization and potentially manipulative marketing tactics. At the same time, individuals are also harnessing non-specialized financial chatbots—such as Perplexity for portfolio research and large language models like ChatGPT or Claude for more in-depth analysis—demonstrating how improved reasoning capabilities in AI increasingly position these solutions as direct competitors to traditional human advisors.

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INSURANCE

Predicting Workplace Injuries

Workplace safety in the United States continues to improve, with fatal work injuries declining by 3.7% between 2022 and 2023, according to the US Bureau of Labor Statistics. To build on this progress, many companies are leveraging AI to enhance safety measures. For example, leading construction contractor JE Dunn collaborated with Newmetrix, an AI-driven risk prediction platform, to implement data-driven safety systems. This initiative enabled them to proactively prevent incidents and improve safety outcomes for their 3,500 employees. Similarly, Amazon has adopted computer vision and machine learning technologies in its warehouses to provide real-time safety alerts, contributing to fewer injuries and operational gains, including a 12% increase in net sales. Siemens also reported a 30% reduction in workplace injuries over two years by incorporating AI-based safety protocols.

Industry research suggests that AI-powered tools could prevent approximately 4,500 injuries and 50 deaths annually in scaffold-related incidents alone. The potential impact expands further with the integration of wearable devices to monitor worker fatigue and environmental sensors that help identify OSHA compliance issues, such as unsafe scaffolding conditions.

Improving Damage Assessment

At the time of this writing, more than 40,000 acres have burned in Los Angeles County, California, since the beginning of 2025. Maxar Intelligence has collected more than 34,000 square kilometers of high-resolution satellite imagery of the affected areas, which is shared through its Geospatial Platform (MGP) Pro and humanitarian Open Data Program. This imagery, made accessible to organizations like NOAA and the public, provides vital visual data for property assessments. Microsoft's AI for Good Lab has put this data to work, deploying AI models to assess the destruction caused by the Palisades and Eaton fires. Its analysis of the Palisades Fire revealed the scope of the damage: Among 18,000 evaluated buildings, 6,803 were damaged while 11,735 remained intact.

The insurance industry has also embraced this technology through McKenzie Intelligence Services' Global Events Observer platform. Using Maxar's imagery, their AI analysis identified more than 12,000 buildings as destroyed or severely damaged, with an additional 16,000 at risk of internal damage. This rapid assessment has accelerated the claims process, helping affected communities recover more quickly. These AI-powered tools represent a significant advance in disaster response, allowing emergency services, insurers, and relief organizations to act faster and more effectively in helping communities rebuild.

AI Powered Fire Prevention

In the wake of the January 2025 Los Angeles wildfires, fire departments and researchers are more urgently working together to develop AI-powered systems that leverage satellite imagery, drones, and smart sensors to provide early warnings and real-time insights. California's ALERTCalifornia program, run by UC San Diego, uses more than 1,100 cameras and sensors to monitor fire-prone areas 24/7, automatically identifying signs of wildfires in video footage. In December 2024, it detected a fire in Black Star Canyon at 2 a.m., allowing firefighters to contain it to less than a quarter-acre. Austin Energy has implemented an AI-driven camera network that monitors a 437-square-mile area in Texas, providing live images and alerts when smoke is detected. Meanwhile, startups like Los Angeles-based PriviNet are designing sensor networks capable of running on solar power for extended periods, further enhancing early detection capabilities. IBM and NASA are also contributing to wildfire prevention efforts, with geospatial AI models that analyze past fire events to help scientists better understand fire behavior and refine prevention strategies. While challenges

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remain, AI's ability to detect and predict wildfires offers a promising path to mitigating their devastating impact.

The Connected Worker

In 2024, insurance companies expanded their focus on the "Connect and Protect" approach, a strategy that uses advanced technologies like IoT, telematics, AI, and data analytics to shift from reactive to proactive risk management. Rather than simply compensating for losses after they occur, this approach connects insured assets—such as vehicles, homes, businesses, or even employees themselves—with real-time monitoring and predictive insights to reduce risks and enhance safety. A notable example is Swedish safety equipment company Guardio, which introduced the Armet PRO helmet in late 2024. This innovative helmet features the Multi-directional Impact Protection System to reduce the risk of brain injury during impacts, along with a Quin intelligent sensor for enhanced monitoring and safety.

However, this increased reliance on data collection and monitoring raises concerns about privacy and the potential for overly intrusive surveillance. Companies that cross the line into "Big Brother"–style oversight risk pushback from employees.

Liability Insurance for AI

What happens if machine learning systems are compromised by attackers who inject fake training data, leading to flawed outcomes? Or if a health care company's AI misinterprets patient data and fails to detect cancer? Who is responsible when machines behave badly? This is not just a philosophical dilemma but also a pressing legal issue that demands resolution as AI becomes more pervasive.

Right now, AI-related liability insurance is still a patchwork. Most coverage falls under existing policies—like professional liability or cyber insurance—rather than under standalone AI-specific products. Yet when AI fails, it can expose companies to an array of risks that may stretch beyond traditional coverage, from corrupted outputs and data breaches to significant reputational harm. Cyber insurance might protect against third-party hacking and ensuing lawsuits, but won't defend against every AI-driven hazard. In health care, malpractice insurance usually applies when AI tools malfunction, since providers remain responsible for validating the technology they use. Providers can, however, seek indemnification from third-party AI vendors if an algorithmic error leads to patient harm.

As AI systems grow in complexity, many worry existing policies won't keep up—prompting debates over new liability frameworks. Some experts propose a strict liability approach, making operators or developers liable regardless of fault. Others advocate adapting today's duty-of-care model to ensure AI providers diligently monitor and maintain their systems. Meanwhile, specialized endorsements and AI-focused insurance products are emerging to address the "black box" challenges inherent in AI and the security risks tied to generative AI. These evolving offerings aim to protect both software developers and end-users as AI continues to expand into more critical areas.

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HR

Autonomous Talent Acquisition

AI is transforming recruitment by handling time-consuming tasks like resume screening and candidate communications. For example, in 2024, LinkedIn announced its Hiring Assistant, a highly integrated agent that fits into the LinkedIn workflow. Companies like Siemens, Canva, and AMS are already using the tool to identify and hire candidates. LinkedIn believes they can automate nearly 80% of the pre-offer workflow.

Companies like Unilever expanded their use of AI tools like HireVue, which analyzes video interviews for language and facial cues, paired with anonymized resume screening to reduce unconscious bias. In 2024, it introduced multilingual AI analysis to better assess global candidates. Other AI agents in the space include Paradox, which is the current leader in recruitment automation. These systems can quickly analyze resumes against job requirements, identify top candidates, and maintain ongoing communication through chatbots. It's been used successfully by Chipotle, which announced in October 2024 that Paradox reduces time to hire by 75%. Notably, there is now also an outcrop of articles and blogs on "how to get your resume past AI screening tools," with tips and tricks on how to "beat the systems" with smart formatting and wording choices.

While there are some fully autonomous recruitment agents available on the marketplace today, most organizations are choosing to integrate AI tools with existing applicant tracking systems. However, organizations must watch for potential bias in AI hiring decisions, as these systems can reflect discriminatory patterns found in their training data. HR professionals should proceed with caution—in 2024, a California court found that HR vendors using AI can be liable for discrimination claims stemming from the customers' job applications (additional details can be found in the Policy and Regulation section of this trend report).

AI Onboarding and Integration

Poor onboarding has become a retention issue. Nearly half of new hires rate their post-onboarding training as inadequate, and 30% of those dissatisfied with onboarding plan to seek new jobs within three months. However, data shows that AI-supported onboarding reduces first-year turnover by 30% compared with traditional methods. There are lots of potential applications here: AI could transform onboarding from a generic, one-size-fits-all approach into a deeply personalized experience, analyzing each new hire's background to create tailored training content. A sales representative in Seattle might encounter examples featuring local clients and technology sales scenarios drawn from their previous roles. A financial analyst in Miami might see cases involving regional markets they've already worked with. Rather than generic company policies, employees would receive contextual examples relevant to their specific responsibilities and experience.

AI could also adapt how information is delivered based on learning preferences. Visual learners might receive interactive diagrams and illustrated workflows, while auditory learners get podcast-style content and guided walkthroughs. The system would continuously refine its approach based on engagement data, ensuring optimal information retention. Beyond content delivery, AI could identify potential knowledge gaps by analyzing a new hire's background and proactively suggest relevant resources. It could track engagement patterns to flag when additional support might be needed, enabling HR teams to provide targeted assistance before small challenges become major obstacles. This personalized approach could help employees feel genuinely understood and supported from day one.

Employee Engagement and Retention

Companies across industries are tapping into AI systems to personalize employee development. IBM's Watsonx Assistant

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streamlines routine HR inquiries while recommending career moves tailored to individual skills and interests. Oracle Grow maps out customized development tracks that adapt as employees gain new competencies, transforming career progression from an abstract concept into a series of actionable steps.

Behind the scenes, AI can scan for subtle warning signs of employee turnover. By tracking changes in communication, meeting engagement, and work output, these systems flag potential issues early enough for meaningful intervention. This shifts HR from reactive problem-solving to proactive engagement. AI could also transform how companies gather and use employee feedback. Rather than relying on annual surveys, AI systems continuously analyze input from multiple channels—chat logs, team meetings, performance reviews, and more. NLP can then extract themes, giving leaders clear insight into team dynamics.

Communicorp UK transformed their employee check-ins using Employment Hero, an AI-powered platform that streamlines one-on-one meetings previously hampered by managers' time constraints. The system ensures consistent, structured conversations while making both managers and employees more accountable for follow-through. By standardizing the check-in process, the platform facilitates more meaningful discussions and clearer goal-setting. Building on this success, Communicorp UK has expanded the platform's use to include performance reviews and goal tracking, creating a more comprehensive employee development framework.

Benefits Selection and Management

Oracle introduced an AI agent to help employees make open enrollment choices. Employees can ask back-and-forth questions using Oracle's benefits analyst AI agent, which is part of the Oracle Fusion Cloud Human Capital Management platform. For example, an employee who will be married this year can ask questions like, "What are the costs to add my spouse to different health plan tiers?" Or, "Do I need to wait until after the wedding to make changes?" Or, "Which plans offer the best coverage for both of us?" Oracle's AI pulls data from the company's benefits documentation and other company sources, such as existing benefit choices, benefits eligibility, or home location, as needed. The AI system integrates data from benefits documentation, employee elections, eligibility rules, and location requirements to answer employee questions. By analyzing this data, it can provide specific guidance for each employee's situation. Bswift's AI assistant Emma demonstrates similar capabilities, handling benefits support questions day and night. Data shows Emma resolves 87% of employee inquiries without human intervention, with most questions (77%) occurring after business hours. This automated support helps employees get answers when they need them and reduces the volume of routine questions HR teams must handle.

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MARKETING

AI Shifts Search

If you've Googled anything in the past few months, you've noticed that Google has been experimenting with AI-generated summaries at the top of search results. Instead of the traditional "10 blue links," users increasingly see AI-generated snapshots that pull information from multiple sources. For the small but mighty group of Bing users out there, Microsoft's Bing Chat (powered by GPT-4) offers conversational answers, often eliminating the need for users to click onto a website. As a result, users may get their core answers directly in the Search Engine Results Page or via a chat-like interface, clicking fewer links. This shifts how marketers should approach SEO and content strategy.

AI isn't just changing what is presented when something is searched, it's changing how people search. For example, query length has increased, with users now favoring longer, more conversational queries over simple keywords. The average query on AI-powered platforms like Perplexity is 10–11 words, compared to 2–3 keywords on traditional search engines. As of late 2024, Google still leads in the search market, accounting for 92.4% of referral traffic. However, AI-powered search tools are showing significant growth. ChatGPT reached 3.7 billion monthly visits in October 2024, marking 15.9% year-over-year growth. Perplexity saw 90.8 million visits in October 2024, with 199.2% year-over-year growth.

LLMs have also dramatically improved the ability of search engines to better understand the context and intent behind a query—not just keyword matching. As a result, marketers need to provide content that matches user intent more precisely, covering broader contextual and long-tail queries. Also, with natural language processing improving, more users are doing voice queries or "chat" style queries. As such, optimizing content for spoken language and question-based queries ("who," "what," "where," "how") becomes increasingly important.

Dynamic Engagement Through Deep Personalization

Traditional marketing has relied on one-way communications like emails, PDFs, and social posts, but AI is transforming this landscape into an era of dynamic, two-way conversations. The real opportunity isn't in replacing human support with chatbots—it's in creating intelligent conversational interfaces that enhance the customer experience through personalization. When users receive tailored recommendations and contextual support, they get more value from each interaction.

Companies are already implementing AI-powered conversational interfaces that deliver personalized, context-aware recommendations and services. As these experiences become more common, users increasingly expect to interact with brands through voice or text-based AI assistants that understand their needs and preferences. When implemented thoughtfully, this deep personalization creates more meaningful connections, fostering brand loyalty and driving better business outcomes.

Another way to personalize engagement is through the presentation of information. Imagine websites and mobile apps that adapt their layouts and recommendations in real time based on individual user behavior and preferences (see the Generative User Interfaces trend for more details). This approach can make users feel truly understood, leading to longer engagement and higher conversion rates.

AI-Assisted Campaigns

In the 2024 trend report, we started to see the emergence of AI tools for copywriting and design. This year, we started to see more platforms provide full-stack solutions for streamlining of campaigns within a single interface. These platforms now manage everything from ideation to execution to analytics, with advanced reinforcement learning models automatically optimizing campaign parameters based on real-time performance data.

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Dynamic creative optimization has taken a leap forward, with AI systems generating and testing multiple ad variations in microseconds, from images to headlines. Meanwhile, major marketing platforms like HubSpot, Salesforce, and Adobe have integrated LLM capabilities, allowing marketers to adjust email copy, create landing pages, or segment audiences through intuitive chat interfaces. This integration enables marketers to build entire campaign workflows through simple prompts. For example, a marketer could request “Draft a multichannel campaign targeting mid-career tech professionals, focusing on brand awareness,” and tools like Adobe Experience Platform’s AI Assistant will handle everything from audience segmentation to asset creation using Adobe Firefly, while generating multiple content variations for personalized communications.

Anecdotal Observations, Now Usable Marketing Data

AI has transformed our ability to understand subtle human reactions, turning what were once subjective observations into measurable marketing insights. Companies can now analyze video data to detect micro-expressions and facial cues, providing precise measurements of consumer engagement. AI systems evaluate customer responses to store layouts and branded elements in real time, creating a new frontier in consumer behavior analysis.

In the retail space, companies are deploying increasingly sophisticated emotion recognition technologies. MoodMe’s facial analysis system captures real-time emotional responses, while MorphCast’s interactive video platform helps businesses understand viewer engagement through facial expression analysis. Viso Suite takes a broader approach, using deep learning to track customer behavior patterns, from shopping cart usage to wait times and crowd density. Meanwhile, Chinese tech giants like Megvii (the creator of Face++) have emerged as global leaders in facial recognition technology, pushing the boundaries of what’s possible in consumer behavior tracking.

This transformation from anecdotal insights to quantifiable data has opened unprecedented personalization opportunities. However, the intimate nature of tracking human expressions and reactions has prompted serious privacy discussions. The EU’s AI Act reflects these concerns, having banned real-time biometric identification systems in public spaces, with limited exceptions. This regulatory response highlights the delicate balance between technological innovation and privacy protection in the emerging AI landscape.

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2025 TECH TRENDS REPORT • 18TH EDITION

WEB3

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Melanie Subin
Managing Director

If you're focused on NFTs, you're missing the point of Web3.

For years, Web3 has been synonymous with speculation. NFTs, meme coins, and get-rich-quick schemes have shaped the public narrative, making it easy to dismiss as hype. But beneath the noise, something much more fundamental is taking shape—a structural shift in how we secure, verify, and exchange value in the digital world. The internet as we know it was never designed to handle the weight of the global economy. Our systems—financial, legal, and informational—are layered on top of fragile, trust-based networks prone to breaches, fraud, and inefficiency. Every day, companies and individuals place blind faith in intermediaries to maintain records, safeguard assets, and act in good faith. And every day, we see examples of why that faith is misplaced.

Web3 is not just about decentralization for the sake of it, nor is it a rebellion against institutions. It is about infrastructure—about replacing trust with cryptographic certainty, about reducing friction and risk in an increasingly volatile digital landscape. Enterprises, governments, and industries that seem slow to adopt blockchain-based solutions aren't rejecting the technology itself; they are struggling with the human reality of change. Adoption is not just a technical hurdle—it is a cultural one. Yet, this shift to a Web3-powered world is inevitable. It won't come in the form of a single disruptive moment, but as a slow and necessary evolution as blockchain becomes invisible, seamlessly embedded into the fabric of digital commerce, identity, and security. From financial services to supply chains, health care to intellectual property, the most critical sectors will depend on these systems not because they are new, but because they are better.

The challenge ahead is not about convincing people to "believe in crypto." It is about building the systems that make trust obsolete—where integrity is the default and risk is minimized by design. This report is not about hype. It is about what comes next.

While Web3 still feels out of reach for many, there's been real pragmatic progress in the areas of tech evolution and regulation.

1

Web3 adoption accelerates as enterprises explore blockchain solutions

Businesses are increasingly integrating blockchain into operations, from supply chain tracking to digital identity management. This shift marks a move beyond speculative crypto assets, toward practical, enterprise-driven Web3 use cases.

2

Regulatory uncertainty slows crypto, but spurs institutional Web3 growth

While regulatory crackdowns affected cryptocurrencies, enterprises and financial institutions have pushed forward with blockchain initiatives, focusing on compliance-friendly applications like tokenized assets and decentralized identity.

3

Decentralized Finance (DeFi) evolves to meet institutional standards

DeFi platforms are incorporating regulatory frameworks, risk management tools, and institutional-grade compliance to attract enterprise adoption. This evolution is bridging the gap between traditional finance and decentralized protocols.

4

Web3 gaming sees resurgence with focus on player ownership

Following early hype and subsequent decline, Web3 gaming is regaining traction with models emphasizing player ownership, sustainable economies, and enhanced user experiences. Major gaming studios are cautiously entering the space.

5

AI and blockchain converge to unlock new business models

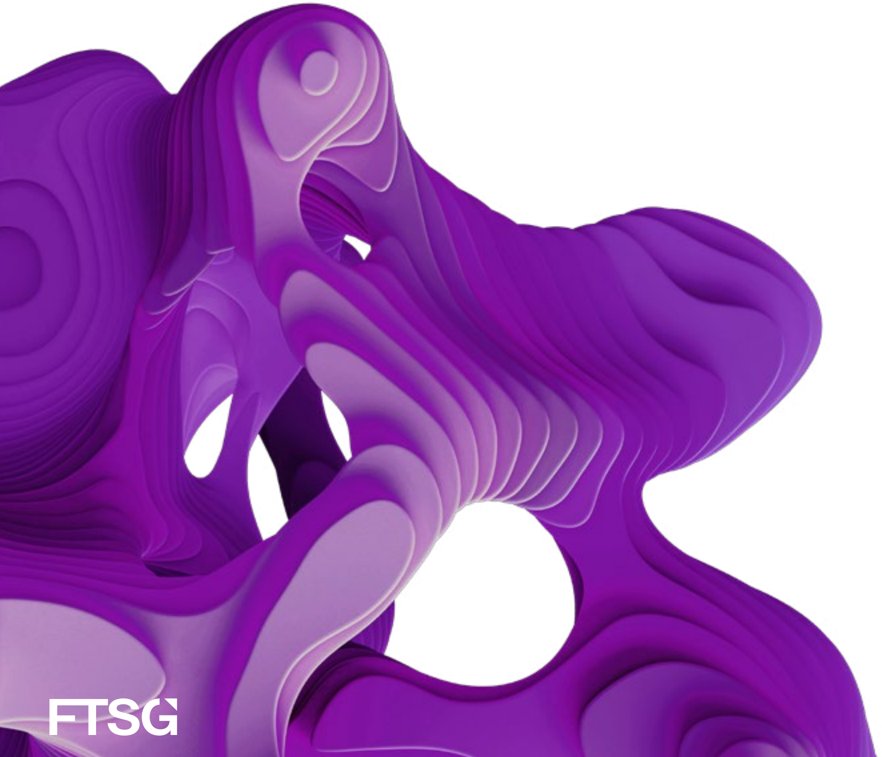
The combination of AI and blockchain is enabling novel applications, from verifiable AI-generated content to decentralized AI models. This synergy is driving new business models across media, finance, and supply chain sectors.

2025 will be a crucial year in determining how Web3 evolves moving forward.

In early 2025, Web3 is at a turning point, transitioning from a niche technology to a mainstream force reshaping digital interactions and business models. This paradigm shift is driven by the convergence of blockchain, decentralized finance (DeFi), and artificial intelligence, creating a new internet infrastructure that prioritizes user ownership, transparency, and peer-to-peer transactions. Business leaders across industries are recognizing Web3's potential to disrupt traditional value chains, create new revenue streams, and redefine customer relationships.

The Web3 ecosystem is rapidly evolving, with key developments in several strategic areas. Decentralized autonomous organizations (DAOs) are emerging as novel governance structures, challenging traditional corporate models. The tokenization of real-world assets is opening new avenues for fractional ownership and liquidity in previously illiquid markets. Meanwhile, the metaverse concept is gaining traction, blurring the lines between physical and digital realms, and creating immersive experiences that are reshaping entertainment, education, and commerce. These trends are compelling businesses to reevaluate their digital strategies and explore how Web3 technologies can enhance their competitive edge.

However, the path to Web3 adoption is not without challenges. Regulatory uncertainty remains a significant hurdle, with governments worldwide grappling with how to oversee this decentralized landscape. Scalability and interoperability issues persist, though Layer-2 solutions and cross-chain protocols are making strides in addressing these concerns. User experience and accessibility continue to be pain points, hindering mass adoption. For business leaders, the key to navigating this landscape lies in strategic experimentation, fostering partnerships within the Web3 ecosystem, and staying agile in response to rapid technological advancements and shifting regulatory landscapes.



2024 was marked by regulatory action and shifting retail strategies.

MAY 2024

Hong Kong Kicks Out Unlicensed Crypto Exchanges

Regulators announced all unlicensed exchanges must apply for a license by February 2025 or cease operations.

JUNE 2024

Adidas Sells Roblox Necklace For $20,000

The digital sale marked the most expensive user-generated item sold on the platform, signaling a new model for brands.

JUNE 2024

MiCA Stablecoin Rules Take Effect

The EU's MiCA regulation implemented rules for stablecoins, further solidifying its comprehensive crypto framework.

JULY 2024

Spot Ethereum ETFs Begin Trading

Spot Ethereum ETFs, approved by the SEC, began trading in the US in July 2024, offering investors exposure to ether.

DECEMBER 2024

Nike Shuts Down RTFKT

Nike ended the virtual sneaker and fashion brand, citing a recalibration of priorities after acquiring the brand in 2021.

« PAST

It could be a busy year ahead for US regulation of crypto and other Web3-based assets.

FUTURE »

JUNE 2025

Crypto Task Force Initial Report

The Presidential Working Group on Digital Asset Markets is tasked with submitting a report within 180 days.

AUGUST 2025

Potential Resolution of Binance Case

Following the 60-day stay requested in the SEC's lawsuit against Binance, this case may be resolved by August.

OCTOBER 2025

Possible Rulemaking Proposals

Given the SEC's shift towards a "rules-over-enforcement" approach, we may see proposed rules from the Crypto Task Force.

DECEMBER 2025

Year-End Review of Crypto Task Force Progress

The SEC might provide a year-end update on the Crypto Task Force's progress and achievements since its February formation.

ONGOING-2025

No-Action Letters and Exemptive Relief

Commissioner Peirce indicated the SEC will increase its use of no-action letters and exemptive relief.

Organizations, especially those in high-trust environments, can greatly benefit from the security Web3 trends provide.

Decentralization Enhances Security and Trust

Web3 reduces reliance on centralized authorities, lowering risks of single points of failure and data breaches. Organizations can leverage blockchain-based verification to ensure transparency, improving customer and stakeholder trust.

New Business Models and Revenue Streams

Tokenization and decentralized finance open new monetization opportunities, such as fractional ownership, micropayments, and smart contract-driven transactions. Organizations can leverage NFTs, Decentralized Autonomous Organizations (DAOs), and blockchain-based services to create novel customer experiences and engagement models.

Greater User Control Over Data and Digital Identity

With self-sovereign identity and decentralized identity solutions, users gain more control over their personal data. This shift can redefine customer relationships, reducing compliance risks (e.g., GDPR) and improving personalization without intrusive tracking.

Enhanced Transparency and Compliance

Immutable ledgers ensure auditability and traceability, which is particularly valuable for industries like finance, supply chain, and health care. Smart contracts automate compliance and reduce operational inefficiencies in contract execution and enforcement.

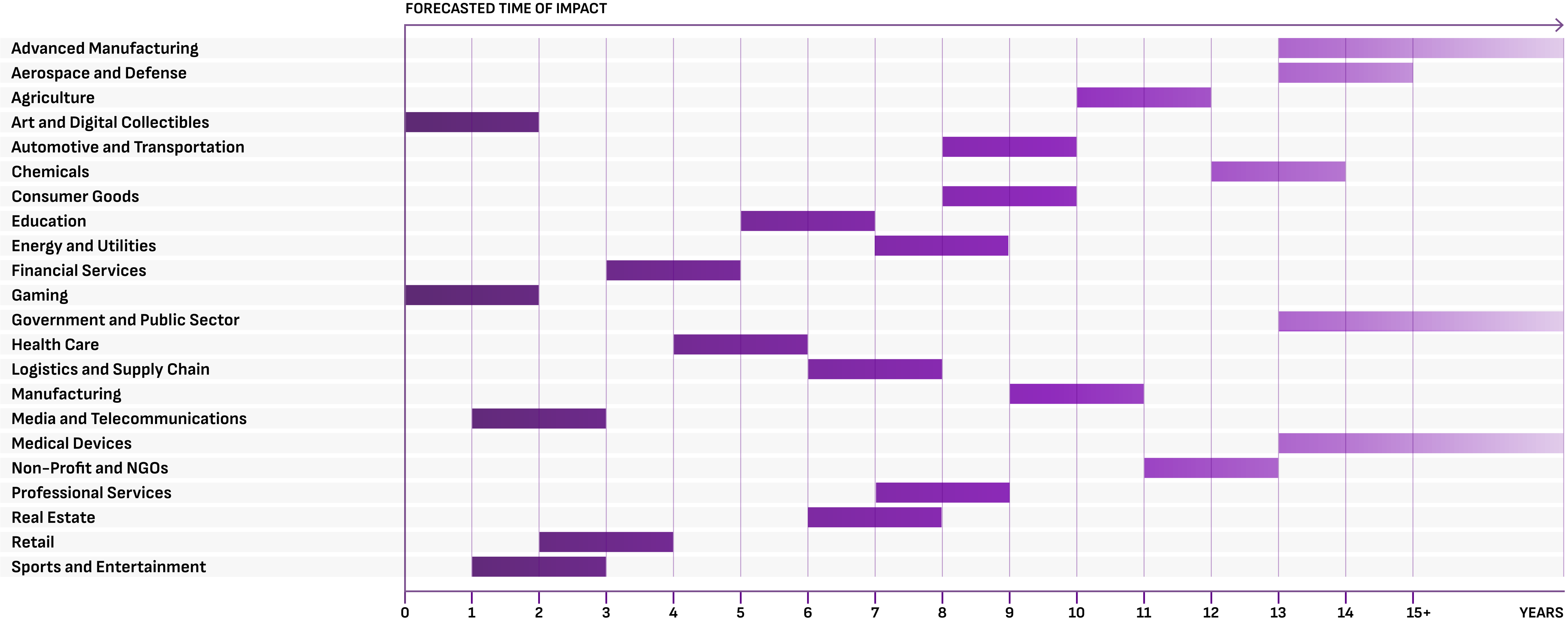
Community-Driven Innovation and Governance

DAOs empower community-driven decision-making, fostering innovation through collective intelligence. Organizations can leverage DAOs for ecosystem governance, funding mechanisms, and strategic partnerships without traditional bureaucracy.

Interoperability and Digital Asset Ownership

Web3 enables seamless interoperability across platforms, allowing assets (e.g., tokens, digital identities, virtual goods) to move freely across ecosystems. This enhances customer engagement and loyalty, particularly in industries like gaming, media, and finance, where digital ownership is a major value driver.

Many industry operations are already being directly impacted.



Willingness to invest in infrastructure will determine your firms' ability to benefit from the early mover advantage.

SCALING

Industries with modular processes or digital-first operations, such as gaming and fintech, can implement and scale Web3 incrementally. In contrast, sectors with complex, interconnected systems face longer adoption curves due to the need for holistic transformation and ecosystem-wide coordination.

COSTS

Sectors with high transaction costs or intermediary fees see a compelling ROI, driving faster adoption. Conversely, industries with slim margins or capital-intensive operations may delay implementation until the technology matures and costs decrease, balancing innovation against fiscal prudence.

CONSTRAINTS ON ADOPTION

Interoperability issues between different blockchain protocols and legacy systems create significant technical debt, particularly in industries with entrenched IT infrastructures. This will be challenging for industries with numerous legacy businesses, but less so for digital-native sectors.

REGULATIONS

Regulatory uncertainty, especially around tokenization and DAOs, is creating a "wait-and-see" approach in many industries. But in some jurisdictions, proactive frameworks are creating regulatory sandboxes that accelerate adoption, and provide companies with a place to experiment.

MEDIA MENTIONS

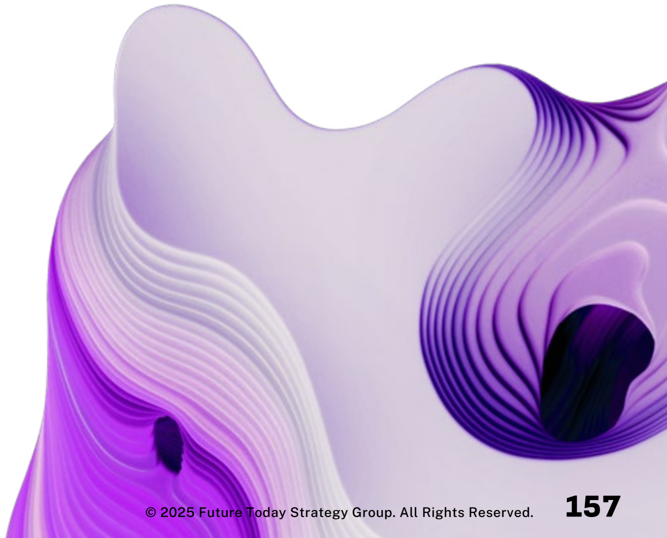
In B2C industries, increased media attention often translates to faster adoption, but in B2B sectors, the hype cycle generated by media leads to more measured, strategic approaches. The challenge for business leaders lies in distinguishing between media-driven hype and genuine transformative potential.

PUBLIC PERCEPTIONS

The evolution of Web3's public image from crypto phenomenon to utility-driven technology is fundamentally altering adoption patterns across industries. This shift is particularly impactful in sectors where trust and transparency are paramount, such as health care, and financial services.

R&D DEVELOPMENTS

The cross-pollination of Web3 with other technologies such as AI and edge computing is catalyzing a new wave of innovation, creating novel use cases and accelerating adoption in unexpected sectors. This is enabling industries to leapfrog traditional adoption timelines, creating new centers of innovation.



These individuals are shaping the creation of a new Web3 infrastructure.

- **Tim Beiko, Ethereum Foundation protocol support lead,** for bi-weekly All Core Devs calls, and his work coordinating Ethereum's core developers and orchestrating network upgrades.
- **Samczsun, head of security at Paradigm, for discovering and preventing major DeFi vulnerabilities,** saving projects like SushiSwap from multimillion-dollar exploits.
- **Primavera De Filippi, research director at CNRS,** for her work on blockchain governance, decentralized law, and pioneering blockchain-based art DAOs like the Plantoid project.
- **Gabby Dizon, co-founder of Yield Guild Games,** for leading the play-to-earn gaming movement and helping players in developing regions earn income through NFT-based games.
- **Tarun Chitra, founder of Gauntlet Networks,** for applying quantitative finance to DeFi, optimizing protocols like Aave and Compound, and managing financial risks in crypto lending.
- **Kevin Owocki, co-founder of Gitcoin,** for championing public goods funding through quadratic grants, distributing more than $64M to open-source projects in the Web3 ecosystem.
- **Olayinka Odeniran, founder of Black Women Blockchain Council,** for driving diversity in Web3 and leading an initiative to train 500,000 Black female blockchain developers by 2030.
- **Ameen Soleimani, creator of Moloch DAO,** for pioneering grant-giving DAOs to fund Ethereum infrastructure and open-source development through collective decision-making.
- **Taylor Monahan, product lead at MetaMask,** for improving crypto wallet usability and security, from founding MyCrypto to integrating user protections in MetaMask.
- **Sheila Warren, CEO of Crypto Council for Innovation,** for shaping global blockchain policy, founding WEF's blockchain division, and advocating for responsible Web3 adoption.
- **Lucía Gallardo, founder of Emerge,** for using blockchain to drive social impact, creating solutions for supply chain transparency, humanitarian aid, and sustainable development.
- **Aya Miyaguchi, executive director of Ethereum Foundation,** for leading Ethereum's global growth, funding ecosystem development, and advocating for decentralization.

Web3 will help businesses remain compliant with evolving regulations...

OPPORTUNITIES

New Revenue Streams and Business Models

Tokenization, DeFi, and NFTs unlock new ways to monetize digital assets, intellectual property, and services. Subscription-based models can be replaced with tokenized access.

Enhanced Customer Engagement and Loyalty

Web3 enables personalized, user-owned experiences through decentralized identity and blockchain-based loyalty programs. Brands can create exclusive experiences using NFTs and DAOs to build deeper community engagement.

Decentralized Infrastructure Reduces Costs

Smart contracts automate business processes, reducing reliance on intermediaries and lowering transaction costs. Decentralized storage and computing can enhance efficiency and security while decreasing infrastructure expenses.

Transparency and Security Improvements

Blockchain-based systems can help reduce fraud and increase trust in financial transactions, supply chains, and data management. Decentralized identity solutions enhance privacy and security.

...but implementation could be costly and tricky to achieve.

THREATS

High Implementation Costs and Technical Complexity

Developing Web3-based solutions requires expertise in blockchain, smart contracts, and decentralized infrastructure, which can be expensive and difficult to source.

Scalability Limitations and Performance Bottlenecks

Blockchain networks can struggle with transaction throughput, high gas fees, and network congestion, making them less efficient for large-scale business operations.

Interoperability Challenges with Existing Systems

Businesses must integrate Web3 technologies with their current IT stack, including CRM, ERP, and cloud services, which can be cumbersome and require middleware solutions.

Uncertain ROI and Long Adoption Cycles

Consumer adoption of decentralized applications (dApps) remains slow, meaning businesses must be prepared for extended timelines before seeing significant user engagement and revenue.

Businesses should take action today to ensure they are ready for scale when the market matures.

Before full-scale adoption, businesses should pilot Web3 initiatives such as tokenized loyalty programs, decentralized identity verification, or blockchain-based supply chain tracking. Identify potential use cases while ensuring scalability and integration with existing infrastructure.

Create governance policies to ensure compliance with global regulations, including the EU's GDPR, the US' AML, and securities laws regarding tokenization. Work with legal experts to define a strategy for handling smart contract liabilities, data privacy, and cross-border blockchain transactions.

Choose blockchain protocols that support high transaction throughput, low fees, and interoperability (e.g., Layer 2 solutions, modular blockchains, or hybrid models). Assess whether private, public, or consortium blockchains best suit the organization's needs.

Join industry consortia, such as the Blockchain Association or Enterprise Ethereum Alliance, to help shape regulations and advocate for business-friendly policies. Establish a compliance team to monitor evolving regulations on digital assets, smart contracts, and DeFi to mitigate legal risks.

Invest in cloud-based or on-premise infrastructure capable of supporting Web3 applications, including distributed storage (e.g., IPFS, Arweave) and decentralized identity solutions. Establish partnerships with blockchain service providers to ensure secure and scalable implementation.

Offer targeted training on blockchain, smart contracts, DeFi, and token economies to ensure employees understand Web3's impact on their roles. Establish cross-functional Web3 task forces within the company to drive innovation and identify new business opportunities.

Technology Deployment

Capital Expenditure

Talent Development

Regulatory Influence

Important terms to know before reading.

AIRDROP

A marketing strategy where a project team distributes tokens to users for free in exchange for using the protocol or other requirements. Airdrops are often used as a guerrilla marketing technique to stimulate interest and adoption.

APPCHAINS (APPLICATION SPECIFIC CHAINS)

Special-purpose blockchains serving a single application. This gives developers total control of software upgrades and gives users less competitive block space of general-purpose blockchains.

BLOCK SPACE

The storage area on a blockchain for transaction and data storage, including smart contracts. Block space significantly impacts blockchain scalability and decentralization, and therefore gas fees for data inclusion.

BLOCKCHAIN

A distributed ledger technology typically employed for the transaction and storage of data. It utilizes cryptography to provide an immutable and verifiable data source for participants in a network.

BLOCKCHAIN TRILEMMA

An optimization challenge faced by monolithic blockchains, requiring trade-offs between decentralization, scalability, and security; only two can be maximized. Solana, known for high transactions per second (TPS), prioritizes scalability and security over decentralization.

BRIDGE

A tool to facilitate the transmission of information and assets between distinct blockchains regardless of the interoperability of the networks.

DECENTRALIZATION

The process of constructing architectural infrastructure, system logic, and social systems without the presence of a centralized authority that holds decision-making power or exerts disproportionate influence. Instead, control is distributed among the stakeholders of the network.

DECENTRALIZED AUTONOMOUS ORGANIZATION (DAO)

An internet-native organization formed by individuals who agree to adhere to a specific set of rules and goals without a central authority. DAOs employ tokenized ownership and smart contracts to implement decisions.

DECENTRALIZED EXCHANGE (DEX)

A peer-to-peer marketplace for users to trade crypto assets.

DECENTRALIZED FINANCE (DEFI)

Financial services including banks, asset managers, insurance companies, and other financial services that leverage blockchain and smart contracts for transactions, data sharing, and other operations.

EXIT SCAMS ("RUG PULLS")

A common type of fraud where a project team deceives investors to garner their investments and uses a purpose-built vulnerability to drain all funds and abandon the project.

FORK

A term commonly used to describe the act of copying and/or modifying existing code to either upgrade an existing system or launch a new product. Forks are frequently necessary for blockchain-wide software updates and are commonly observed in the DeFi sector, where one project replicates the code of another.

LAYER 2 BLOCKCHAIN

A broad term that describes blockchains that delegate core infrastructure to another blockchain. Examples include Ethereum's Rollups and Bitcoin's Lightning Network, which aim to enhance scalability.

MODULAR VS. MONOLITHIC

Blockchains can be modular, breaking core components (execution, settlement, data availability, consensus) into separate specialized networks to address the blockchain trilemma. Monolithic chains like Ethereum provide all core modules within their infrastructure.

NFT (NON-FUNGIBLE TOKEN)

A digital token on a blockchain that contains unique and indivisible data. It is frequently used in digital art or when tokenizing real-world assets.

NODES

Individual devices within a connected network of computers that serve various functions such as communication, transaction validation, and historical data storage within a blockchain network. Different nodes exist, each with functionality specific to the network they support. Examples include full, light, super, and archive nodes.

ORACLE

A capability or service that gathers, collects, and transmits data on-and off-chain to facilitate real-time transactions and information transmissions. Oracles are bridges between blockchains and external off-chain information sources on the internet.

PHYGITALS

This refers to the blending of physical and digital assets into an NFT. Phygitals are commonly used for tokenizing physical collectibles and art pieces; they frequently include a burn and redeem functionality where the NFT is destroyed for the owner to receive the physical item.

PROOF OF STAKE (POS)

A blockchain consensus mechanism that uses stake tokens to secure the network. Validators (nodes responsible for verifying blocks of transactions) must stake their tokens (use them as collateral) to participate in the block verification selection process. Malicious validators—those that fail to validate or attempt to mislead the network—will see their collateral value slashed, while benevolent validators earn yields or other benefits for their work. Ethereum successfully transitioned from proof of work to PoS, resulting in a 99% reduction in the blockchain's energy consumption.

ROLLUPS

A subcategory of Layer 2 blockchains with a scalability focus that process and bundle transactions to be submitted to Ethereum for settlement and consensus. The most popular types include optimistic rollups like Arbitrum and Optimism and zkRollups like zkSync.

SCALABILITY

A blockchain's capacity to process and store data as network demand grows, typically measured in TPS.

SECURITY TOKENS (ST)

Digital assets representing ownership of off-chain assets such as bonds, commodities, or real estate. Off-chain assets are tokenized into STs to enable trading on blockchain networks.

SHARDING

A database partitioning technique that divides an extensive database into more manageable parts called shards. Ethereum's roadmap plans to use an adapted sharding methodology to improve the scalability of the blockchain by partitioning the chain and its validators into distinct but interconnected shards, allowing for parallelized transaction processing.

SMART CONTRACTS

A blockchain-based computer program that executes autonomously when predetermined criteria are met.

STABLECOIN

Cryptocurrency assets whose value is referenced (or pegged) to another financial instrument, often a fiat currency. These assets are typically collateralized by fiat currencies, cryptocurrencies, and liquid assets.

TOKENOMICS

The economic framework of tokens, encompassing elements such as consensus mechanisms, yields, supply limits, and other monetary policies.

TRADITIONAL FINANCE (TRADFI)

Conventional means of money or asset management where services are provided by traditional banks, asset managers, insurance companies, etc.

ZERO-KNOWLEDGE PROOFS (ZKPS)

Mathematical techniques that allow users to prove knowledge (the prover) of something without divulging the private knowledge associated with it to another user (the verifier). Zero-knowledge proofs encompass two core principles important to blockchain technology: succinctness, which means that verifying the proof is significantly easier than producing the computation itself, and privacy-preserving, which involves hiding portions of computation while maintaining correctness during verification.

WEB3 TRENDS

THE WEB3 LANDSCAPE

THE WEB3 LANDSCAPE

The Rising Regulation of Web3

The financial world is entering a new era as governments create rules for digital currencies and assets. Just as traditional banking has regulations to protect customers and maintain stability, countries are now establishing similar guardrails for digital money and related technologies.

The European Union is implementing its first comprehensive framework for digital assets, the Market in Crypto Asset (MiCA) regulation, which was passed in 2023. The European Commission has also proposed a new framework that is more technologically up to date than MiCA, which would replace all other EU and national rules currently governing the issuance, trading and storing of crypto assets such as utility tokens or payment tokens which are not covered under MiCA.

Other major economies are following suit. South Korea launched new consumer protection rules in July 2024, focusing on companies that help people buy and sell digital assets. The United Kingdom is expanding its financial watchdog's authority to oversee digital currencies, aiming to have a complete system in place by 2026. Unlike some countries that are taking a gradual approach, the UK plans to regulate all aspects of digital assets simultaneously.

This trend is widespread—about 70% of major economies worked on new regulations for digital assets in 2024. International organizations like the G20's Financial Stability Board have provided recommendations, while countries from Australia to Brazil announced plans for their own rules. This global movement suggests that digital assets are becoming a permanent part of the financial landscape, albeit with proper oversight. While these regulations should help large institutions feel more confident about participating in digital markets and protect everyday users, finding the right balance is crucial—too many restrictions could prevent beneficial innovations in financial technology.

Trust-Minimized Infrastructure Development

The blockchain industry is strengthening its foundation by reducing reliance on single companies or organizations. This shift mirrors traditional finance's move away from concentrated risk—instead of one institution controlling critical functions, responsibility is distributed across multiple independent parties.

New systems now enable safer movement of digital assets between different blockchains. The Union protocol, for example, allows Bitcoin transfers with enhanced security by distributing oversight across multiple parties instead of depending on a single custodian.

Companies maintaining the Ethereum network, the second-largest blockchain after Bitcoin, are also improving their security measures. Lido, which manages about 32% of all Ethereum staking, began testing technology in 2024 that splits control of funds among several independent operators. This approach protects against both technical failures and potential misconduct by any single operator.

Infrastructure providers are similarly becoming more distributed. Infura, a major service provider, launched a network in 2024 that spreads its operations across many independent operators rather than running everything through centralized servers. By late 2024, this network supported a dozen different blockchain systems, making the entire infrastructure more resilient to outages.

Different blockchain networks are also establishing more secure ways to communicate with each other. Instead of relying on trusted intermediaries to relay messages between chains, new protocols use mathematical proofs to verify information directly. These improvements make the blockchain ecosystem more robust by eliminating single points of failure. The enhanced security and reliability are essential for businesses considering long-term adoption of blockchain technology.

THE WEB3 LANDSCAPE

Invisible Blockchain Integration in Critical Sectors

Major industries are now using blockchain technology in their daily operations—not as a flashy marketing tool, but as practical infrastructure that works quietly behind the scenes. Much like how consumers don't think about the technical systems processing their credit card payments, blockchain is becoming an invisible part of business operations.

The shipping industry provides a clear example. In late 2024, shipping company COSCO tested a blockchain system that manages safety certificates for hazardous materials like carbon black. The system allows ports, carriers, and regulators to instantly verify these critical documents, reducing delays and ensuring safety compliance.

In health care, pharmaceutical companies are using blockchain to meet strict drug tracking requirements. The MediLedger project, conducted with FDA oversight, proved that blockchain technology can effectively trace prescription drugs through complex supply chains. This system helps ensure medicine authenticity and protect patient safety.

Financial institutions are also adopting blockchain for traditional operations. By August 2024, organizations, including the World Bank and European Investment Bank, had issued 14 bonds using blockchain systems. These bonds function exactly like traditional ones from an investor's perspective, but the underlying blockchain technology makes them more efficient to manage.

The diamond industry demonstrates another practical application. De Beers expanded its Tracr platform in 2023-24 to track diamonds from mines to retail stores. This system verifies each diamond's origin and characteristics, ensuring authenticity and ethical sourcing without changing how customers buy jewelry.

This shift toward using blockchain as invisible infrastructure, rather than a marketing buzzword, signals its evolution into a practical business tool. Organizations can now gain the benefits of permanent, tamper-proof record-keeping without requiring their customers or partners to understand the underlying technology.

AI Integration in Web3

Artificial intelligence technology is rapidly merging with blockchain systems to create more powerful and automated business tools. This integration is happening across multiple industries, creating new capabilities for data processing, customer engagement, and financial operations.

Major financial institutions are already testing these combined technologies. In 2024, data company Chainlink worked with Swift and Euroclear to use AI for processing complex financial information. Their system used advanced AI models to automatically read and standardize corporate information about mergers and dividends, making this data immediately available and verified on blockchain networks. This solved a common business problem: turning scattered market data into reliable, standardized information that all parties can trust.

The technology is also transforming customer engagement. A company called Alethea AI launched a system in April 2024 that creates interactive digital characters, verified through blockchain technology. These AI characters can display realistic emotions and hold conversations, offering businesses new ways to provide customer service or create engaging content in virtual environments.

The financial sector is seeing particularly interesting developments. The derivatives platform SynFutures introduced an AI system called "Synthia" that can execute complex trading strategies through simple voice commands. This points to a future where AI agents could handle sophisticated financial operations automatically while maintaining a clear record of all transactions on the blockchain.

Security is another key application. Machine learning systems are now analyzing blockchain transactions in real time to identify potential fraud or unusual patterns,

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adding an extra layer of protection to digital assets and transactions.

These developments suggest a fundamental shift in how businesses can operate: combining AI's ability to process and act on complex information with blockchain's capability to create permanent, verified records of all activities.

Security Risks in the Age of AI

Artificial intelligence is dramatically changing the security landscape for digital assets and blockchain technology, creating both new threats and defensive capabilities. This dual impact requires business leaders to understand both the risks and protective measures.

The scale of the challenge is significant. Cryptocurrency-related fraud reached unprecedented levels in 2024, with estimated losses of $10-12 billion—a 40% increase from the previous year. According to blockchain analysis firm Chainalysis, AI tools played a major role in this surge. Criminals now use AI to create highly convincing fake websites, business communications, and even technical documents that appear legitimate to even experienced investors.

The threats are sophisticated. In December 2024, the FBI warned that criminals were using AI to create perfect grammatical phishing emails and clone executive voices for fraud. These techniques can deceive even experienced professionals into authorizing fraudulent transactions or revealing sensitive security information.

However, businesses are also using AI to strengthen their defenses. Security firms now employ machine learning to monitor blockchain transactions in real time, identifying suspicious patterns that might indicate fraud or money laundering. For example, Chainalysis uses AI to track illegal fund movements through cryptocurrency networks, helping law enforcement recover stolen assets. Security auditors are also using AI to scan business contracts for potential vulnerabilities before they can be exploited.

New security measures are emerging in response to these challenges. Organizations are developing ways to verify the authenticity of digital communications and protect digital identities from AI impersonation. These tools will be crucial for maintaining trust in digital business transactions.

The key message for business leaders is clear: while AI makes fraud easier and more convincing, it also provides powerful new tools for protection. Success in this environment requires understanding both aspects and preparing accordingly.

Real-World Asset (RWA) Tokenization

A major transformation is underway in how traditional assets—from government bonds to real estate—are being digitized using blockchain technology. This process, called tokenization, is gaining significant traction with major financial institutions and governments.

The numbers tell a compelling story. Consider MakerDAO, a leading digital finance protocol: by late 2023, 60% of its more than $5 billion in assets were backed by traditional investments like US Treasury bills, rather than cryptocurrencies. This shift demonstrates how digital finance is increasingly connected to conventional financial markets.

Major asset management firms are actively entering this space. Franklin Templeton launched a blockchain-based US government money market fund that grew to $270 million by early 2024. BlackRock's CEO Larry Fink has predicted that eventually all stocks and bonds will use blockchain technology. By early 2024, investment firms had already put more than $1 billion in tokenized money market funds on blockchain networks, offering benefits like instant settlement and continuous trading.

Government participation adds further credibility. Hong Kong made history in February 2024 by issuing a HK$800 million (approximately US$100 million) government bond using blockchain technology—the first of its kind globally. Singapore's and Australia's central banks are conduct-

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ing similar experiments with digital government securities.

This trend matters because tokenization can solve several longstanding business challenges: it can make traditionally illiquid assets easier to trade, reduce settlement times from days to minutes, and allow for partial ownership of expensive assets. For business leaders, this represents an opportunity to improve operational efficiency and access new markets. The involvement of established financial institutions and governments suggests this technology is moving beyond speculation to practical business applications.

Sustainable Public Goods Funding Models

The blockchain industry is pioneering innovative ways to fund public resources like open-source software, infrastructure, and social projects. These new funding models could transform how businesses support critical shared resources and social initiatives.

One leading example is Gitcoin, which distributed $10.4 million in 2024 using a unique matching system called quadratic funding. This approach amplifies small donations from many contributors with larger matching pools, effectively identifying which projects have the broadest community support. In 2024, more than 141,000 donors helped fund nearly 1,750 projects spanning technology, climate initiatives, and education.

A new concept called Retroactive Public Goods Funding is gaining traction. Rather than providing speculative upfront grants, this model rewards work after its value is proven. Optimism, a blockchain platform, demonstrated this approach by distributing millions in tokens to developers who had already created valuable tools for their ecosystem. This results-based funding model could provide more sustainable incentives for innovation.

Specialized organizations called “impact DAOs” are channeling blockchain-based funding to social causes. KlimaDAO, for example, has facilitated the retirement of more than 17 million tonnes of carbon offsets. Other organizations fund community gardens or humanitarian relief. These groups leverage blockchain’s transparency to show donors exactly how their money is used, operating with lower overhead than traditional nonprofits.

Major blockchain networks are also building public goods funding into their core operations. Some protocols automatically direct a portion of their revenue to development grants and community projects. This creates a sustainable cycle where successful platforms continuously reinvest in their foundational infrastructure and community resources.

These innovations matter because traditional funding for public resources often falls short. By creating more efficient, transparent, and sustainable funding models, the blockchain industry is demonstrating how technology can address broader social and environmental challenges while supporting critical infrastructure development.

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Cross-Chain Interoperability Advancements

A fundamental shift is occurring in how different blockchain networks connect and communicate, similar to how the early internet evolved from isolated networks into today's interconnected web. This development makes blockchain technology more practical for mainstream business use.

In 2024 there were several illustrative examples of this shift. The Cosmos network enhanced its communication protocol to enable faster, more secure transfers between different blockchain systems. Similarly, Polkadot, another major platform, released new technology in October 2024 that allows different blockchain networks to exchange assets and information more efficiently.

Perhaps most significantly for the business world, SWIFT—the network that handles most international bank transfers—conducted successful trials with multiple banks between July and October 2024. These tests proved that SWIFT could serve as a central connection point between different blockchain networks and traditional banking systems. Based on these results, SWIFT announced plans for live trials in 2025 with banks across North America, Europe, and Asia, focusing on cross-border transactions and foreign exchange.

This shift toward interconnection solves a critical business challenge: different blockchain networks are designed for different purposes, but businesses need them to work together seamlessly. For example, one network might excel at processing transactions quickly, while another offers better security for high-value assets. Connecting these networks allows businesses to leverage the best features of each.

These benefits are practical and immediate, letting companies move assets between different blockchain networks more easily, reducing costs and complexity. It also means businesses can spread their operations across multiple networks to improve efficiency and reduce risks. This interconnection is crucial for blockchain technology to become a practical part of mainstream business infrastructure.

Biometric Authentication in Web3

The digital asset industry underwent significant changes in 2024 as companies integrated biometric authentication into their security systems. This shift means users can now use physical characteristics like fingerprints, facial recognition, and iris scans to secure their digital accounts and assets. The technology mirrors familiar tools like Apple's FaceID but applies them to managing digital currencies and assets, making these technologies more accessible to mainstream users and businesses.

The integration of biometric authentication addresses two persistent challenges in digital asset management. First, it enhances security—just as modern smartphones use fingerprints or facial recognition instead of just passwords, digital asset platforms are adopting similar technology to protect valuable digital assets. This additional security layer helps prevent unauthorized access and reduces the risk of theft. Second, it improves the user experience. Traditional digital asset management requires users to remember complex passwords and "seed phrases"—long strings of words used as backup codes. Biometric authentication simplifies this process, allowing users to access company digital assets as easily as unlocking a phone.

Several major developments shaped the landscape in 2024. Companies introduced new security devices with built-in biometric readers, similar to how corporate ID cards might include fingerprint verification. These devices require both physical possession and the correct biometric input to access digital assets, significantly reducing the risk of theft or unauthorized use. Major financial platforms integrated biometric login features similar to mobile banking apps, allowing users to access their digital assets using their phone's built-in fingerprint reader or facial recognition rather than typing passwords. This development makes digital asset management as convenient as modern mobile banking.

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New systems for verifying unique human identity also emerged, though with mixed reception. The most prominent example, Worldcoin, used iris scanning technology to ensure each person could only create one account. While innovative, this raised privacy concerns similar to those faced by traditional biometric databases. In response, researchers developed new methods for using biometric data without storing sensitive information centrally—enabling identity verification without sharing actual fingerprint or facial scan data. This addresses common privacy concerns about biometric data collection and storage.

The business implications of these developments are significant. Biometric authentication offers enhanced security through multiple authentication factors, reduces the risk of password-related security breaches, improves user experience for employees and customers, and provides better protection against account sharing and unauthorized access. However, challenges remain. Biometric data requires careful handling due to its sensitive nature, privacy concerns must be balanced against security benefits, and organizations must consider technology costs, implementation challenges, and regulatory compliance regarding biometric data.

Looking ahead, biometric authentication is likely to become increasingly common in digital asset management, following the path of mobile banking and corporate security systems. Businesses should monitor developments in this space, particularly regarding security standards and regulatory requirements. Organizations might consider starting pilot programs for biometric authentication in controlled environments while developing clear policies regarding biometric data collection and usage. When evaluating vendors, companies should pay particular attention to their approach to privacy and security.

Biometric authentication represents a significant advancement in making digital assets more secure and accessible. While the technology continues to evolve, its potential to improve security and user experience makes it worthy of serious consideration for businesses involved in digital asset management.

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A RETROSPECTIVE FROM THE GLOBAL BUSINESS REVIEW

Ten years ago, Web3 was still largely seen as a fringe technology, synonymous with volatile cryptocurrencies and niche use cases. Today, it's the bedrock of global commerce, securely and efficiently powering operations across countless industries. The transformation wasn't a revolution, but a gradual integration, much like how the internet itself became an indispensable utility.

By now, in 2035, the "blockchain" buzzword has faded, replaced by the quiet hum of trust-minimized systems operating seamlessly in the background. Regulations, carefully balanced to encourage innovation while protecting consumers, have fostered mainstream adoption. International standards and interoperability protocols, spearheaded by organizations like a revamped SWIFT and industry consortiums, allow for seamless data and asset transfer across different blockchain networks and legacy systems. This cross-chain operability has been a game changer for global supply chains. Consider the luxury goods industry: Every diamond, handbag, and bottle of wine is digitally tracked from origin to point of sale, guaranteeing authenticity and ethical sourcing thanks to systems like De Beers' Tracr platform. Consumers can instantly verify a product's provenance, combating counterfeiting and bolstering brand trust.

The financial services sector has been completely transformed. Tokenization of real-world assets (RWAs) is ubiquitous. Major asset managers like BlackRock and Franklin Templeton offer tokenized versions of everything from government bonds to real estate. These digital assets trade 24/7 on decentralized exchanges, offering unprecedented liquidity and fractional ownership opportunities. AI-powered trading platforms, like the descendants of SynFutures' Synthia, execute complex strategies with unparalleled efficiency and transparency, all immutably recorded on-chain. Cross-border payments are instantaneous and nearly frictionless, powered by stablecoins and central bank digital currencies (CBDCs) operating on interoperable blockchain networks.

Of course, with increased integration comes increased risk. AI-powered cyberattacks are a constant threat, necessitating advanced security measures. Biometric authentication is standard, but sophisticated deepfakes and AI-generated phishing scams require constant vigilance. The industry has responded with AI-driven security solutions that analyze blockchain transactions in real-time, detecting and mitigating threats before they can cause damage. Zero-knowledge proofs are also becoming commonplace, allowing businesses to verify data without revealing sensitive information, further enhancing privacy and security.

Web3's evolution has not only improved efficiency and security but has also fostered new models of collaboration and funding. Sustainable public goods, like open-source software and critical infrastructure, are increasingly funded through retroactive funding mechanisms and quadratic funding platforms like Gitcoin. DAOs have become sophisticated governance tools, empowering communities to collectively manage resources and make decisions transparently.

The Web3 of 2035 is not the utopian dream of decentralization maximalists, but a pragmatic and powerful infrastructure layer woven into the fabric of global commerce. Businesses that embraced this evolution early on are now reaping the rewards: increased efficiency, reduced risk, enhanced transparency, and closer relationships with their customers. Those who hesitated are now playing catch-up in a world where cryptographic certainty is the new normal.

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ZKP implementation has fundamentally changed how we approach customer data protection. We’re now able to verify transactions and authenticate users without exposing sensitive information, which has dramatically reduced our security risks while improving customer trust.

Sarah Chen, Chief Information Security Officer, JPMorgan Chase

WEB3 INFRASTRUCTURE

Emerging Forms of Consensus Protocols

The technology that secures blockchain networks is evolving beyond traditional methods, with new approaches that are more efficient, faster, and environmentally friendly. These innovations make blockchain more practical for business applications while maintaining security.

One notable example is Chia Network, which uses computer storage space instead of computing power to secure its blockchain. By 2024, Chia had built one of the world's largest distributed storage networks, with more than 160 exabytes of capacity. This approach achieves the same security level as Bitcoin but uses far less energy, as it only requires keeping hard drives online. Similarly, Filecoin's network provides 6.6 exabytes of useful storage while securing its blockchain, demonstrating how these systems can provide practical business value beyond just transaction processing.

Speed improvements are another key development. Research teams made significant advances in 2024 with new protocols that can process thousands of transactions per second. Companies like Mysten Labs and platforms like Avalanche demonstrated that blockchain networks can handle high-performance applications like social networks or games without sacrificing decentralization.

Security against future threats is also being addressed. Researchers are developing new protocols that can withstand potential attacks from quantum computers, which could theoretically break current cryptographic systems. While still theoretical, this work is crucial for ensuring long-term blockchain security.

Different blockchain platforms are adopting varied approaches based on their specific needs. For example, Kadena uses multiple parallel processing chains for higher throughput, while Solana combines different security mechanisms for better efficiency. This trend toward customized solutions means businesses can choose blockchain platforms that best match their specific requirements for speed, security, and scalability.

These technological advances are making blockchain networks more capable of supporting large-scale business applications while reducing environmental impact and maintaining security — key considerations for business adoption.

Blockchain Modularity

The architecture of blockchain technology is undergoing a fundamental change, moving from all-in-one systems to a modular approach where different components handle specific tasks. This shift is similar to how modern software development uses specialized services rather than building everything from scratch.

A major milestone occurred in October 2023 when Celestia launched the first blockchain dedicated solely to data storage and ordering. This innovation allows other blockchain systems to focus on processing transactions while using Celestia for secure data storage. By mid-2024, multiple development teams were building new systems on top of Celestia's foundation, demonstrating the value of specialized infrastructure layers.

This modular approach is gaining traction in major business applications. Coinbase, a leading cryptocurrency exchange, launched its Base network in August 2023 using modular technology from Optimism. Other major platforms like Polygon are developing similar systems that handle transactions more efficiently by separating different functions. This approach allows for much higher processing capacity without compromising security.

The industry is also developing shared services that multiple blockchain systems can use, similar to how many websites might use Amazon Web Services for cloud computing. Companies like Espresso and Astria are building these shared services, which help manage transaction ordering and security across multiple blockchain networks.

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This architectural shift has important business implications. Companies can now build blockchain systems tailored to their specific needs while relying on established infrastructure for core functions like security and data storage. This is similar to how modern businesses can quickly launch web applications by using existing cloud services rather than building their own data centers.

The trend suggests a future where launching a new blockchain-based business service will be as straightforward as deploying a new web application today, potentially accelerating business innovation in this space.

Advanced Cyptography for Privacy and Efficiency

Advanced cryptographic technology, particularly "zero-knowledge proofs" (ZKPs), is revolutionizing blockchain capabilities. This technology allows verification of information without revealing sensitive details—imagine being able to prove you have sufficient funds for a transaction without showing your account balance.

In 2024, this technology made significant advances in two key areas: improving privacy and increasing processing efficiency. Several major platforms demonstrated practical applications.

StarkWare's StarkNet and Matter Labs' zkSync Era showed how ZKPs can process thousands of transactions off the main blockchain while maintaining security. Scroll launched a system that matches Ethereum's capabilities but at much lower costs, making these benefits accessible to mainstream businesses.

A particularly exciting development is the combination of machine learning with zero-knowledge proofs, called "zkML." Research teams demonstrated how AI models could be run on private data while proving the results are correct—without revealing either the data or the AI model itself. This could enable services like private credit scoring in decentralized finance, where borrowers could prove their creditworthiness without exposing personal financial data.

These advances are drawing significant investment and attention from major technology companies. Many blockchain platforms now have dedicated cryptography teams, and companies are filing patents for innovations in this field. Their focus is on making blockchain systems more powerful and more private.

The business implications are substantial. Companies can process sensitive transactions on public blockchains while keeping details confidential. They can run complex operations more efficiently by processing them off-chain and proving the results. Most importantly, they can build AI-driven smart contracts that maintain privacy while providing verifiable results.

This technology is laying the groundwork for blockchain systems that can handle enterprise-scale operations while protecting sensitive business information—a crucial combination for widespread adoption in the business world.

Layer-2 and Rollup Solutions

Layer-2 solutions—systems built on top of existing blockchain networks—made significant advances in 2024, dramatically reducing costs and improving efficiency. Think of these as express lanes built above an existing highway, allowing for faster, cheaper transactions while maintaining the security of the main network.

A major breakthrough came in March 2024 when Ethereum implemented an upgrade called "Dencun." This update reduced blockchain transaction costs on Layer-2 networks by approximately 90-98%, making them much more affordable for everyday use. This is similar to how the introduction of fiber optic cables dramatically reduced the cost of internet data transmission.

The market responded quickly to these improvements. Coinbase's Layer-2 network, Base, attracted millions of users and secured more than $100 million in assets within months of its launch. Multiple other networks also went live or expanded their

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services, including Linea, Scroll, and Taiko. By 2024, more than a dozen significant Layer-2 networks were operating on Ethereum, collectively managing tens of billions of dollars in transactions.

Another key development was improved connectivity between different Layer-2 networks. New systems emerged allowing users to move assets directly between these networks without going through the main blockchain, similar to how you can transfer money directly between banks without using a central clearing house. Companies like Connext and LayerZero led this effort, making it possible to conduct complex financial transactions across multiple networks efficiently.

This technology isn't limited to Ethereum. Bitcoin's Lightning Network, a Layer-2 solution for instant payments, grew to handle more than 5,000 Bitcoin in transaction capacity by 2024. Other blockchain platforms like Solana are also exploring similar scaling solutions.

These developments mark a crucial shift in blockchain technology: Layer-2 solutions are no longer experimental but are becoming essential infrastructure for business applications. They're making blockchain technology practical for large-scale business use by solving the critical challenges of cost and speed while maintaining security.

Decentralized Physical Infrastructure Networks (DePIN)

A new model of building physical infrastructure is emerging, using blockchain technology to incentivize individuals and communities to deploy and maintain real-world networks. Called DePIN (Decentralized Physical Infrastructure Networks), this approach is showing promise in telecommunications, data collection, and other industries traditionally dominated by large corporations.

Helium, a pioneer in this space, demonstrated significant success in 2024. Their mobile network, partnering with T-Mobile, reached nearly 100,000 subscribers in early 2024. Users spent approximately $1.47 million in the first five months of 2024 to access Helium's services, showing that businesses and individuals are willing to pay for these community-operated networks. The model is simple but effective: individuals host network hotspots and earn tokens for providing coverage.

The concept is spreading to various industries. Pollen Mobile is building a community-operated 4G network in the United States, while HiveMapper is creating a decentralized alternative to Google Street View by paying drivers to collect street imagery with their dashcams. In the automotive sector, DIMO is building a vehicle data network where car owners earn rewards for sharing their vehicle data, and they've already established partnerships with insurance companies in 2024.

This approach is attracting serious attention from investors and institutions. The Helium Foundation received grants for smart city projects, and NATO's Innovation Hub explored these networks for their potential in building resilient infrastructure. This interest suggests that the concept of community-powered infrastructure has applications beyond the cryptocurrency sector.

Challenges remain, including the sustainability of token-based rewards and regulatory compliance (particularly in telecommunications). But despite these hurdles, 2024 showed that this model can work at scale. Eventually, this innovation could transform how we build and maintain infrastructure. Instead of requiring massive centralized investment, communities can collaborate to build networks, potentially bringing services to underserved areas more quickly and cost-effectively than traditional approaches.

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Privacy-First Messaging Protocols

A new wave of messaging platforms is transforming how businesses can protect their sensitive communications. Unlike traditional messaging services that rely on central servers controlled by single companies, these innovative solutions use distributed networks and advanced encryption to ensure messages remain truly private and secure.

Leading this transformation is the xx messenger, developed by security expert David Chaum. It works similarly to familiar apps like WhatsApp or Signal but with a crucial difference: instead of passing through central servers that could be compromised, messages are routed through multiple independent points, making it virtually impossible to track who is communicating with whom. For businesses handling sensitive information, this level of privacy provides unprecedented protection for intellectual property and confidential discussions.

The industry is also seeing the emergence of messaging systems that integrate with digital identity verification, allowing businesses to send encrypted messages to verified partners using unique digital addresses. This works similarly to email but with significantly enhanced security features. Major technology standards organizations, including the Internet Engineering Task Force and World Wide Web Consortium, are developing new protocols for secure group messaging that could revolutionize how businesses communicate internally and with partners.

These developments represent a significant shift from traditional messaging systems that can be vulnerable to surveillance or data breaches. For businesses, the benefits are clear: better protection against industrial espionage, secure channels for sensitive discussions like mergers and acquisitions, and improved compliance with data protection regulations. As digital privacy becomes increasingly crucial in the business world, these new messaging solutions offer a way to ensure that sensitive communications remain truly confidential and secure.

Cryptographic Certainty in Digital Transactions

Digital business is increasingly moving online, from contracts and payments to official documents and credentials. This shift has created an urgent need for ways to prove that digital transactions are authentic and trustworthy—similar to how we traditionally rely on notaries and wet signatures for important papers. New technologies are emerging to provide this certainty in the digital world.

A major development in this space is the European Union's new framework for digital identification and signatures, launched in 2024. This system, known as eIDAS 2.0, creates a standardized way for businesses and individuals to prove their identity and sign documents digitally across all EU countries. Think of it as a secure digital passport and signature that works everywhere in Europe. The system also includes tools to prove exactly when documents were sent and received—critical for business dealings where timing matters.

Financial institutions are also adopting new transparency measures. Major digital asset exchanges have begun publishing cryptographic proof of their reserves, allowing customers to verify that their funds are fully backed without revealing sensitive business details. This is similar to a bank audit but with mathematical certainty, helping restore trust in financial services after several high-profile failures.

Universities and government agencies are starting to issue digital credentials that can be verified anywhere without calling the issuing institution. For example, several European universities now issue diplomas in a digital format that graduates can easily share with employers, who can instantly verify their authenticity. Similarly, businesses can now timestamp important documents using blockchain technology, creating an unchangeable record of when a document existed in a particular form—useful for protecting intellectual property or proving contract terms.

WEB3 INFRASTRUCTURE

These developments are making digital transactions more reliable and trustworthy, reducing the risk of fraud and disputes in an increasingly online business world. By providing mathematical proof of authenticity, timing, and ownership, these tools help businesses operate with confidence even when they can't meet face-to-face or rely on traditional intermediaries.

Quantum-Resistant Cryptography

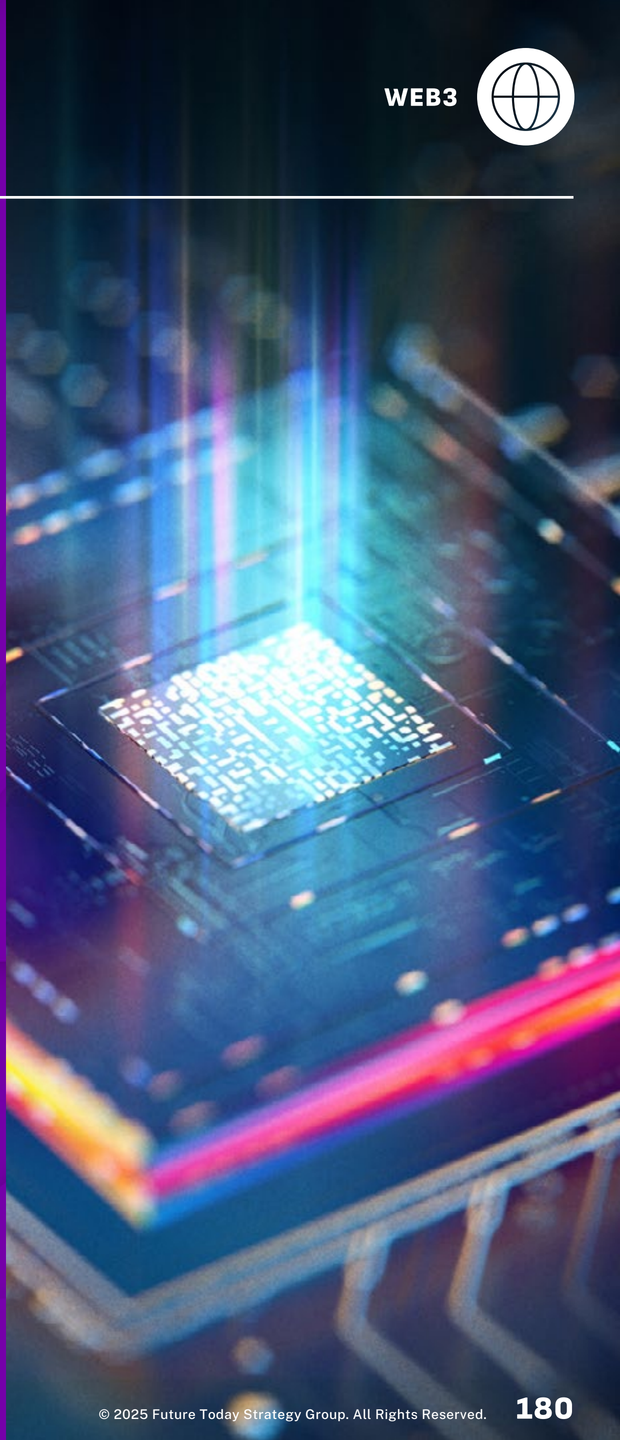
The emergence of quantum computing presents new opportunities. But it also poses a significant security challenge for organizations relying on blockchain technology and cryptographic systems. While quantum computers capable of breaking current encryption don't yet exist, their eventual arrival could compromise the security of cryptocurrency holdings, smart contracts, and other blockchain-based assets. This technological shift requires advance preparation to protect business operations and digital assets.

The US National Institute of Standards and Technology has identified four post-quantum algorithms for standardization, prompting major blockchain platforms like Bitcoin and Ethereum to explore implementation strategies. Industry leaders including IBM and Google are already collaborating with blockchain consortia to test these algorithms in enterprise chains, while government agencies in the US and EU are actively pushing for transition preparation.

The U.S. Department of Commerce's National Institute of Standards and Technology (NIST) finalized its principal set of encryption algorithms in August 2024, and has encouraged organizations to begin implementing them, though that has yet to begin in earnest. In February 2025, China launched an organization to begin developing its own algorithms. Organizations should approach this transition gradually, implementing new quantum-resistant systems alongside existing solutions. This approach allows for thorough testing while maintaining operational continuity.

For businesses with significant digital assets or blockchain operations, preparation should focus on three key areas: assessing current cryptographic vulnerabilities, developing a practical transition strategy, and monitoring emerging standards and best practices. While immediate wholesale changes aren't necessary, organizations should allocate resources for research and testing of quantum-resistant solutions as part of their technology strategy.

Success in this transition requires coordination between business leadership, technical teams, and security experts. Organizations that prepare effectively will be better positioned to protect their assets and potentially gain competitive advantages in an increasingly quantum-aware business environment. The focus should be on systematic implementation rather than rapid transformation, ensuring business continuity while progressively enhancing security against quantum threats.



SCENARIO YEAR 2035

CTOS ARCHITECT THE NEXT ERA OF BUSINESS

The foresight and strategic actions of Chief Technology Officers during the 2020s were instrumental in shaping the business landscape we know today. The integration of Web3 technologies, initially met with skepticism and uncertainty, has become the invisible infrastructure upon which much of modern commerce relies. This transition was far from automatic; it was the result of deliberate, thoughtful planning and execution by CTOs who recognized the transformative potential of decentralized systems.

The first critical step was dismantling the legacy data silos that had long hindered innovation and efficiency. Forward-thinking CTOs championed the adoption of interoperable standards and protocols, facilitating the seamless flow of data between disparate blockchain networks and traditional systems. This commitment to interoperability unlocked entirely new possibilities for collaboration and value creation, enabling businesses to participate in decentralized ecosystems without sacrificing control or security.

These leaders understood that true security stemmed not from centralized control, but from cryptographic certainty. They spearheaded the implementation of advanced cryptographic techniques like zero-knowledge proofs, ensuring that sensitive data could be verified without ever being exposed. This shift towards

trust-minimized systems instilled confidence in the integrity of digital transactions, paving the way for broader adoption of blockchain-based solutions across industries.

AI emerged as a critical tool in this transformation, augmenting human capabilities and automating complex processes. CTOs championed the integration of AI-powered security solutions that could analyze blockchain transactions in real-time, detecting and neutralizing potential threats before they could cause harm. AI also played a key role in streamlining operations, optimizing resource allocation, and enhancing decision-making across the enterprise.

Consider the logistics industry: by 2035, AI-powered supply chain management systems leverage blockchain technology to track goods from origin to destination with unparalleled transparency and efficiency. This has not only reduced fraud and waste but has also enabled businesses to respond more quickly and effectively to disruptions in the supply chain. Or, consider the financial services sector: AI-driven trading platforms execute complex strategies on decentralized exchanges, providing investors with access to new asset classes and investment opportunities while maintaining a transparent and auditable record of all transactions.

The successful integration of Web3 technologies required more than just technical expertise; it demanded a new mindset, a willingness to experiment, and a commitment to continuous learning. Visionary CTOs invested in training and development programs to equip their teams with the skills and knowledge they needed to thrive in this rapidly evolving landscape. They fostered a culture of innovation, encouraging their teams to explore new use cases for blockchain technology and to challenge conventional wisdom.

As we look back on this period of transformation, it is clear that the CTOs who embraced Web3 early on were the ones who positioned their organizations for long-term success. They understood that blockchain technology was not just a fad, but a fundamental shift in the way businesses operate. Their foresight and leadership have helped to build a more efficient, secure, and transparent digital economy for all. The next era of business was truly architected by these visionary technologists.

DECENTRALIZED APPLICATIONS

DECENTRALIZED APPLICATIONS

Decentralized AI

Decentralized AI networks represent an emerging market opportunity that challenges the current AI industry dominance of major technology companies. These networks distribute AI development and computing power across multiple participants through blockchain-based systems, creating new business models for AI services, data marketplaces, and computational resources.

The market opportunity stems from growing concerns about AI resource concentration and transparency. Current AI development requires substantial computing infrastructure, limiting innovation to a few well-resourced companies. Decentralized networks address this by enabling broader participation in AI development while creating new revenue streams for resource providers and developers.

And increasingly, these market developments are demonstrating commercial viability. SingularityNET's AI Marketplace 2.0 has established a functioning ecosystem where developers monetize AI services through token-based transactions. The platform routes user requests to distributed nodes rather than centralized servers, demonstrating a viable alternative to traditional AI service delivery models. Ocean Protocol has created new revenue opportunities in data markets, particularly in sectors like health care, where organizations can monetize data assets while maintaining control through smart contracts.

The computing resource market shows particular promise. Networks like Golem and Akash have successfully facilitated distributed AI model training, creating new revenue streams for computing resource providers. This development suggests potential for organizations to monetize underutilized computing infrastructure or participate in community-driven AI development projects.

Practical applications are emerging across industries. In Munich, Fetch.ai demonstrated real-world utility with a blockchain-based system connecting drivers with parking facilities, automating booking and payment processes. This implementation shows how decentralized AI can streamline operations and create new service offerings in traditional industries.

Governance innovations present additional opportunities. Organizations are exploring blockchain-based systems for AI oversight, including training data verification and output authentication. These developments address growing concerns about AI transparency and accountability, potentially creating competitive advantages for early adopters.

There are several ways to invest in this technology. First, direct participation in decentralized AI networks through computation provision or service development. Second, integration of decentralized AI services into existing business operations to reduce costs or enhance capabilities. Third, development of new products and services leveraging decentralized AI infrastructure.

The technology remains in early stages compared to established AI providers, but market indicators suggest growing adoption. Organizations should evaluate opportunities based on their specific circumstances, considering factors such as existing computational resources, data assets, and strategic alignment with decentralized technologies.

The key consideration is strategic positioning. While decentralized AI networks may not immediately replace traditional AI services, they offer unique capabilities and market opportunities. Organizations should monitor developments in this space and consider pilot projects to gain practical experience with these emerging technologies.

DeFi AI Hybrids (DeFAI)

Artificial intelligence is beginning to transform the world of digital finance, particularly in emerging decentralized financial platforms. This combination—sometimes called "DeFAI"—is creating new opportunities for automated trading, risk management, and investment strategies that weren't possible before.

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One significant development is the emergence of AI-powered trading assistants like SynFutures' "Synthia." The AI agent allows users to execute complex financial trades using simple English commands. Instead of navigating complicated trading interfaces, users can simply type what they want to do—like "swap $100 for ethereum"—and the AI handles all the technical details, including automatically finding the best prices across multiple markets.

AI is also enhancing investment management. Several investment protocols are now using machine learning to automatically adjust their investment strategies based on market conditions. These AI-driven investment vaults can shift funds between different types of assets when they detect changing market patterns, aiming to improve returns while managing risk. Early results suggest that these AI-managed portfolios are performing better than traditional static investment strategies.

Perhaps most importantly, AI is being used to improve risk assessment in lending. New platforms are using artificial intelligence to evaluate borrowers' creditworthiness using various data points, similar to how traditional banks use credit scores. This could make it possible for businesses to access loans through digital platforms without putting up excessive collateral. Major lending platforms are also using AI simulations to optimize their interest rates and risk parameters, helping them operate more efficiently while protecting against defaults.

But there are still challenges to navigate in this merger of AI and finance. Financial institutions are carefully considering how to maintain transparency when AI makes important decisions, and how to protect against potential errors or market disruptions caused by automated systems. Even so, the trend is clear: artificial intelligence is making digital finance more sophisticated, automated, and accessible to everyday users and businesses.

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Enterprise-Grade DApps for Traditional Industries

Across industries, major companies are now adopting blockchain technology to improve their core business operations, marking a shift from early experimental uses to practical applications. These enterprise blockchain systems are designed to meet the strict requirements of large organizations, including privacy controls, regulatory compliance, and the ability to handle high transaction volumes.

A major development in this space is the Canton Network, launched in July 2024, which connects more than 30 leading financial institutions including Goldman Sachs, Deutsche Börse, and HSBC. The network helps these organizations streamline financial operations like clearing trades and managing collateral. One application on this network is already processing $1.5 trillion in financial transactions monthly, demonstrating that blockchain technology can reliably handle large-scale, regulated financial operations.

In global trade, several industry groups have moved blockchain projects from testing to actual implementation. Networks like Marco Polo and Contour are helping banks and companies digitize traditional trade documents, while other platforms are being used to track shipments and supply chains in real time. These systems are designed to work with companies' existing software systems while providing better visibility and security for all parties involved.

The real estate industry is also embracing this technology. Real estate companies in Europe and the UAE are using blockchain platforms to manage property investments in new ways. For example, a Swiss real estate fund now allows qualified investors to trade shares instantly using a blockchain system that complies with local regulations—a significant improvement over traditional property investment methods.

To make adoption easier, major technology companies like SAP and Oracle have begun offering blockchain tools that integrate with their existing business software. This development suggests that blockchain technology is becoming a standard part of business infrastructure, much like cloud computing did before it. Companies can now implement blockchain solutions with the same level of support and reliability they expect from their other business software.

Hyperfinancialization with RWA Integration

Traditional financial markets are increasingly merging with new digital financial platforms, creating an environment where almost any valuable asset—from real estate to Treasury bills to business loans—can be traded and used as collateral in digital markets. This trend, sometimes called "hyperfinancialization," is making it possible to trade and finance assets 24/7 with instant settlement and even fractional ownership.

A leading example of this trend is MakerDAO, a digital finance platform that issues a cryptocurrency called DAI. By the end of 2023, about 60% of DAI's backing came from traditional assets like government bonds and bank deposits. In 2024, the platform expanded further, managing a $1.6 billion portfolio of US Treasury bills and partnering with a Florida bank to offer insured deposits. As seen here, digital finance platforms are becoming more like traditional financial institutions, while offering new levels of accessibility and efficiency.

New lending platforms are also emerging that connect global investors with real-world borrowers. For instance, platforms like Goldfinch have facilitated more than $150 million in loans to businesses in emerging markets. This means that individual investors can now participate in financing opportunities that were previously only available to large institutions, such as funding small businesses in Nigeria or real estate projects in the United States.

These platforms are also creating new financial products that combine traditional and digital finance. Investment managers are now offering structured products that let investors choose their preferred level of

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risk, similar to traditional financial products but with the added benefits of digital trading and broader accessibility. For example, investors can choose between lower-risk and higher-yield options in the same asset pool, all managed through digital platforms.

However, this merger of traditional and digital finance brings new challenges. Regulators are paying close attention to these developments, and platforms must carefully manage risks related to real-world assets. Despite these challenges, the trend suggests a future where traditional and digital finance become increasingly interconnected, potentially making financial services more efficient and accessible to everyone.

AI Agents for Autonomous Decision-Making

A new trend is emerging in digital organizations: the use of artificial intelligence to help run day-to-day operations and decision-making. These AI systems are being tested in decentralized autonomous organizations (DAOs)—online communities that make decisions collectively—to handle tasks that would typically require constant human attention.

In 2024, several organizations began experimenting with AI in practical ways. For example, VitaDAO, an organization focused on longevity research, used AI tools to evaluate grant applications, helping their community identify the most promising candidates. Another organization integrated AI into its voting platform to analyze and summarize lengthy discussion threads, making it easier for members to understand key points before voting on important decisions.

Some organizations are testing even more ambitious applications. One investment group allocated a small fund for an AI system to manage autonomously, essentially creating a mini AI-run hedge fund as an experiment. While results were mixed, it provided valuable insights into how AI might handle unpredictable market conditions. Other groups are developing AI systems that can monitor financial positions and automatically adjust strategies based on market changes, working around the clock without human intervention.

Looking ahead, industry experts envision organizations that could operate with minimal human oversight, using AI to handle routine tasks like managing finances, processing emails, and making basic decisions. These AI systems would be programmed to follow the organization's rules and values, only deferring to human judgment for contentious or unusual situations. This could help solve common problems in online organizations, such as low participation in voting and slow decision-making.

However, giving AI systems this level of autonomy raises important questions about safety and trust. Organizations are carefully considering how to ensure these AI systems remain transparent in their decision-making, align with human values, and have appropriate limitations on their actions. While it's still early days for this technology, the initial steps taken in 2024 suggest a future where AI could become an integral part of how organizations operate.

Reducing Friction in Cross-Border Transactions

One of the original promises of digital currencies was to make international money transfers faster and cheaper. In 2024, this promise has finally become reality through various digital payment solutions, including stablecoins (digital currencies tied to traditional money like the US dollar) and new partnerships between traditional financial institutions and blockchain technology companies.

A notable example is MoneyGram's crypto-based transfer service, which uses digital dollars on the Stellar network. This service allows someone in the US to send money abroad with fees under 2%, compared to traditional international transfer fees of 5-7%. The recipient can collect their money in local currency through MoneyGram agents, often within minutes rather than the days it typically takes for traditional transfers. Financial technology companies in Latin America, Africa, and Southeast Asia are now incorporating similar systems into their apps, making these

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faster, cheaper transfers available to users who may not even realize they're using blockchain technology.

Major financial institutions are also exploring blockchain-based international transfers. In late 2023, central banks from China, Hong Kong, Thailand, and the UAE, working with the Bank for International Settlements, conducted a successful trial that processed $22 million in cross-border payments. The system reduced transaction times from days to seconds and eliminated many traditional banking fees. Similarly, Mastercard is developing its own blockchain network to help banks settle international transactions more efficiently.

The technology is becoming increasingly user-friendly. New services are making it as easy to send money internationally as using a regular payment app. For example, a person in the Philippines can now use a simple wallet app to send pesos that are automatically converted to digital dollars, transferred to the US, and converted to US dollars in the recipient's bank account—all within minutes. This is a dramatic improvement over traditional international money transfer services, which often take days and charge higher fees.

These developments are particularly important for foreign workers sending money home to their families, small businesses engaged in international trade, and anyone who needs to make cross-border payments. By reducing fees and speeding up transfers, these new systems are making international commerce more efficient and helping more of each dollar reach its intended recipient.

Decentralized Science (DeSci) Platforms

A new movement called Decentralized Science (DeSci) is bringing innovation to how scientific research is funded, conducted, and shared. Instead of relying solely on traditional funding sources like government grants or corporate sponsorship, this approach uses blockchain technology to allow direct community funding and participation in scientific research.

One notable success story is VitaDAO, an organization focused on longevity research. In late 2023, VitaDAO launched its first biotech company, Matrix Biosciences, providing $300,000 in community-pooled funds to develop new treatments for age-related diseases. This project demonstrated how community funding could accelerate research that might otherwise take years to secure traditional grant funding. Similar organizations are now funding early-stage research in various fields, including psychology and laboratory services.

The movement is also transforming how scientific findings are published and shared. New platforms like ResearchHub are creating alternatives to traditional academic journals, allowing researchers to publish their work and share it directly with the public while receiving compensation through digital tokens.

A particularly innovative development is the creation of "IP-NFTs"—digital certificates representing ownership in scientific intellectual property. This allows research organizations to sell partial rights to their discoveries to raise funding for further development. In 2024, this model proved successful when a pharmaceutical company licensed a compound that had been funded through community contributions, sharing the proceeds among the contributors.

Traditional academic institutions are beginning to take notice. The University of Copenhagen, for example, partnered with a blockchain project to explore issuing digital diplomas and using community voting for grant allocation. Even prestigious journals like Nature have acknowledged the potential of this approach to promote innovative, high-risk research through community funding. While challenges remain—including many scientists' unfamiliarity with these new technologies—the developments in 2024 suggest that this new approach to scientific research has gained legitimate traction.

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Tokenized Loyalty Programs

Tokenized loyalty programs represent a significant evolution in customer engagement strategy, leveraging blockchain technology to transform traditional loyalty points into tradable digital assets. This transformation offers businesses new opportunities for customer retention, cross-brand partnerships, and market differentiation while addressing the current challenges of fragmentation and limited transferability in the loyalty program market.

Several market leaders have already demonstrated successful implementations across different sectors. In aviation, Lufthansa Group's Uptrip platform has acquired more than 20,000 users during its soft launch. The platform issues digital trading card NFTs for travel destinations, integrating with the Polygon blockchain while maintaining a traditional user experience. The program offers reward mechanics including lounge access and flight upgrades, and has shown particularly strong engagement among younger demographics.

The retail and luxury segment has seen varied approaches to implementation. Nike's .SWOOSH platform connects digital collectibles with physical merchandise benefits, while luxury brands like Louis Vuitton and Gucci leverage NFT ownership for exclusive VIP access. Universal Pictures has expanded into the entertainment sector with franchise-specific tokens for fan engagement.

In the hospitality industry, innovative implementations include a Maldives resort's introduction of tradable "Reward Tokens" for nights and services, demonstrating enhanced liquidity compared to traditional hotel points. This approach has proven particularly effective for offering VIP access and exclusive experiences through token ownership.

Technical implementation requires careful consideration of architecture and user experience. Successful programs typically integrate backend blockchain systems with simplified user onboarding through traditional login systems. Most platforms offer optional self-custody for advanced users while maintaining managed wallets for typical customers. Risk management focuses on regulatory compliance regarding token classification, with emphasis on utility over speculation, supported by clear terms of service and usage guidelines.

Risk mitigation remains crucial, with organizations needing to ensure regulatory compliance from the outset, implement robust security measures, and maintain clear communication with users. The technology itself should remain largely invisible to end users, with focus placed on the benefits and experiences it enables.

Tokenized loyalty programs present a compelling opportunity for businesses to modernize their customer engagement strategies. Early adopters have validated implementation models, while market trends suggest growing acceptance and demand for these solutions. Organizations should evaluate their readiness for pilot programs while maintaining awareness of implementation challenges and regulatory requirements. Success in this space will likely depend on seamless user experience, clear value proposition, and strategic partnership development rather than technical sophistication alone.

SCENARIO YEAR 2030

THE DAPP REVOLUTION

Looking back at the landscape just five years ago, it's remarkable how profoundly decentralized applications have reshaped our daily lives. In 2025, dApps were still largely considered a niche technology, mostly used by crypto enthusiasts. Today, in 2030, they're an integral part of how we work, play, and interact with the world.

The key to this transformation was the shift from experimental projects to enterprise-grade dApps tailored for traditional industries. Major companies finally recognized the potential of blockchain technology to improve their core operations, leading to a wave of practical implementations across diverse sectors.

Finance
The rise of “DeFAI” (Decentralized Finance AI Hybrids) has revolutionized how we manage our money. AI-powered trading assistants like Synthia, which seemed novel back in 2025, are now commonplace. They execute complex trades based on simple voice commands, finding the best prices across multiple markets automatically. Investment management is also largely automated, with AI algorithms adjusting portfolios based on market conditions.

Supply Chain
The promise of blockchain in supply chain management has finally been realized. We can now track products from origin to consumer with unparalleled transparency and security. This has not only reduced fraud and counterfeiting but has also enabled businesses to respond more quickly and effectively to disruptions.

Identity
The European Union’s eIDAS 2.0 framework, launched in 2024, proved to be a catalyst for secure digital identity. We now have a standardized way to prove our identity and sign documents digitally across all EU countries, making cross-border transactions seamless and secure. Platforms like Worldcoin, despite initial privacy concerns, paved the way for more privacy-preserving biometric authentication methods, which are now integrated into most dApps.

Infrastructure
Decentralized Physical Infrastructure Networks (DePINs) have transformed how we build and maintain essential services. Community-operated mobile networks like Helium have expanded dramatically, providing affordable internet access in underserved areas. We’re also seeing the rise of decentralized alternatives to traditional data storage and computing, empowering individuals and businesses to participate in the digital economy.

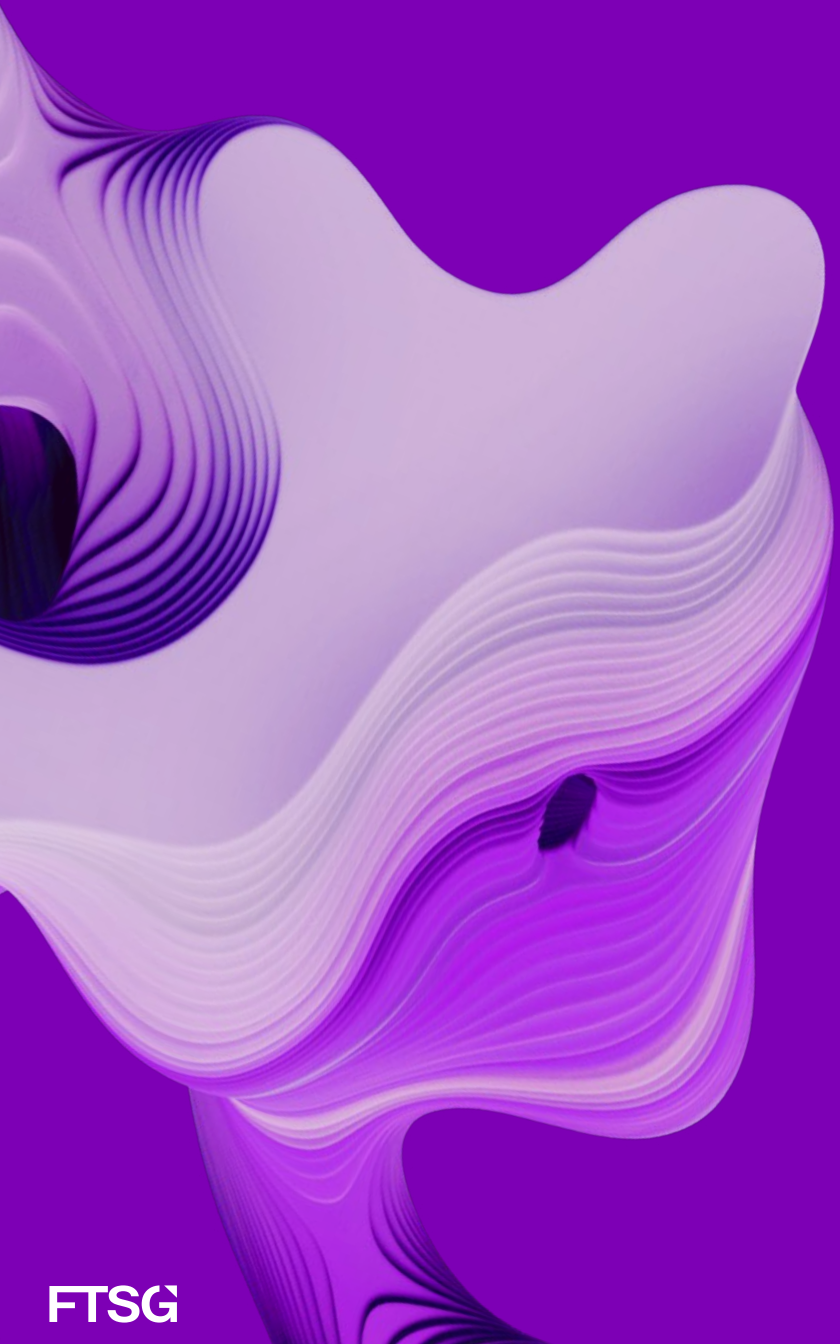
Science
Decentralized Science (DeSci) platforms have disrupted the traditional model of scientific research. Organizations like VitaDAO have demonstrated the power of community funding to accelerate research in critical areas like longevity. Researchers can now publish their work directly to the public and receive compensation through digital tokens, bypassing the traditional academic publishing system.

Social Media
Privacy-first messaging protocols have become the norm. We communicate using platforms like xx messenger, which route messages through multiple independent points, making it virtually impossible to track who is communicating with whom.

Loyalty Programs
Tokenized loyalty programs are ubiquitous, offering customers tradable digital assets that can be used across multiple brands. These programs have proven to be a powerful tool for customer retention and engagement.

Of course, the dApp revolution hasn’t been without its challenges. Security risks have become more sophisticated, requiring constant vigilance and the implementation of AI-driven security solutions. Regulatory frameworks have evolved to address the unique challenges of decentralized technologies, balancing innovation with consumer protection.

But overall, the impact of dApps on our lives has been overwhelmingly positive. They’ve empowered individuals, fostered innovation, and created new opportunities across diverse industries. As we look to the future, it’s clear that decentralized applications will continue to play a critical role in shaping the digital world. The foundations were set—the invisible transformation has occurred.



WEB2 + WEB3 INTEGRATION

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Digital Content Provenance and Authentication

The rise of artificial intelligence and sophisticated content manipulation tools has created new challenges for businesses in verifying the authenticity of digital media. In response, major technology companies are developing new solutions to verify and track the origins of digital content, from corporate communications to marketing assets. These developments are particularly relevant for businesses concerned about brand protection, intellectual property rights, and maintaining trust with customers.

Adobe, a leader in creative software, made significant strides in 2024 with its Content Authenticity Initiative. This system, now integrated into Photoshop, works similarly to how companies currently track document changes in Microsoft Word, but for images and other media. When a designer creates or edits an image, the software automatically records who made the changes and when, creating a verifiable history that stays with the file. Major news organizations, including the Associated Press and BBC, have adopted this system for their photo journalism, setting a new standard for content verification that businesses may soon need to consider for their own digital assets.

Large technology companies including Microsoft and Intel are developing similar authentication systems for video and audio content. Microsoft's Azure cloud platform now offers business customers the ability to add cryptographic signatures to their video content. This works like a digital seal of authenticity—if someone tampers with the video, the signature breaks, alerting viewers to the manipulation. This technology is particularly valuable for businesses that rely heavily on video content for training, marketing, or communication, as it helps ensure the integrity of their materials.

Social media platforms are also adapting to these changes. Twitter (X) and YouTube are exploring ways to display verification badges on media uploads, similar to the verified checkmarks on business accounts. This development could affect how companies manage their social media presence and verify their official content across platforms. It may soon become standard practice for businesses to authenticate their digital content just as they currently verify their social media accounts.

These verification tools are also extending past social media. Browser extensions and mobile apps now allow users to quickly verify the authenticity of images and videos, similar to how they currently check website security certificates. This trend suggests that consumers may soon expect to see authentication credentials on business content, making content verification as routine as checking for a secure website padlock icon.

For businesses, these developments present both opportunities and challenges. Organizations can now better protect their intellectual property and brand assets by creating verifiable records of their original content. This is particularly valuable for industries where image manipulation or counterfeit content could damage reputation or lead to liability issues. Marketing departments can prove the authenticity of their campaigns, while legal teams can better protect against unauthorized use or manipulation of company materials.

However, implementing these authentication systems requires investment in new tools and workflows. Businesses need to consider how to integrate content authentication into their existing digital asset management systems, train staff on new procedures, and potentially update their content creation and distribution processes. The cost of not adapting could be significant—as authentication becomes standard, unverified content may be increasingly treated with suspicion by customers and partners.

Looking ahead, businesses should prepare for a future where content authentication becomes as fundamental as digital signatures are today. Organizations that deal with sensitive information or valuable digital assets should particularly consider

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early adoption of these technologies. As AI-generated content becomes more prevalent, the ability to verify authentic business communications and materials will become increasingly crucial for maintaining customer trust and protecting brand integrity.

Self-Sovereign Identity Solutions with Privacy Focus

A significant shift is occurring in how organizations handle digital identity and credentials, moving away from centralized databases toward systems that give individuals control over their own information. This new approach, known as user-controlled digital identity, allows people to store and manage their credentials (like professional certifications, identity documents, and employment verification) on their own devices, similar to how they might keep physical documents in a wallet.

The European Union is leading this transformation with its Digital Identity Wallet initiative. Under this program, citizens will store official credentials like driver's licenses, diplomas, and professional certifications on their smartphones. These digital credentials work like their physical counterparts but with enhanced privacy features. For example, when proving age at a venue, users can simply confirm they're over 18 without revealing their actual birthdate or other personal information. This represents a fundamental change in how businesses verify customer information.

Major technology companies are already adapting to this trend. Microsoft has introduced verifiable credentials in its enterprise systems, allowing companies to issue digital versions of employee IDs and certifications. These credentials can be instantly verified anywhere while reducing administrative overhead. Universities are also adopting this technology, issuing digital diplomas and transcripts that students can share with employers. Apple has updated its Wallet app to support digital driver's licenses in some regions, signaling broader adoption of digital credentials in everyday business transactions.

For businesses, this shift offers several advantages. First, it reduces the liability and cost of storing sensitive customer data. Instead of maintaining databases of customer information, businesses can simply verify credentials when needed, similar to checking a physical ID card. Additionally, this approach also streamlines customer onboarding and verification processes. Financial services companies, for instance, are already testing systems where customers can prove their identity or credit status instantly without lengthy paperwork or manual verification.

The implications for business operations are substantial. Employee credentials, professional certifications, and compliance requirements can be managed more efficiently. When hiring, companies can instantly verify candidates' credentials without contacting previous employers or educational institutions. For regulated industries, proving compliance becomes more straightforward as required certifications can be verified in real time.

These systems also have privacy features that address growing consumer data protection concerns and regulatory requirements. Businesses can verify necessary information about customers or employees without collecting and storing excess personal data. This aligns with privacy regulations like GDPR while reducing the risk of data breaches.

However, adoption challenges remain. The system requires coordination between credential issuers (like governments and educational institutions) and the organizations that need to verify these credentials. Progress is being made as governments, particularly in Europe and parts of North America, establish frameworks for digital credential recognition. Banks and other financial institutions are also creating standards for accepting these digital proofs of identity.

Looking ahead, businesses should prepare for a future where digital credentials become as common as email addresses. Organizations may soon need to accept these new forms of digital verification while also

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considering how to issue their own credentials to employees, partners, or customers. The transition might require updating verification processes and training staff, but the potential benefits in efficiency, security, and customer privacy make this a worthwhile investment.

The rise of user-controlled digital identity represents a fundamental shift in how businesses handle verification and credentials. While the technology is still evolving, forward-thinking organizations are already preparing for this change. Those who adapt early will likely gain advantages in operational efficiency, customer trust, and regulatory compliance.

Web3-Powered Education and Skill Verification

The education and professional development landscape is undergoing a significant transformation as institutions adopt new digital technologies for issuing and verifying credentials. This shift promises to streamline hiring processes, reduce credential fraud, and create new opportunities for continuous learning in the workplace.

Major universities are leading this change by issuing digital diplomas alongside traditional paper certificates. MIT, the University of Toronto, and several European universities have implemented systems where graduates receive tamper-proof digital credentials that employers can instantly verify online. The European Union is taking this further by developing a region-wide system that allows any EU university to issue digital credentials that employers across the continent can easily verify through a standardized application. This development is particularly valuable for international recruitment, as candidates can prove their qualifications without the lengthy process of obtaining and translating paper documents.

The corporate world is also embracing this digital transformation. Salesforce has implemented a digital certification system for its professional training programs, where completing specific learning paths earns participants a verified digital badge. These credentials are already recognized by consulting partners when evaluating job candidates' expertise. Some IT companies in India have begun accepting digital certificates from online courses as proof of technical skills, reducing their reliance on additional testing during hiring.

New approaches to professional development and training are emerging through incentive-based learning platforms. These systems reward employees for completing training modules or acquiring new skills, similar to how loyalty programs reward customer purchases. Some platforms allow professionals to accumulate "skill tokens" as they complete training or contribute to projects, creating a verifiable portfolio of their capabilities. While still early, these systems show promise in increasing engagement with corporate training programs and providing more transparent ways to track professional development.

The education marketplace is also evolving. New platforms are emerging that connect instructors directly with learners, allowing for more flexible and targeted professional development. These systems enable companies to offer specialized training modules that employees can access on demand, with automatic verification of completion. This approach challenges traditional corporate training models by making professional development more modular and adaptable to specific business needs.

For human resources departments, these developments offer significant advantages. Digital credentials can streamline the verification process during hiring. Instead of manually contacting universities or previous employers to verify qualifications, HR systems can instantly verify candidates' credentials through secure digital checks. This could dramatically reduce the time and cost associated with background checks while increasing their reliability.

The implications for business operations extend beyond hiring. Companies can better track and verify employee skills and certifications, ensuring compliance with industry requirements and identifying skills gaps more effectively. Training

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programs can be more precisely targeted, and achievement can be more accurately measured. This is particularly valuable for regulated industries where maintaining current certifications is crucial.

Looking ahead, organizations should prepare for a future where digital credentials become standard in professional development and hiring. This might involve updating HR systems to handle digital verification, reconsidering how internal training programs issue and track certifications, and developing new policies for accepting digital credentials during recruitment.

The transformation of educational and professional credentials represents more than a technological shift—it's a fundamental change in how organizations verify skills and manage talent development. While the systems are still evolving, forward-thinking organizations are already preparing for this change, recognizing that early adoption could provide significant advantages in recruitment, training, and workforce development.

Decentralized Cloud Computing Services

A new approach to cloud computing is emerging that could change how businesses think about their digital infrastructure. Unlike traditional cloud services provided by major vendors like Amazon Web Services or Google Cloud, these new systems distribute computing power and storage across networks of independent providers. This shift offers businesses new options for hosting websites, storing data, and running applications.

This transformation matters for several reasons. Traditional cloud services, while reliable, create potential vulnerabilities when a single provider experiences outages or technical issues. The new distributed approach reduces this risk by spreading resources across multiple providers. It also addresses growing concerns about data privacy and security, as information isn't concentrated in a single company's data centers. For businesses operating internationally, these systems can provide more flexibility in how and where they store and process data.

Storage solutions have significantly advanced. New storage networks have expanded rapidly, with thousands of providers offering competitive rates for business data storage. These systems are particularly cost-effective for long-term storage of documents, images, and other digital assets. While accessing frequently-used data can be slower than with traditional services, businesses are finding success with hybrid approaches that combine new storage methods with traditional content delivery networks.

Computing services are also evolving. New marketplaces have emerged where businesses can access computing power for specific tasks, often at lower costs than traditional cloud providers. This is particularly relevant for companies needing significant computing power for specialized tasks like video processing or artificial intelligence training. While these services may not yet match the consistency of traditional providers for critical business operations, they're proving valuable for specific use cases and non-time-critical tasks.

Major technology companies are taking notice. Google Cloud has partnered with data exchange platforms to help their enterprise clients better monetize their data assets. Amazon Web Services now supports some of these new services through their marketplace, making it easier for businesses to experiment with these alternatives while maintaining their existing cloud infrastructure. These developments suggest that future cloud services might blend traditional and new approaches, giving businesses more flexibility in how they manage their digital resources.

Reliability, a key concern for business operations, has improved significantly. New networks have implemented sophisticated systems to ensure data persistence and service uptime. Some video streaming services using these distributed networks have achieved reliability rates comparable to traditional providers. This progress is particularly important for businesses considering these alternatives for customer-facing applications.

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But the business implications extend beyond technical considerations. Companies can now monetize their excess computing resources by contributing them to these networks, potentially creating new revenue streams from existing infrastructure. This democratization of cloud services could be particularly valuable for businesses with significant computing resources that aren't continuously utilized.

These developments also offer new options for business continuity and disaster recovery. Some organizations are using these distributed systems as backup solutions, ensuring their websites and applications remain accessible even if their primary hosting service experiences issues. This approach has proven valuable in regions where internet access might be restricted or during large-scale service outages.

Looking ahead, businesses should consider how these evolving cloud services might fit into their infrastructure strategy. While they may not be ready to replace traditional cloud providers entirely, these new options could complement existing services, particularly for specific use cases like long-term data storage or backup systems. Organizations should evaluate these alternatives based on their specific needs for reliability, data access speed, cost, and regulatory compliance.

The evolution of cloud services represents a significant shift in how businesses can approach their digital infrastructure. While the technology continues to mature, forward-thinking organizations are already exploring how these new options might enhance their operations and reduce their dependence on single providers.

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Regulatory Compliance Frameworks for Web3 Technologies

The regulatory environment for digital assets and blockchain technologies is rapidly evolving as governments worldwide work to create comprehensive oversight frameworks. These new regulations aim to provide clearer guidelines for businesses while protecting consumers and maintaining financial stability. Understanding these developments is crucial for organizations considering entering the digital asset space or expanding their existing operations.

A major focus of regulatory efforts has been transaction monitoring and reporting requirements. The European Union has implemented new regulations requiring financial service providers to share sender and receiver information for large digital asset transfers, similar to existing banking regulations. Japan, South Korea, Hong Kong, and Singapore have adopted similar requirements. These rules primarily affect companies handling digital assets on behalf of customers, such as exchanges and custodial services. To help businesses comply, industry groups have developed standardized formats for sharing this information, and technology providers now offer automated compliance solutions.

Financial regulators are also addressing new business models that emerged with digital assets. The US Commodity Futures Trading Commission has clarified that decentralized organizations must comply with existing financial laws, prompting many businesses to implement stronger compliance measures. Some organizations now use blockchain analysis tools to screen transactions for potential risks, while others have created separate pools of assets specifically for regulated institutions that require strict compliance measures. These developments indicate that even innovative business models must adapt to traditional regulatory frameworks.

Licensing frameworks are becoming clearer across major financial centers. The European Union is creating a unified licensing system that will allow digital asset service providers to operate across all EU countries with a single license, similar to existing financial services passporting. Hong Kong has launched a licensing system for digital asset platforms, with major companies already applying. The United Arab Emirates has established comprehensive rules for digital asset businesses through Dubai's Virtual Assets Regulatory Authority. These frameworks typically require businesses to maintain specific capital reserves, undergo regular audits, and follow strict marketing guidelines.

Tax and accounting standards are also evolving to accommodate digital assets. The US Internal Revenue Service has provided updated guidance on taxing various types of digital asset transactions, while countries like Portugal and Germany have refined their tax treatment of these assets. On the accounting front, standard-setting bodies are adapting their guidelines to better reflect how businesses should report digital assets on their balance sheets. The US Financial Accounting Standards Board has made progress in allowing companies to use fair value accounting for digital assets, making it easier for businesses to reflect these holdings accurately in their financial statements.

For businesses, these regulatory developments create both opportunities and challenges. Clear frameworks reduce legal uncertainty, potentially making it easier for organizations to incorporate digital assets into their operations. However, compliance requirements can be substantial, requiring investment in new systems and processes. Organizations need to carefully evaluate their capabilities and resources when considering entry into regulated digital asset activities.

Looking ahead, businesses should prepare for increased regulatory oversight while watching for opportunities created by clearer rules. Organizations already operating in this space may need to update their compliance programs to meet new requirements. Those considering entering the market should factor compliance costs and operational requirements into their planning. Financial institutions, in particular,

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may find new opportunities as regulatory clarity makes it easier to offer digital asset services to their clients.

The evolution of digital asset regulation represents a maturation of the industry. While some worry that regulation might stifle innovation, others see it as necessary for mainstream adoption. As frameworks continue to develop, businesses that can navigate these requirements while maintaining innovative services will likely find significant opportunities in this emerging market. Success will require staying informed about regulatory changes while maintaining flexible compliance programs that can adapt to new requirements.

SCENARIO YEAR 2038

THE INEVITABLE UNFOLDING: HOW WEB3 WILL COME TO FRUITION

In the 1990's, the internet felt newfangled, unnecessary, and destined to stay hidden in the halls of government and "high-tech." The internet as we know it has transformed society, but it was never designed to handle the complexities of modern digital commerce. This has led to a patchwork of regulations layered on top of antiquated infrastructure. Now, as Web3 technologies mature, a new paradigm is emerging—one where trust is embedded in the infrastructure itself. This is how it will unfold.

2025–2029: Seeds of Change

Enterprise

- **Experimentation Phase**
  Enterprises will begin dipping their toes into Web3, primarily focusing on proof-of-concept projects and exploring potential use cases. Areas like supply chain tracking, digital identity management, and tokenized loyalty programs will see initial adoption. Early adopters will be driven by the promise of increased efficiency and transparency, but adoption will be cautious due to regulatory uncertainty and technological immaturity.

- **Skill Gaps & Early Adopters**
  Businesses will face a shortage of skilled Web3 developers and architects. Early adopters will invest in training programs and strategic partnerships to bridge this gap.

Government

- **Regulatory Scaffolding**
  Governments will start laying the regulatory groundwork for digital assets and blockchain technology. The EU's MiCA regulation will serve as a key example. Initial regulations will focus on consumer protection and preventing illicit activities, with less clarity on more complex areas like DeFi.

- **Central Bank Digital Currencies (CBDCs)**
  A few nations will begin piloting CBDCs, but widespread adoption will be limited due to privacy concerns and technical challenges.

Technology

- **Layer-2 Scaling Solutions**
  Layer-2 scaling solutions like Optimism, Arbitrum, and zkSync will gain traction on Ethereum, drastically reducing transaction fees and increasing throughput. This will make dApps more viable for everyday use.

- **Cross-Chain Interoperability**
  Cross-chain interoperability protocols will emerge, enabling seamless asset transfer and data sharing between different blockchain networks. However, security concerns will remain a major hurdle.

- **AI-Blockchain Convergence**
  The initial integration of AI and blockchain will emerge, with projects exploring AI-powered smart contracts and decentralized AI marketplaces.

2030–2034: Web3 Becomes Invisible

Enterprise

- **Mainstream Adoption in Specific Verticals**
  Web3 technologies will gain mainstream adoption in specific industries where the benefits are clear and regulation is favorable. Supply chain management, finance, and digital identity verification will be at the forefront.

- **Focus on User Experience**
  Enterprises will prioritize user experience, abstracting away the complexities of blockchain technology and creating user-friendly interfaces for dApps.

- **RWA Tokenization Emerges**
  Enterprises will start experimenting with Real World Asset (RWA) tokenization. This will lead to increased liquidity and fractional ownership opportunities.

Government

- **Clear Regulatory Frameworks**
  Governments will establish more comprehensive and clear regulatory frameworks for digital assets and blockchain technology, providing legal certainty for businesses.

- **Digital Identity Initiatives**
  Governments will launch digital identity initiatives based on blockchain technology, empowering citizens to control their own data and streamlining access to public services.

Technology

- **Interoperability Standards**
  The industry will coalesce around interoperability standards, enabling seamless communication and data exchange between different blockchain networks and legacy systems.

- **Privacy-Enhancing Technologies**
  Advanced cryptographic techniques like zero-knowledge proofs (ZKPs) will become more widely adopted, enabling businesses to protect sensitive data while participating in blockchain networks.

- **DAO Governance Models**
  DAOs will evolve into more sophisticated governance tools, enabling communities to collectively manage resources and make decisions transparently.

- **DePINs Continue to Grow**
  More and more people will participate in Decentralized Physical Infrastructure Networks.

2035–2038: The Web3 World Realized

Enterprise

- **Web3 as Core Infrastructure**
  Web3 technologies will become deeply embedded in enterprise IT infrastructure, powering core business processes and enabling new business models.

- **Decentralized Applications Everywhere**
  Enterprises will leverage decentralized applications (dApps) to improve efficiency, transparency, and security across diverse functions, from supply chain management to customer relationship management.

Government

- **Global Regulatory Harmonization**
  International organizations will work to harmonize regulatory standards for digital assets and blockchain technology, creating a more level playing field for businesses operating globally.

- **AI-Assisted Regulation**
  Regulators will leverage artificial intelligence to monitor Web3 activity, detect fraud, and identify emerging risks.

- **CBDCs Gain Traction**
  Some government entities will utilize the blockchain for CBDCs.

Technology

- **AI-Driven Web3 Ecosystem**
  Artificial intelligence will play a critical role in managing and optimizing the Web3 ecosystem, automating complex tasks, enhancing security, and personalizing user experiences.

- **Quantum-Resistant Security**
  Quantum-resistant cryptography will be widely adopted, safeguarding blockchain networks and digital assets from the threat of quantum computing.

- **Self-Sovereign Identity**
  Individuals will have complete control over their digital identities, using self-sovereign identity solutions to securely manage their credentials and access online services.

Looking back from 2038, it will be clear that the transition from Web2 to Web3 was not a technological revolution, but a cultural and societal evolution. It was a gradual shift towards a more decentralized, transparent, and equitable digital world, where individuals are empowered to control their own data, assets, and online experiences. It was a journey, not a destination, and where it will ultimately lead is yet to be defined. But what is clear is that by 2038, society as a whole will live on a new foundation.

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Melanie Subin is Managing Director at Future Today Strategy Group, serving on our management committee and leading our consulting division. Renowned for her pragmatic, forward-thinking approach, Melanie has successfully steered numerous clients toward future-ready strategies, harnessing emerging trends and technologies to identify risk and opportunity early enough for action. Her leadership has significantly impacted how industries envision and execute their long-term strategies.

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2025 TECH TRENDS REPORT • 18TH EDITION

METAVERSE & NEW REALITIES

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Melanie Subin
Managing Director

You're already living in the metaverse; you just don't know it.

The metaverse isn't what you think it is. For the past five years, we've been sold a vision of the future that's more science fiction than reality. Tech titans, inspired by dystopian novels, poured billions into creating virtual worlds that promised to revolutionize how we live, work, and play. They built it, but we didn't come. Why? Because the metaverse, as it's been defined, is a mirage—an unaffordable, inaccessible, and unrealistic fantasy that ignores the fundamental ways humans want to experience life.

The truth is, the real metaverse is already here, but it's not what you've been told to expect. It's not a virtual playground requiring expensive headsets and impossible bandwidth. Instead, it's the invisible, interconnected digital layer that surrounds us every day. It's in the sensors in our phones, the smart devices in our homes, and the digital footprints we leave behind with every interaction. The metaverse isn't a place we go to escape reality; it's the technology that's seamlessly becoming our reality.

We're at a turning point. The decisions we make now will shape our digital future for years to come. The next decade will determine which companies and industries thrive in this hyper-connected world and which become obsolete. The winners will be those who understand that the metaverse isn't about creating new virtual worlds but enhancing our existing ones through data, connectivity, and intelligence.

This book is your guide to navigating the real metaverse—a world where digital and physical realities converge in ways both subtle and profound. We'll explore how this shift is already reshaping industries, altering human behavior, and creating unprecedented opportunities and challenges. The future is here, and it's time to see it clearly.

Welcome to the true metaverse. It's not what you expected, but it's far more exciting—and it's already transforming the world around us.

AI and invisible technologies are redefining the metaverse, sparking privacy debates, transforming industries and revolutionizing social interactions.

1

AI integration redefines the metaverse landscape

Generative AI technologies are enhancing user experiences and creating more realistic digital environments. This integration transforms how we interact with digital layers in our everyday lives, from recommendations to smart home controls.

2

The rise of 'invisible' metaverse technologies

The development and adoption of technologies that seamlessly blend into our physical reality—including advanced IoT devices, spatial computing, and edge computing—is helping fuel the development of the metaverse as an interconnected digital layer.

3

Privacy concerns spark debate over metaverse data collection

The increasing prevalence of sensors and data collection has ignited a debate about data ownership. This has led to new regulations and innovative approaches to data protection, as society grapples with the balance between personalization and privacy.

4

Companies embrace industrial metaverse applications

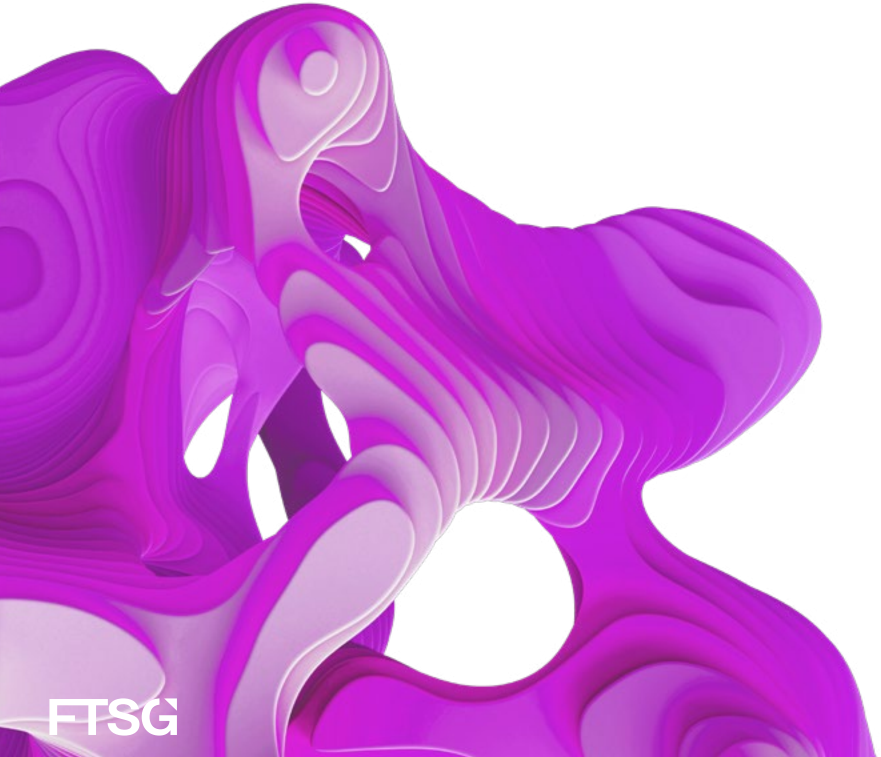
Industries are rapidly adapting to our new understanding of the metaverse. Now, they're focusing on "industrial metaverse" applications, leading to real productivity gains and growth in sectors like urban planning and manufacturing.

5

Data interoperability is critical for metaverse evolution

For the metaverse to develop, it needs a unified digital infrastructure that enables safe real-to-virtual interactions. Such data interoperability must focus on seamlessly integrating capabilities like digital identities and payment systems.

The metaverse is shifting from a hyped-up sci-fi future to a practical reality.



The metaverse is undergoing a significant recalibration after the initial hype of the early 2020s, with investment and resource allocation slowing considerably. However, this deceleration is a natural and expected part of the technology adoption curve, mirroring the trajectory of other transformative innovations. The concept of the metaverse is evolving from an overhyped, VR-centric vision to a more nuanced and practical integration into daily life. Much like the internet's gradual adoption in the 1990s, the metaverse is poised to become a subtle yet powerful augmentation of reality rather than a separate, immersive world accessible only through specialized hardware.

This shift in perspective is crucial for understanding the metaverse's true potential. Instead of viewing it as a niche technology for enthusiasts, it's more accurate to consider it as an extension of our digital interactions, seamlessly blending physical and virtual experiences. This integration is already manifesting in various sectors, from education and health care to business and entertainment, enhancing rather than replacing traditional modes of interaction. The industrial metaverse, for instance, is gaining traction with digital twins and augmented reality solutions enhancing design, monitoring, and employee training processes. In e-commerce, the integration of virtual products with physical world tie-ins is driving innovation and creating new market opportunities.

As the technology matures and becomes more accessible, the metaverse's impact on daily life will likely be profound yet subtle, reshaping how we work, learn, and interact without the need for constant immersion in virtual reality. This recalibration period is crucial for addressing challenges such as privacy concerns, regulatory frameworks, and technological limitations. It allows for a more thoughtful and sustainable development of the metaverse, ensuring its integration into society is both beneficial and responsible.

As we move beyond the initial hype, the true potential of the metaverse as a transformative force in our daily lives is beginning to take shape, promising a future where digital and physical realities coexist seamlessly.

Artificial intelligence prompts new product rollouts and several regulatory changes.

JANUARY 2024

EU Moves to Regulate Virtual Worlds

The European Parliament calls for guidelines clarifying the legal obligations of different stakeholders in virtual spaces.

JANUARY 2024

Davos Hosts a Metaverse Collaboration Village

More than 200 people participated in immersive dialogues via the World Economic Forum's virtual Global Collaboration Village.

FEBRUARY 2024

Apple Launches the Vision Pro Headset

The headset blends digital content with the physical world, and marks Apple's entry into mixed reality hardware.

FEBRUARY 2024

South Korea Enacts Metaverse Industry Law

The new law both supports and regulates the metaverse, prioritizing permissionless development with oversight after implementation.

SEPTEMBER 2024

Meta Unveils New Metaverse Hardware and Features

Meta releases a new headset and a refreshed strategy for its metaverse platform, and teases more lifelike avatars and AI-driven NPCs.

« PAST

Integrated displays and headset advancements will mark much of the progress in 2025.

FUTURE »

MARCH–APRIL 2025

Global Conference on Metaverse Governance

The EU's conference will discuss metaverse regulation, including interoperability, ethics, and global policy coordination.

APRIL 2025

Osaka Expo Virtual World Opening

The virtual "Yumeshima Islands in the Sky" will allow visitors to join as avatars, explore, and enjoy exclusive events.

MID-2025

Samsung & Google's XR Headset Launch

The standalone mixed-reality headset features state-of-the-art displays, eye/hand tracking, and an external battery.

MID-2025

Meta Adds Integrated Displays to Ray-Ban Smart Glasses

Meta's updated glasses will feature integrated displays capable of showing notifications and responses from a virtual assistant.

AUGUST 2025

MetaCom 2025

Researchers, industry professionals, and academics will discuss emerging technologies and innovations shaping the metaverse landscape.

Businesses that prepare now for the metaverse will gain an early advantage.

Business Model Reinvention

In the metaverse era, companies will reinvent their business models to blend physical and digital offerings, integrating virtual goods, services, and immersive experiences. This transformation unlocks new revenue streams and reimagines value propositions, allowing early movers to shape the standards.

Optimized Operations

Metaverse technologies like augmented reality and data-driven digital twins are enabling unprecedented efficiencies. By simulating factory floors, supply chains, and complex systems in 3D, companies can predict issues and optimize processes in advance, leading to leaner operations and lower costs.

Immersive Customer Engagement

Metaverse platforms are redefining how companies interact with customers. Businesses will build virtual showrooms, interactive events, and branded worlds where customers play an active role, forging deeper loyalty and emotional connections that will shape the future of customer experience.

Workforce Evolution

Organizations are leveraging metaverse tools to transform their workforce, using virtual reality for everything from employee training and onboarding to seamless collaboration. This shift will fundamentally reshape how companies attract, develop, and retain talent in a borderless work environment.

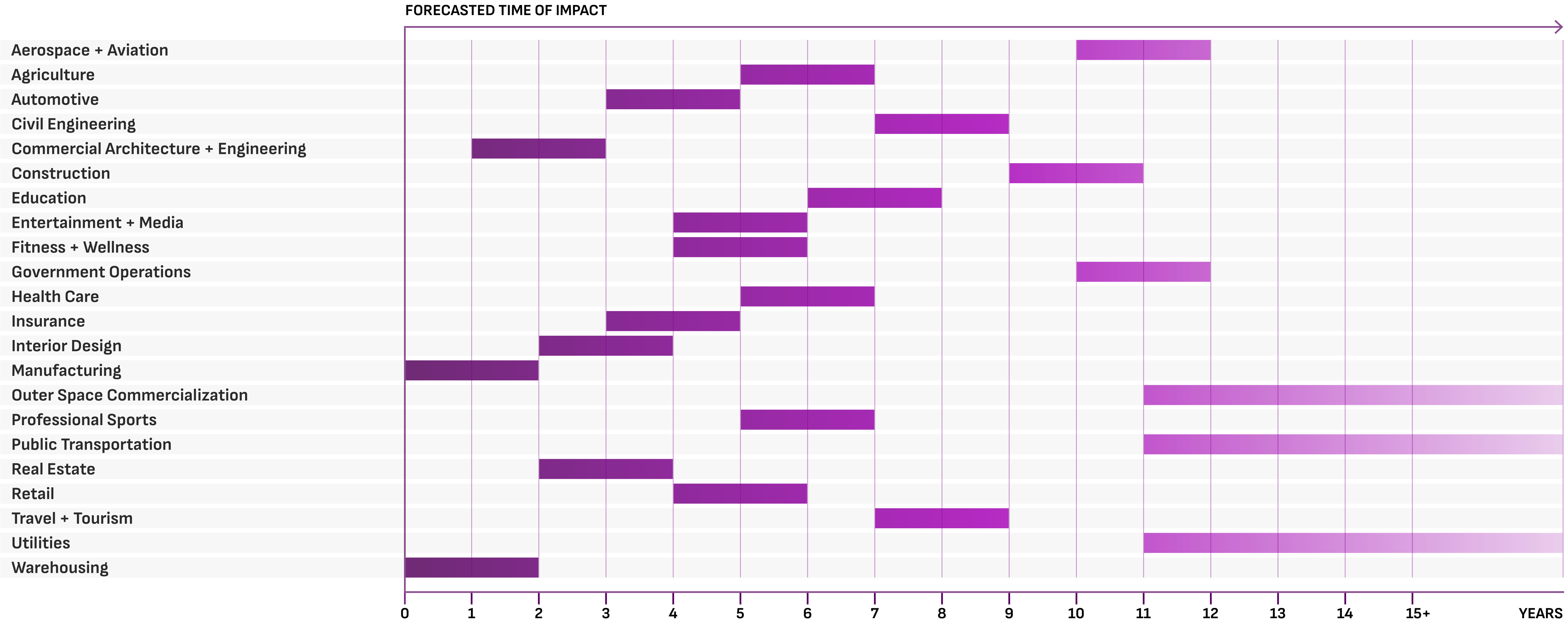
Decentralized Governance and Trust

The metaverse will accelerate the adoption of decentralized governance models, where smart contracts and blockchain-based decision-making replace traditional hierarchical structures. This will compel businesses to rethink corporate governance, compliance, and stakeholder engagement strategies.

Data Sovereignty and Privacy

Data ownership, security, and privacy concerns will become critical as businesses enter the metaverse. Ethical data stewardship will evolve from a compliance requirement into a key competitive advantage, distinguishing brands in an increasingly surveilled digital landscape.

Many industry operations are already being directly impacted.



Willingness to invest in infrastructure will determine firms' ability to benefit from the early mover advantage.

SCALING

Industries with established digital ecosystems, such as gaming and entertainment, are already experimenting with metaverse applications, while sectors requiring complex integrations face longer timelines. Cloud computing, edge processing, and AI-driven simulations will be crucial in enabling scale.

CONSTRAINTS ON ADOPTION

Workforce readiness, interoperability between platforms, and need for standardization are significant barriers to adoption. Industries with existing digital twin applications can quickly integrate metaverse solutions while fields requiring compliance or physical infrastructure will take longer to adapt.

MEDIA MENTIONS

Public discussions around the metaverse impact organizational urgency to invest. Industries with high consumer engagement will feel pressure to adopt metaverse solutions sooner. Frequent coverage can accelerate experimentation and investment, while limited or negative media narratives can slow enthusiasm.

R&D DEVELOPMENTS

The pace of technological advancements will impact adoption timelines. Fields like spatial computing and blockchain integration are making rapid progress, accelerating adoption in industries such as automotive and aerospace. Industries with long R&D cycles will take longer to see implementation.

COSTS

The metaverse demands substantial investment in infrastructure, computing power, and hardware. Early adopters with large budgets, such as manufacturing and automotive industries, will leverage metaverse applications in the near term, while industries constrained by cost sensitivity will see slower adoption.

REGULATIONS

Metaverse adoption will be shaped by emerging policies on digital identity, data privacy, intellectual property rights, and cybersecurity. Highly regulated industries, such as health care and financial services, will experience delays while industries like retail and media, will see faster integration.

PUBLIC PERCEPTIONS

Consumer trust in digital environments will shape adoption rates. Industries where immersive experiences enhance customer interactions, such as real estate and interior design, will see earlier integration while sectors requiring trust, like insurance and health care, must address skepticism before scaling.

These individuals are defining and building the original metaverse.

- **Jeremy Bailenson, Professor of Communication at Stanford University and Founding Director of the Virtual Human Interaction Lab,** for examining how humans learn and behave in virtual environments.

- **Matthew Ball, CEO of Epyllion and Author of "The Metaverse: And How It Will Revolutionize Everything,"** for his thought leadership framing the metaverse's evolution.

- **Alvin Wang Graylin, Global VP at HTC,** for leading VR/AR adoption in China through HTC, focusing on the convergence of AI and XR, and advocating for an inclusive, AI-driven metaverse.

- **John Hanke, Founder & CEO of Niantic,** for championing the "real-world metaverse" via AR to make the world more interactive and magical.

- **Mic Mann, CEO of Africarare,** for launching "Africarare" to showcase African art and innovation in a virtual world, aiming to connect Africa to the global digital economy.

- **Dr. Morgan McGuire, Chief Scientist at Roblox,** for his work as the driving force behind one of the world's largest user-created metaverse platforms.

- **Herman Narula, Co-founder & CEO of Improbable,** for building the backbone of large-scale virtual worlds through platforms like SpatialOS that enable massive simulations.

- **Tony Parisi, Chief Product Officer at Lamina1,** for his work as a veteran VR pioneer and co-creator of several international 3D graphics standards, including VRML, X3D, and glTF.

- **Nonny de la Peña, Founder & CEO of Emblematic Group; Program Director,** ASU Narrative and Emerging Media, for pioneering immersive journalism and innovating new ways to tell stories in VR.

- **Mike Rockwell, Vice President of Apple's Vision Products Group,** for leading the driving force behind Apple's Vision Pro, redefining AR/VR interfaces and accelerating metaverse development.

- **Yat Siu, Co-founder & Executive Chairman of Animoca Brands,** for being a leading advocate for digital property rights and an open metaverse.

- **Neil Trevett, VP of Developer Ecosystems at Nvidia; President of the Khronos Group and the Metaverse Standards Forum,** for his work as a key architect of metaverse interoperability.

The metaverse brings the potential of new revenue and increased efficiencies...

...but implementation will need to mind existing regulatory and legal limitations.

OPPORTUNITIES

New Revenue Streams and Digital-First Economies

Businesses can generate revenue through digital products, immersive advertising, and blockchain assets, such as selling NFTs, leasing virtual real estate, or offering digital services.

Novel Channels for Customer Engagement

Companies can connect in new ways with consumers, from virtual storefronts and interactive brand experiences to immersive events and gamified marketing campaigns, creating refreshed engagement.

Cost Reduction Through Immersive Technologies

VR/AR and digital twins can reduce operational expenses, such as by cutting travel and onboarding costs, lowering product development expenses, and reducing the need for physical office spaces.

Data-Driven Personalization and Market Insights

Metaverse interactions generate valuable data, enabling businesses to use customer behavior data and insights to refine product offerings, personalize marketing efforts, and optimize experiences.

THREATS

Regulatory and Legal Uncertainty

The metaverse lacks clear regulatory frameworks. Companies must navigate complex legal landscapes and risks related to digital ownership, taxation, intellectual property, and jurisdictional disputes.

Changing Communication Models

Traditional digital marketing methods, such as social media ads and search engine optimization, may lose effectiveness in immersive environments, requiring businesses to adapt to new advertising models.

Data Privacy and Security Concerns

The metaverse collects vast amounts of personal and biometric data, making it a target for cyber threats. Companies must secure digital environments to maintain trust and avoid reputational damage.

Ethical and Reputational Risks

Issues like harassment, misinformation, and addictive experiences can lead to public backlash or legal consequences if not properly managed, necessitating governance policies and ethical safeguards.

The time to begin preparing is now, before the metaverse is fully scaled.

Invest in robust cloud infrastructure, cybersecurity frameworks, and blockchain systems to ensure safe, efficient, and scalable metaverse operations while protecting digital assets and transactions.

Develop specialized training programs to equip employees with VR/AR, blockchain, and digital commerce expertise, ensuring teams can effectively operate and innovate in metaverse environments.

Redefine revenue strategies by integrating digital assets, immersive experiences, and metaverse-driven commerce, positioning businesses to thrive in evolving virtual marketplaces.

Engage with policymakers and industry groups to advocate for balanced regulations on digital ownership, virtual asset taxation, and data privacy, ensuring business-friendly policies that promote innovation.

Begin transitioning from traditional ad formats to immersive brand experiences, influencer-driven interactions, and in-world sponsorships to align with evolving marketing dynamics in virtual spaces.

Allocate resources to develop metaverse environments, enhance VR/AR capabilities, and support long-term innovation in virtual commerce, ensuring sustained growth in immersive digital ecosystems.

Technology Deployment
Capital Expenditure
Talent Development
Regulatory Influence

Important terms to know before reading.

AUGMENTED REALITY (AR)

A technology that overlays digital information, images, and objects onto the real-world environment. Users see virtual elements mixed into their actual surroundings through a device screen or AR glasses/headset.

AVATAR

A digital representation of a user, often in the form of a 3D model or illustration. Avatars serve as a user's persona in online/virtual environments.

CYBERSICKNESS

Nausea or motion sickness experienced by some VR users due to proprioception disorientation. It arises from the mismatch between perceived and actual spatial positions in VR, with research suggesting that factors like vertical orientation, perception, and inclusion of music can influence its severity.

DATA PORTABILITY

The ability for users to transfer their digital identities, including avatars, and associated data between platforms and services.

DECENTRALIZATION

A core principle shared by the metaverse and blockchain technology, emphasizing an open network of interconnected virtual worlds, as opposed to closed, proprietary platforms.

DEEPFAKES

Manipulated video/audio that uses AI to realistically substitute someone's likeness and voice in existing content without their consent, raising ethical concerns.

DIGITAL TWINS

Virtual replications of physical systems used for simulation and optimization.

EXPERIENTIAL ARTIFACTS

Lingering sensory and cognitive effects in VR users, blurring the lines between virtual and real-world experiences. These artifacts result from the dissonance between virtual and physical realities, leading to feelings of disembodiment or altered physical world perceptions.

EXTENDED REALITY (XR)

An umbrella term that encompasses virtual reality, augmented reality, and mixed reality. XR provides immersive digital experiences that blend the physical and virtual worlds across a spectrum of realities. It enhances interactions with the environment and digital elements.

HAPTICS

Technology related to tactile sensations and feedback. Can include vibration, motion, pressure, and temperature changes.

HOLOGRAPHY

A technique for creating three-dimensional projections; it's becoming key in populating the metaverse with realistic avatars and environments, and merging with technologies like deepfake for various applications.

HUMAN-MACHINE INTERFACES

The components and methods through which humans interact with and control machines, like keyboards, mice, touchscreens, and voice commands.

HYPERREALISTIC AVATARS

Highly detailed avatars that closely mimic a person's real facial features, expressions, and movements through advanced 3D modeling and scanning.

INTEROPERABILITY

Blockchain's capability allowing assets and information to seamlessly transfer between different worlds and platforms within the metaverse.

MIXED REALITY (MR)

A hybrid form of reality that merges the real and virtual worlds to produce new environments and visualizations where physical and digital objects coexist and interact in real time.

NEURAL INTERFACES

Technologies that connect directly to the user's neural activity, like brain waves or facial muscle signals, to enable hands-free and silent control.

NON-FUNGIBLE TOKENS (NFTS)

Unique digital assets representing ownership of virtual items like land and avatars in the metaverse, made credible and secure through blockchain technology.

OLFACTORY FEEDBACK

Technology that generates smells and aromas digitally, allowing smells to be simulated in a virtual environment.

PANOPTICON

A system of control where individuals are aware they might be watched at any time, leading to self-regulation of behavior. In the context of smart glasses, it refers to the heightened sense of being observed and changing behavior because of it.

PASSTHROUGH

A feature in some headsets that uses outward-facing cameras to display the physical environment to the user while wearing the headset. Provides awareness of surroundings.

PLAY-TO-EARN GAMES

Virtual environments in the metaverse where players can earn real-world value through gameplay, with blockchain technology enabling the collection, breeding, and trading of digital assets as NFTs.

SITUATED VIRTUAL REALITY (SITUATED VR)

A concept proposed to align the physical and virtual worlds, minimizing experiential artifacts. It focuses on syncing physical actions with virtual feedback to create a congruent reality, including mirroring body language and emotional expressions in virtual and real worlds.

SYNTHETIC PERSONALITIES

Fully artificial digital influencers and identities generated through AI training, not tied to any specific human individual.

SYNTHETIC SPEECH

AI-generated simulated speech that clones a person's vocal characteristics to create natural sounding vocalizations. Enables voice banking, which benefits people who may lose their ability to speak later in life.

VIRTUAL REALITY (VR)

An artificial digital environment that is fully immersive and isolates users from the physical world. Users typically wear a headset with stereoscopic displays and head tracking to look around the virtual world.

METAVERSE & NEW REALITIES TRENDS

METAVERSE FORM FACTOR

METAVERSE FORM FACTOR

VR Headsets

The VR headset market is transforming, with key players refining their strategies to balance high-performance capabilities with mass-market accessibility. Apple's Vision Pro, launched in February 2024, set a new benchmark for mixed reality (MR) devices, integrating spatial computing with a $3,499 price tag—positioning itself as a premium, productivity-focused headset. Meanwhile, Meta responded with the Quest 3S in October 2024, emphasizing affordability at $299.99 and signaling a commitment to bringing XR to a broader consumer base. Sony also entered the XR race, announcing a 4K OLED microdisplay-equipped headset optimized for immersive content creation, further expanding VR's professional and creative use cases.

HTC's VIVE Focus Vision, released in September 2024, targeted enterprise and high-end gaming markets with its 5K resolution and 120Hz refresh rate, underscoring a push toward high-fidelity standalone VR experiences. At the same time, Samsung and Google revealed a strategic partnership to create an Android-based XR ecosystem, with Samsung leading headset development. This move could introduce a new platform challenger to Apple's visionOS and Meta's Quest ecosystem. The competition may also extend beyond traditional tech heavyweights—Immersed's upcoming XR visors, expected in summer 2025, indicate a shift toward lightweight, screen-mirroring headsets optimized for productivity. Additionally, rumors of the Pico 5 headset suggest ByteDance may be preparing to strengthen its presence in non-US markets, competing with Meta's Quest lineup in Europe and East Asia.

These developments illustrate the VR industry's divergence: on one hand, ultra-premium headsets aimed at professional and enterprise users; on the other, more accessible devices targeting mainstream adoption. As hardware capabilities improve, enabling better displays, lighter form factors, and expanded ecosystems, the next phase of VR will likely be shaped by competition between closed ecosystems (Apple) and open-platform approaches (Meta, Samsung, and Google). The battle for consumer and enterprise adoption will define the future of immersive computing.

Contact Lens Displays

The race to develop smart contact lenses as next-generation augmented reality (AR) interfaces accelerated in 2024, with key advancements in display technology, eye tracking, and human-machine interaction. XPANCEO has showcased multiple AR-enabled contact lens prototypes, including a model designed to enhance color perception and another for immersive 3D imaging. Meanwhile, RaayonNova filed a patent for a waveguide electro-optical display embedded directly into a contact lens substrate, enabling a wide field of view and the ability to refocus within a projected 3D frame of reference.

Scientific breakthroughs further pushed the field forward. In April, researchers from Nanjing University published a paper in Nature Communications on a frequency-encoded eye-tracking smart contact lens, which operates wirelessly without batteries or chips. This technology introduces a highly flexible, non-toxic interface for human-machine interaction, with applications in health care and AR. In August, scientists from KAIST in South Korea unveiled a method for integrating metasurfaces onto contact lenses, enabling holographic light projection through compact, biocompatible near-eye displays.

These innovations mark a fundamental shift from bulky headsets to ultra-thin, nearly invisible wearable displays. Smart contact lenses could revolutionize AR by offering a seamless, always-on interface that integrates directly into daily life. Potential applications range from health care and accessibility enhancements to immersive, hands-free computing. With a fully functional prototype expected by 2026, the next stage of AR adoption may no longer depend on glasses or headsets but on discreet, high-tech optics worn directly on the eye.

METAVERSE FORM FACTOR

Smart Glasses

Companies across the tech landscape are moving significantly toward lightweight, AI-powered, and mixed-reality eyewear. Meta finally unveiled Orion in September—its most advanced AR glasses yet—delivering immersive visuals in a sleek form factor. Meanwhile, Google and Magic Leap joined forces to co-develop AR experiences. Qualcomm signaled its intent to challenge Meta's dominance by partnering with Samsung and Google on AI-powered smart glasses that integrate with smartphones.

While quiet on product launches, Apple had a busy year at the US Patent Office. In December, it granted the company multiple patents, including an "audio privacy mode" and a smart frame system designed to align AR visuals—even during physical activity. Google's own patent filings (including one published in China) revealed a concept for advanced smart glasses featuring built-in displays, eye-tracking sensors, and voice/gesture input.

Beyond Silicon Valley, China's AR sector saw significant growth. Baidu launched AI-driven smart glasses powered by its ERNIE AI, while Xreal (formerly Nreal) secured $60M in funding and debuted its Xreal Air 2 Ultra AR glasses at CES. Rokid, another Chinese AR startup, introduced a new line of smart glasses with the eyewear brand Bolon, featuring prescription lens support.

The smart glasses market is also seeing increasing collaboration between tech and eyewear companies. Ray-Ban parent EssilorLuxottica and Meta extended their partnership into the next decade. Meanwhile, Snap Inc. launched its fifth-gen Spectacles, which are now running the new Snap OS. Industrial AR also saw momentum, with RealWear acquiring Almer Technologies and Vuzix partnering with Avegant to enhance waveguide optics.

With AI integration, advanced optics, and expanded partnerships, 2024 positioned smart glasses as the next significant wave in consumer and enterprise AR. The race to deliver lightweight, fashionable, and functional AR eyewear is intensifying.

Company	In-house Development	Partnership	Notable Features
Apple	✔	✖	Patents: Audio privacy, deformation sensors
Google	✔ Patents	✔ Magic Leap, Qualcomm	Eye tracking, voice/gesture input, phone processing
Baidu	✔	✖	Built-in AI assistant, cameras, fitness tracking
Meta	✔ Orion	✔ Ray-Ban	AI overlays, AR visuals, Ray-Ban collaboration
Magic Leap	✖	✔ Google	AI optics expertise
Qualcomm/ Samsung	✖	✔ Google	AI-powered interactions, phone integration
RealWear	✔ Acquired Almer	✖	Industrial AR smart glasses
Rokid	✔	✔ Bolon	AI, lightweight, prescription support
Snap Inc.	✔	✖	Standalone AR, Snapchat Lenses
Vuzix	✖	✔ Avegant	AI-powered waveguide optics
Zreal	✔	✖	3D sensors, computer vision

Source: FTSG Proprietary Research

AI is the missing technology that AR glasses are waiting for.

Frank Furnari, Co-founder & CEO of ARuVR

METAVERSE FORM FACTOR

Haptic Wearables

Haptic wearables enable realistic and adaptive touch feedback across gaming, XR, assistive tech, and even prosthetics. Recent breakthroughs in multi-sensory feedback, AI-enhanced haptics, and new form factors bring touch into digital interactions.

WEART's TouchDIVER Pro gloves debuted with force, texture, and thermal feedback, while Ubisoft integrated OWO's Second Skin haptic vest into video game "The Crew Motorfest," letting players feel engine vibrations and crashes. SenseGlove's Nova 2 introduced active palm feedback, making virtual object interactions more lifelike. Meta's licensing deal with Immersion Corp signals future high-fidelity haptics in Quest hardware.

Stanford's Haptiknit sleeve replaced traditional vibration with soft pneumatic pressure for immersive VR and rehab applications. Northwestern University's flexible epidermal haptic patch delivered pressure, vibration, and twisting feedback, showing promise for accessibility and prosthetics. Max Planck's silent CUTE electrohydraulic actuators expanded tactile sensations from slow strokes to heartbeat-like pulses.

dotLumen's haptic navigation glasses helped blind users "feel" spatial information through forehead vibrations, while Shape, a smart cane from Imperial College, physically bent to direct users. MIT's adaptive haptic glove recorded and replayed touch to teach skills from playing piano to operating robots. In health care, brain-computer interface (BCI) research enabled amputees with prosthetic hands to feel touch with stable, long-term precision.

Haptic tech is moving beyond XR novelty into essential applications—from AI-assisted touch interfaces to accessibility solutions. As gaming, AR/VR, and prosthetics integrate richer haptics, the ability to "feel" digital experiences becomes more seamless and intuitive.

Voice, Gesture, and Neural Interfaces

Digital interfaces, once limited to screens and keyboards, are quickly embracing AI-powered speech, neural control, and ultra-precise gesture recognition. Apple's Vision Pro set a new standard for intuitive spatial computing with hands-free, eye-tracking-based controls. Meanwhile, Volkswagen became the first automaker to integrate ChatGPT into its infotainment systems, enabling natural language voice interactions while driving.

Gesture and neural control technologies also took significant strides. Mudra Link introduced a neural wristband that translates micro-movements into precise digital inputs, while Ultraleap Helios combined neuromorphic vision with real-time micro-gesture tracking for AR interfaces. OpenBCI's Galea headset fused biosensors with VR for real-time brain-physiology insights, opening doors for cognitive-enhanced interactions. In medical advancements, Neuralink implanted its first human BCI chip, and UC Davis's brain-to-speech system achieved unprecedented accuracy for ALS patients, restoring lost voices.

AI's role in accessibility also expanded—Whispp's real-time voice conversion app empowered those with speech impairments, and Florida Atlantic University developed an AI-driven ASL translator with 98% accuracy, bridging communication gaps.

Interfaces are shifting from physical inputs to seamless, intuitive interactions—whether through voice, gestures, or even thoughts. The coming decade will redefine how humans engage with technology, making digital experiences more natural, inclusive, and immersive.

Senses In The Metaverse

Immersive technology has expanded beyond visuals and audio, bringing scent and taste into virtual environments. Kyoto-based Aromajoin unveiled two XR-compatible scent devices at CES—the Aroma Shooter Wearable, a neck-worn "scent collar" delivering rapid, on-demand fragrances, and the Aroma Speaker 60, a system

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with 60 base scents for dynamic olfactory experiences. Meanwhile, City University of Hong Kong researchers introduced a “virtual lollipop” that simulates flavors using iontophoresis, allowing VR users to taste digital content.

The 8th Digital Olfaction Society World Congress in Tokyo highlighted the growing role of smell in extended reality, showcasing applications like “digital incense” for VR meditation and custom fragrances designed for metaverse worlds. With these advancements, XR is moving toward full-spectrum immersion, where scent and taste enhance realism in gaming, training, and wellness experiences.

True immersion requires more than sight and sound. Olfactory and gustatory feedback could redefine virtual experiences—improving presence, memory recall, and even emotional engagement. From culinary VR training to therapeutic applications, the metaverse is expanding into the senses we’ve long overlooked.

Movement in The Metaverse

From digital avatars to prosthetic limbs, 2024 saw major strides in enhancing motion realism—whether in the metaverse or real life. Meta Motivo, Meta’s new AI-driven system, refined avatar movement, improving spatial awareness and embodiment in VR. Meanwhile, Roto VR introduced the Explorer chair, a motorized seat that syncs real-world rotations with VR, reducing motion sickness and increasing immersion.

Sports simulations also advanced with Rezzil’s “Premier League Player,” which leveraged actual player-tracking data to let users recreate iconic football moments in VR. Beyond virtual environments, MIT researchers achieved a historic breakthrough in prosthetic mobility. This neural-controlled bionic leg restored near-natural gait by directly linking the prosthesis to the nervous system.

As XR technologies evolve, motion fidelity is becoming crucial for immersion, accessibility, and user experience. AI-driven avatars, VR motion synchronization, and neural prosthetics contribute to a future where digital and physical movement feel seamless, intuitive, and natural.

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THE NEURAL TAPESTRY

The metaverse revolution didn't come from headsets or augmented reality glasses. It emerged from something far more intimate: the Neural Tapestry, a biotechnological breakthrough that transformed the human experience.

The Neural Tapestry is a quantum-organic mesh, a living network of engineered neurons that integrates with the human nervous system. Unlike its crude predecessors, this isn't just an interface—it's an extension of human consciousness.

The installation process is remarkably elegant: a precision-guided swarm of medical nanobots weaves the Tapestry through the nervous system, creating millions of synaptic connections. The procedure takes just hours but permanently bridges the gap between biological and digital reality.

Daily Life in 2050

Maya stretches as she wakes, her consciousness gradually tuning into the morning symphony of sensory streams. The Neural Tapestry automatically adjusts her circadian rhythms, gently transitioning her from sleep to wakefulness with a cascade of natural neurotransmitters.

Her apartment appears spartanly minimal to untapped eyes, but through the Tapestry, it's a rich landscape of interactive possibilities. She reaches out to adjust the temperature, and the Tapestry translates her intention into action, the environmental systems responding instantly to her neural commands.

During breakfast, Maya browses her messages—not by reading them, but by experiencing them. Each communication arrives as a carefully crafted sensory package. A note from her mother carries the familiar scent of home-baked bread and the warm sensation of a hug. A work update delivers itself as an intuitive understanding, complete with emotional context and priority weighting.

At work, Maya leads a team of architectural synthesists. Their latest project exists simultaneously in physical and digital space: a skyscraper that adapts its form and function based on the collective needs of its occupants. Through the Neural Tapestry, she can literally feel the building's stress points, intuitively understanding structural loads and energy flows as if they were extensions of her own body.

Team meetings transcend traditional communication. Ideas flow as shared experiences, with concepts materializing in the group's collective consciousness. Cultural and language barriers become irrelevant when meaning can be transmitted directly through sensory and emotional channels.

The Neural Tapestry has fundamentally reshaped human connection. People can share not just thoughts and feelings, but entire experiences. Memory becomes a collaborative space, with friends able to relive shared moments, complete with every sensation and emotion.

This unprecedented intimacy has led to new social norms. "Tapestry etiquette" emerges as people learn to respect mental boundaries. The ability to filter and control sensory input becomes as important as emotional intelligence was in the past.

But the Neural Tapestry's impact hasn't been without its shadows:

- **The "Untapped" minority—those who choose to remain disconnected—face increasing social and economic isolation. Some argue that authentic human experience is lost as more people opt for enhanced reality.**
- **"Neural drift" becomes a recognized condition where individuals lose their sense of physical embodiment, becoming too immersed in the expanded consciousness the Tapestry offers.**
- **Security concerns reach new heights. "Neural hackers" attempt to exploit the Tapestry's interconnectedness, leading to the emergence of "psychic firewalls" and "consciousness encryption."**

As humanity approaches the mid-21st century, the Neural Tapestry continues to evolve. Research focuses on expanding its capabilities while addressing its risks. Some theorists suggest it's just the first step toward a new phase of human evolution—a bridge between individual consciousness and collective intelligence.

Yet questions persist: Are we enhancing human experience or fundamentally altering what it means to be human? The answer lies in how we choose to weave this new reality into the fabric of our existence.

DIGITAL IDENTITY

DIGITAL IDENTITY

Avatars

Avatars are becoming more realistic, expressive, and accessible, transforming how users interact in virtual spaces. DeepBrain AI, in collaboration with Lenovo, unveiled a hyper-realistic AI avatar for a 24-year-old ALS patient, preserving her voice and enabling seamless communication. Meanwhile, NTT DOCOMO introduced a world-first generative AI system that automatically creates fully detailed NPCs (non-player characters) in the metaverse based on simple text descriptions, eliminating the need for manual design.

Meta further advanced AI-powered digital identity with a patent for personalized avatar generation from text prompts, mapping user profile data to create dynamic, custom 3D avatars. In contrast, Microsoft announced the discontinuation of its “Next Generation” Xbox Avatar Editor due to low engagement, offering refunds to users who made purchases in the past year.

Avatar realism also saw major improvements through the widespread adoption of facial tracking and AI-assisted motion. Apple’s Vision Pro introduced “Persona” avatars, which capture facial expressions and hand movements for FaceTime calls, creating a more natural digital presence. Roblox launched Roblox Connect, allowing users to animate their avatars’ faces in real-time using phone cameras. At the same time, VRChat introduced a “Selfie Expression” feature for head, eye, and face tracking using a smartphone.

Machine learning continues to refine avatar movement and response. Meta rolled out AI-powered inside-out body tracking on Quest headsets, using onboard cameras and inference models to create natural full-body motion, even without external trackers. In late 2023, Meta’s Avatar SDK introduced virtual legs, using “Generative Legs” AI to animate lower-body movements dynamically. Alongside graphical upgrades such as lifelike eye reflections and improved hair and clothing textures, these advancements solved the long-standing issue of avatars appearing as floating half-bodies in VR.

Avatar Portability

As the metaverse expands, avatar interoperability is becoming a priority. Key players are moving toward standardization and cross-platform compatibility, enabling users to maintain persistent digital identities across virtual spaces. The VRM Consortium partnered with the Khronos Group to integrate the VRM avatar format into glTF 2.0, establishing a universal, platform-independent avatar file format. This shift promotes seamless movement between virtual worlds, supporting a more interconnected metaverse.

Ready Player Me reinforced this trend with its PlayerZero initiative, a Web3-driven system for cross-platform avatar collectibles. By October 2024, PlayerZero had recorded more than 81,000 Collection ZERO wearable mints, with integration into 15+ games. Meanwhile, Meta announced a major avatar overhaul at Connect 2024, introducing more expressive, high-fidelity avatars to unify its metaverse ecosystem.

A standardized, cross-platform avatar system is essential for a unified metaverse. The industry is moving toward persistent digital identities, allowing users to seamlessly navigate between VR, AR, and traditional platforms with a single avatar. As AI-driven realism improves, virtual personas will become an increasingly natural extension of self-representation in digital spaces.

Hyperrealistic Avatars

Advances in rendering, AI, and XR technology are bringing photorealistic avatars closer to everyday use. EON Reality unveiled Photorealistic XR Avatars, which replicate human facial features, expressions, and gestures with remarkable accuracy, making them appear “genuinely alive” in virtual spaces.

Meta’s Codec Avatars also took a major step forward, gaining public attention after a high-profile podcast where Mark Zuckerberg and Lex Fridman held a conversation entirely as photorealistic avatars. The response was overwhelmingly

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positive, signaling strong demand for near-real digital presence. Meta is also developing lower-fidelity photoreal avatars, using neural networks to generate lifelike 3D faces from just a smartphone depth camera, making high-quality avatars more accessible.

Meanwhile, Roblox is pushing beyond static avatars with its 4D generative AI, an initiative to create not only detailed 3D models but also dynamic behaviors and interactions—effectively automating the creation of lifelike virtual characters. These advancements hint at a future where digital personas move, react, and express emotions as fluidly as real humans.

As photorealistic avatars become more accessible, they will transform social VR, virtual meetings, gaming, and even digital identity preservation. The ability to create and control lifelike digital doubles could redefine human interaction in the metaverse, making virtual presence nearly indistinguishable from reality.

Leasing Identity

Celebrities are embracing AI avatars to extend their influence into digital spaces, blurring the lines between real and virtual presence. Meta introduced AI-driven versions of Charli D'Amelio and Kendall Jenner, allowing fans to interact with digital replicas of these stars. Similarly, Singaporean actors Gurmit Singh, Li Nanxing, and Vivian Lai collaborated with a startup to create their own AI avatars, enhancing fan engagement.

Platforms like Genies continued to dominate the celebrity avatar space, with Paris Hilton, Migos, Justin Bieber, Shawn Mendes, Rihanna, and Cardi B using digital personas to engage with audiences in new ways. Meanwhile, the advertising industry adapted to AI-driven voices, with a new union agreement allowing actors to approve AI voice replicas for audio ads.

The legal landscape around AI likenesses also evolved. Anil Kapoor won a landmark case in India, securing control over his AI-generated image and voice. Chloe Amour sold the rights to her digital likeness, creating an AI version of herself to interact with fans. In posthumous AI usage, Alain Dorval's family authorized an AI-generated replica of his voice for Sylvester Stallone's film "Armor," preserving his legacy even after his passing.

AI-generated celebrity avatars are already transforming fan interactions, marketing, and entertainment. As legal protections emerge alongside commercial opportunities, the debate over digital ownership, authenticity, and identity rights will only intensify.

Synthetic Speech

AI-powered text-to-speech (TTS) and voice synthesis have significantly improved real-time multilingual speech, content localization, and creative applications. Japan's National Institute of Information and Communications Technology introduced a neural TTS system capable of synthesizing speech in 21 languages. Optimized for efficiency, this model generates one second of speech in just 0.1 seconds on a single CPU core, making it ideal for real-time applications on mobile devices and embedded systems.

AI voice cloning also saw rapid adoption. Amazon's Audible launched a beta program that allows select narrators to create AI replicas of their voices, enabling synthetic narration for audiobooks while maintaining the original speaker's tone and style. Meanwhile, Pheme, an advanced AI speech model, demonstrated the ability to generate high-quality, conversational speech in parallel, using compact datasets to enhance efficiency.

Multilingual AI dubbing expanded as ElevenLabs introduced support for more than 28 languages, allowing automatic translation while preserving the original speaker's voice, emotions, and intonation. This development streamlines content localization for global media, reducing the need for traditional dubbing processes. In creative industries, Respeecher, a Ukrainian speech synthesis company, continued refining its technology, allowing one person to speak

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in another's voice. Their AI-driven voice replication has been used in film and television to bring historical figures' and late actors' voices back to life, enriching storytelling and deepening audience engagement.

The ability to synthesize, clone, and translate speech with high fidelity is transforming industries from entertainment to accessibility. AI-generated voices are enhancing audiobook production, expanding multilingual media, and even recreating voices from the past. As AI voice models improve in realism and efficiency, they will redefine how people interact with digital content, breaking language barriers and revolutionizing communication.

Synthetic Personalities

AI-powered avatars are becoming intelligent, interactive, and autonomous. ESPN unveiled FACTS, a generative AI avatar tested on its SEC Nation show, delivering real-time sports analytics and engaging fans with data-driven insights during broadcasts. Meanwhile, the University of Cincinnati in partnership with Kinetic Vision introduced Lucy, an AI-powered avatar that can assist users in navigating the university's tech transfer offerings, demonstrating AI's growing role in business and academic engagement.

Beyond user-controlled avatars, AI-driven NPCs (non-player characters) advanced in realism and autonomy. Generative animation models now allow virtual characters to move, gesture, and interact convincingly without direct human input, making digital interactions feel increasingly like face-to-face conversations. In gaming, Inworld AI—a startup partnered with Ubisoft—and other platforms introduced AI NPCs capable of responding to voice or text, engaging in unscripted conversations, and exhibiting lifelike behaviors. These advancements bring virtual worlds closer to full immersion, where AI-driven personalities adapt and respond dynamically rather than following pre-scripted interactions.

AI-powered avatars and NPCs are reshaping entertainment, education, and digital interactions. Whether enhancing live sports broadcasts, streamlining tech transfer processes, or creating lifelike NPCs in games, AI is making digital entities more engaging and intelligent. As realism continues to improve—from photorealistic rendering to nuanced body language—AI avatars will play a larger role in virtual economies, interactive media, and personalized digital experiences.

Human Digital Twins

Advancements in AI and generative technology are making digital avatars more lifelike and personalized, bringing us closer to true human digital twins. In November 2024, researchers used cutting-edge voice reconstruction to recreate the speech of King Richard III, giving the 15th-century monarch a historically accurate Yorkshire accent. This project combined expertise from speech therapy, forensic psychology, archaeology, and dentistry to digitally restore a lost voice, showcasing how AI can resurrect historical figures with unprecedented realism.

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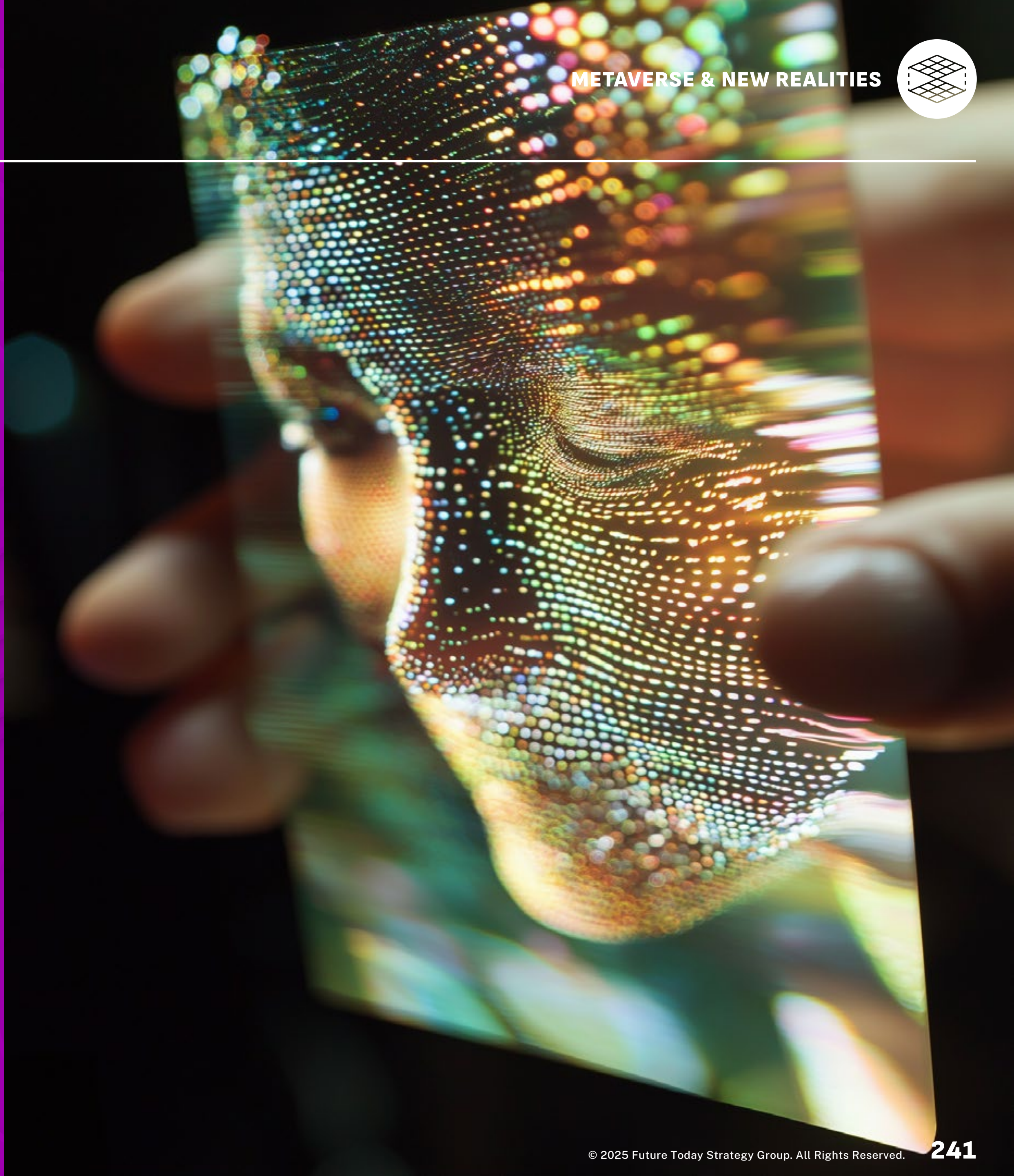
Meanwhile, Meta overhauled its metaverse avatars in September 2024, introducing advanced customization options—including adjustable eye size, nose shape, and body types—across Meta Horizon OS, Facebook, Instagram, and Messenger. This update enhances self-expression by enabling more precise digital self-representation. At GDC 2024, Roblox unveiled a generative AI-based character creator capable of designing avatar bodies and clothing from text descriptions or learned user preferences, simplifying customization and personalizing virtual identities at scale.

Ready Player Me is also pushing the boundaries of AI-powered avatars, allowing users to generate a 3D avatar from a single selfie. Its system, used across thousands of apps, automatically predicts facial features and maintains visual consistency across games, reducing the time developers spend on character creation while ensuring users retain a unified digital identity.

As digital twins become more advanced, the way we represent ourselves in virtual spaces is changing. AI-driven avatar customization, historical voice recreation, and generative character design are creating more accurate, expressive, and immersive digital identities. Whether preserving history, enhancing gaming, or personalizing social media, human digital twins are shaping the future of virtual presence.



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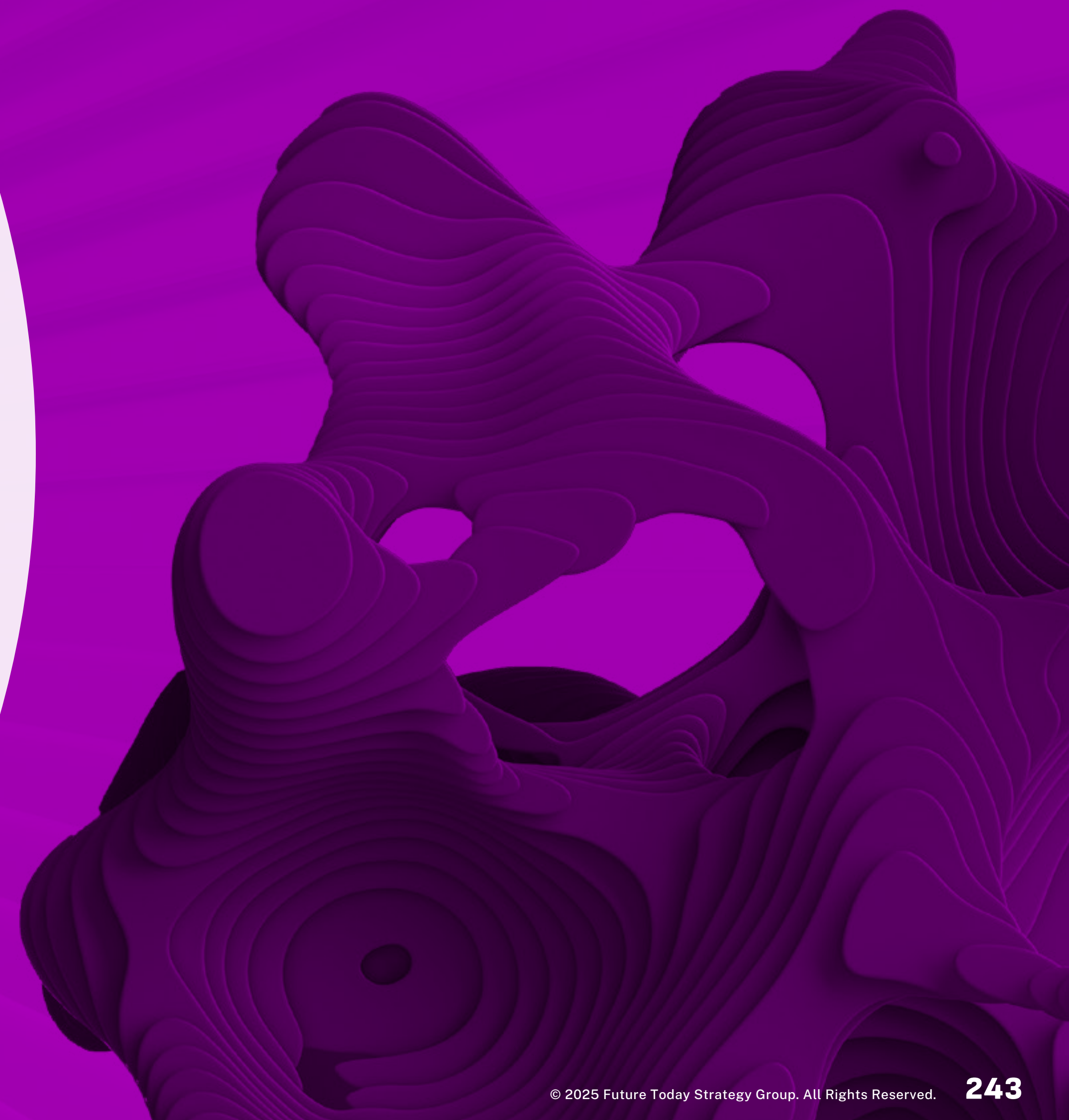
HYPERREAL CONNECTIONS

By 2030, businesses reliant on strong interpersonal connections are navigating a landscape radically transformed by advancements in avatar technology, synthetic speech, and AI personalities. Hyperrealistic avatars, capable of mirroring subtle emotions and personal mannerisms, are ubiquitous, offering photorealistic digital doubles for professionals and clients alike. These avatars are increasingly powered by AI, enabling personalization at scale and adapting to the nuances of individual conversations, with Meta and others developing systems for personalized avatar generation from text prompts. Synthetic speech has reached a point of near perfection, capable of replicating voices, translating languages in real-time while maintaining emotional tone, and even generating entirely new voices tailored to specific brands or individuals. The rise of autonomous NPCs (non-player characters), powered by sophisticated AI-enabled unscripted conversations and lifelike interactions, is further blurring the lines between the physical and digital realms, showcased by NTT DOCOMO's AI system and Inworld AI's work with Ubisoft. Avatar portability has become a reality as key players like the VRM Consortium and Ready Player Me moved toward standardization and cross-platform compatibility, enabling users to maintain persistent digital identities across virtual spaces. Celebrities have been embracing AI avatars to extend their influence into digital spaces for years, as demonstrated by Meta's AI-driven versions of celebrities and Genies' dominance in celebrity avatar space. AI-driven voices also impacted the advertising industry, although legal landscapes are still evolving around AI likenesses, highlighted by cases like Anil Kapoor's. These technologies have transformed how companies interact with customers, train employees, and build relationships, presenting both unprecedented opportunities and complex ethical considerations.

The opportunities for businesses are vast. Today, companies achieve global scalability by leveraging AI to deliver personalized coaching and training programs in any language, anywhere in the world. Enhanced personalization is possible through AI-driven individual needs and preferences analysis, leading to more impactful and engaging experiences. Data-driven insights from avatar interactions help identify patterns, measure engagement, and optimize strategies. New revenue streams emerge from premium services like digital twin creation, AI-powered assistants, and immersive training simulations. However, to get to this point significant challenges had to be addressed. Maintaining authenticity is crucial in hyperreal simulations, requiring a clear distinction between human and AI interaction. The threat of deepfakes and misinformation necessitated robust security measures and education. Addressing the digital divide was essential to ensure inclusivity and accessibility for those without access to advanced VR/AR technology. Navigating the evolving legal and regulatory landscape surrounding digital ownership, AI-generated content, and data privacy was an ongoing imperative. To succeed in this transformed environment, business leaders have to invest in AI literacy, experiment with pilot programs, prioritize ethical considerations, foster human-AI collaboration, and remain informed and adaptable. Ultimately, success hinges on balancing leveraging technological advancements and preserving the core values of human connection, trust, and authenticity.



METAVERSE IN INDUSTRY

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Virtual Training For Real-World Jobs

Virtual reality (VR) and AI-driven digital humans are reshaping corporate training, allowing employees to develop skills in immersive, risk-free environments. In one recent example, Cornerstone OnDemand launched Immerse Companion, a generative AI platform featuring virtual human companions that provide interactive coaching. Employees can practice sales pitches, negotiations, and customer interactions with an AI avatar that role-plays and delivers real-time feedback.

Across industries, major enterprises are leveraging VR for workforce development. BMW trains employees in design, prototyping, and lean manufacturing principles, while Volkswagen uses VR simulations for assembling vehicle components, reducing the need for physical travel. In the financial sector, Bank of America implemented VR for onboarding and customer service training, while Walmart and Lowe's use VR to enhance customer service and management skills. Pfizer has a 3D cube that enables scientists to walk in and virtually explore molecules. Johnson & Johnson offers VR-based surgical training, allowing surgeons to practice complex procedures before operating on real patients. UPS has integrated VR into driver training, simulating challenges like navigating busy streets and handling aggressive dogs. Similarly, Delta Air Lines uses VR to train flight attendants in emergency response procedures, ensuring preparedness for real-world crises.

The industrial sector has also embraced VR training. Siemens uses the technology to train workers in offshore wind turbine installations, Alcoa uses it to focus on equipment safety, and UPS uses it to teach package stacking and field safety. By simulating high-risk environments, these companies enhance learning while minimizing workplace hazards.

VR and AI-driven avatars are making corporate training more interactive, scalable, and effective. Employees can practice critical tasks in realistic virtual environments, reducing training costs, improving retention, and increasing workplace safety. As AI avatars become more sophisticated, virtual coaching and role-playing will further transform professional development across industries.

True-To-Reality Simulations

Virtual environments are evolving to offer highly realistic and functional simulations, bridging the gap between digital and physical interactions. In October 2024, Meta filed a patent for a virtual space configuration system that customizes artificial reality environments based on user posture. This technology dynamically adjusts virtual space settings for seated users, altering floor height, adapting application mechanics, refining virtual boundaries, and enabling passthrough workspace interactions. These advancements bring VR closer to real-world usability, allowing seamless transitions between seated and standing interactions without breaking immersion.

Beyond system-level enhancements, AI-driven avatars are redefining simulations in professional training. EY's "eVe", an AI-powered avatar introduced in November 2024, offers job candidates metaverse-based interview preparation, mimicking real-world hiring scenarios with responsive AI interactions. This marks a shift toward AI-driven, immersive job training and assessment.

The retail industry is also leveraging true-to-reality simulations to enhance customer engagement. Valentino Beauty's New York pop-up featured a smart mirror that allowed visitors to virtually try on products, blending physical retail with interactive digital experiences. Meanwhile, IKEA launched a virtual store in Roblox, hiring real employees to staff the digital space. This initiative demonstrated how virtual commerce can replicate in-person shopping experiences, offering interactive and service-driven engagement in the metaverse.

The ability to tailor virtual spaces to user posture, conduct AI-driven training in metaverse settings, and integrate digital simulations into retail signals a shift toward

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hyper-realistic virtual experiences. These advancements make virtual environments more practical, accessible, and purpose-driven, unlocking new possibilities for education, commerce, and daily interactions.

Industrial Digital Twins

Industrial digital twins are transforming operations across sectors by providing real-time, AI-driven simulations of complex systems. These virtual models enhance predictive maintenance, optimize efficiency, and reduce costs by allowing engineers to test scenarios and anticipate failures before they happen.

In the UK, Northumbrian Water launched a £20M smart sewer initiative using a real-time digital twin of its wastewater network. Integrated with hundreds of IoT sensors, the twin simulates water flow under various conditions and forecasts where overflows may occur. When heavy rain is predicted, the system "runs ahead" of the live network, suggesting how to reroute or balance flows to prevent flooding and spills. This AI-powered approach enables proactive sewer management, reducing storm overflows and protecting rivers and coasts at a fraction of the cost of traditional infrastructure upgrades. The initiative is a first-of-its-kind in the UK water industry, pioneering the use of digital twins for environmental protection.

Shell, in collaboration with Kongsberg Digital, developed an interactive 3D digital twin of its offshore platforms and plants called the Industrial Work Surface. This system integrates real-time operational data, IoT sensors, and AI analytics, allowing engineers to navigate a virtual model of the facility to monitor equipment health, analyze process data, and run "what-if" simulations. The twin predicts equipment failures, such as when a critical pump or compressor might go out, enabling proactive maintenance and preventing costly shutdowns. By improving decision-making speed and operational awareness, Shell has enhanced offshore safety, reduced unplanned downtime, and optimized workflows for greater cost-efficiency.

Airbus employs a high-fidelity digital twin of its A350 XWB aircraft, continuously ingesting flight and sensor data to track fuel consumption, engine performance, and component health. Engineers and airline operators use this virtual model to simulate different flight conditions and optimize performance. The impact has been substantial: Airbus has greatly reduced its fuel consumption and emissions, saving 1,250 tonnes of CO_2 and 3.65 GWh of energy annually. Additionally, Rolls-Royce, which supplies the A350's engines, leverages twin data for predictive maintenance, ensuring proactive repairs and preventing unexpected failures. The system also provides valuable feedback to Airbus for refining future aircraft designs, making the A350 program more efficient and sustainable.

Industrial digital twins bridge the physical and digital worlds, allowing real-time monitoring, predictive maintenance, and optimization across critical infrastructure, energy, and transportation. These AI-powered systems reduce downtime, lower costs, and improve sustainability, making industries more resilient and efficient in the face of increasing complexity.

Medical Metaverse

The integration of XR and AI into health care is accelerating, reshaping patient care, surgical precision, and medical education. The Cleveland Clinic's "Zen Quest" on Roblox exemplifies how gaming platforms are becoming tools for mental health interventions, offering guided relaxation exercises in virtual spaces. Meanwhile, Apple Vision Pro headsets are enhancing surgical outcomes at the University of California, San Diego, by overlaying critical data directly into a surgeon's field of view, minimizing distractions and improving precision.

Rehabilitation is also evolving through brain-computer interfaces (BCIs). Australian company Synchron's device enables paralyzed patients to interact with digital environments via brain signals, demonstrating the potential of minimally invasive neurotechnology. Similarly, VR is fostering

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empathy in health care through immersive storytelling. Experiences like Emperor, which simulates aphasia, are being explored for medical training and therapy.

Beyond patient care, medical training is advancing through platforms like Virti, which leverages XR and AI for interactive learning. These tools are already being implemented globally by institutions such as Cedars-Sinai and the NHS. Meanwhile, 3D-printed prosthetics and game-based rehabilitation therapies pioneered in Israeli medical centers, such as Sheba Medical Center, highlight how innovations designed for conflict-related injuries can extend to civilian health care applications. The metaverse's role in medicine is expanding, signaling a future where digital and physical health care systems are seamlessly integrated.

Education In The Metaverse

Immersive technologies are revolutionizing education, bringing AI-driven avatars, virtual field trips, and realistic simulations into classrooms and training programs. AI-powered mentors like Sofia from EON Reality now personalize learning experiences, dynamically responding to student input. Meanwhile, schools such as Cholla High in Arizona are using VR for cultural experiences, enabling students to explore Indigenous art and history in 360° environments. Greensboro Middle School's AR/VR lab, funded by the Air Force, is another example of immersive STEM education reaching underserved communities, making abstract concepts tangible.

Special education is also benefiting. Spaulding Academy utilizes VR to create personalized learning scenarios, helping students with autism practice social skills or engage with interactive science lessons at their own pace. At the university level, VR is transforming archaeology at Indiana University through Yorescape, allowing students to walk through ancient cities as they once were. Similarly, New Zealand's University of Canterbury is training early childhood educators using VR and haptic gloves to simulate infant care, ensuring teachers develop practical caregiving skills before handling real infants.

Other fields are embracing immersive training. The University of Utah's mining program leverages VR for hazard response training, reducing real-world risks. Parker University's metaversity offers a digital twin of its campus, enabling remote students to engage in virtual labs and classrooms with real-time interaction. Meanwhile, Catawba College's Dreamscape Learn turns biology into a cinematic, story-driven adventure, increasing student motivation and understanding. As these technologies scale, the metaverse is poised to redefine education, making learning more experiential, accessible, and effective.

Synthetic Media in Hollywood

Hollywood is undergoing a seismic shift as AI-driven synthetic media reshapes how films are made, edited, and even acted. Robert Zemeckis' "Here" marked a major milestone by using Metaphysic's AI deepfake technology to age and de-age Tom Hanks and Robin Wright in real-time on set. This eliminated the need for extensive prosthetics and months of VFX work, allowing Zemeckis to see final shots live as he filmed. The director noted that such a production would have been impossible just a few years ago. However, this efficiency has raised concerns about the future of VFX jobs and the role of human craftsmanship in post-production, fueling discussions in 2024's union negotiations about AI's impact on the industry.

AI isn't just altering actors' appearances—it's resurrecting them. "Furiosa" used AI face-swapping to bring back Richard Carter's Mad Max character, mapping the late actor's digitally reconstructed face onto a stand-in's performance. "Alien: Romulus" reportedly applied similar technology to bring back Ian Holm's android character from the 1979 original. These developments have sparked intense ethical and legal debates, leading California to pass legislation requiring estates' explicit consent for AI-generated performances of deceased actors. Some performers, like Robert Downey Jr., have even preemptively barred AI versions of themselves after death. Despite concerns, AI-driven recreations are opening new storytelling possi-

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bilities—allowing long-dead historical figures or beloved characters to return to the screen in ways previously unimaginable.

Meanwhile, AI-generated filmmaking is becoming a reality. Indie creator Hooroo Jackson's “DreadClub: Vampire's Verdict” was constructed from more than 17,000 AI-generated images, with all visuals, performances, and even music synthesized by AI. The entire film was produced for just $405—compared to the typical $1-2 million cost of an animated feature. Similarly, AiMation Studios released “Where the Robots Grow,” another fully AI-animated film, showcasing how small teams (or even a single person) can use AI to create content at a fraction of the time and cost. While these films demonstrate AI's potential to democratize filmmaking, they also highlight its current limitations—early AI-generated films have been met with mixed reviews, with critics noting the lack of emotional depth and coherence in storytelling.

AI-generated audio also emerged as a powerful new tool in Hollywood. The Robbie Williams biopic “Better Man” used AI to generate Williams' voice for a surreal animated chimpanzee version of the singer. In National Geographic's “Endurance,” AI resurrected the voice of Antarctic explorer Sir Ernest Shackleton, training on century-old gramophone recordings to synthesize an eerily realistic narration of his own journal entries. This technology allows actors to dub themselves in multiple languages without re-recording and lets filmmakers use historical figures' voices in new contexts. AI voice synthesis also streamlines production—allowing for dialogue replacement without requiring actors to return to set. However, this advancement raises concerns about consent and authenticity, as studios rush to establish legal guidelines for AI voice replication.

As Hollywood embraces synthetic media, the industry is navigating an uncertain future. AI promises lower costs, faster production, and expanded creative possibilities, but it also threatens traditional roles in visual effects, animation, and voice acting. While some filmmakers see AI as an augmentation tool rather than a replacement, others worry about a future where AI-generated films dominate, reducing the human touch in storytelling. As studios, unions, and lawmakers scramble to define ethical boundaries, one thing is clear: AI is no longer just a futuristic concept in Hollywood. It is already reshaping the industry in real-time.

Forensic AR/VR

Augmented and virtual reality are reshaping forensic science, law enforcement, and legal proceedings. In October 2024, the Bavarian State Criminal Police Office partnered with HTC VIVE to develop the Holodeck, a VR platform that creates photorealistic 3D reconstructions of crime scenes. Investigators, forensic analysts, and prosecutors can now simultaneously immerse themselves in crime scenes without disturbing physical evidence, testing hypotheses and analyzing details collaboratively. This innovation enhances crime scene preservation and could expand into police training applications.

VR is also changing how courts handle evidence. In December 2024, a Broward County, Florida judge used an Oculus Quest 2 headset to virtually step into a crime scene during a stand-your-ground hearing—believed to be the first time immersive VR evidence was presented in a US courtroom. The simulation, created by a forensic artist, placed the judge in the defendant's perspective, allowing for a deeper understanding of spatial relationships and incident dynamics. Legal experts predict this could set a precedent for VR-based evidence, potentially transforming how judges and juries experience complex crime scenes.

Beyond physical crimes, law enforcement is now investigating virtual offenses. In January 2024, UK police began investigating an unprecedented case—the alleged virtual rape of a 16-year-old girl's avatar in a metaverse game. Officers are treating this as a serious sexual offense, analyzing server logs, chat records, and suspect accounts much like a real-world crime. This case has sparked debate over jurisdiction, victim trauma, and the responsibility

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of tech companies to implement better safeguards. Meanwhile, in the UAE, Sharjah Police introduced Virtual Reality Radar, an AI-driven monitoring tool designed to detect cyberbullying and harassment in metaverse environments. Using machine learning, the system scans virtual interactions, flags harmful behavior, blocks malicious content, and generates real-time reports for investigators, demonstrating how law enforcement can extend their reach into digital spaces.

AI is also accelerating traditional forensic investigations. In April 2024, the police department in Warner Robins, Georgia deployed Cybercheck, an AI-powered digital forensics tool that scours the surface web, deep web, and dark web for relevant case data. It compiles extensive suspect profiles by analyzing social media activity, online interactions, cryptocurrency transactions, and hidden connections. The system has already contributed to hundreds of breakthroughs in homicide, missing persons, and child exploitation cases. As forensic AR, VR, and AI evolve, law enforcement is gaining powerful new tools to investigate both physical and digital crimes, ushering in a new era of high-tech policing.

Metaverse-Enhanced Science

VR and AR are revolutionizing scientific research, enabling immersive exploration of brain function, cellular biology, and molecular structures. Neuroscientists are using VR simulations to study cognitive processes in real-time, recreating complex scenarios to observe neural responses under controlled conditions. This approach provides unprecedented insight into brain activity, enhancing studies on memory, decision-making, and neurological disorders. By eliminating real-world variability, VR experiments allow for precise data collection, improving the reproducibility of cognitive and behavioral research.

In cellular biology, generative AI is accelerating drug discovery and genetic research through AI-powered virtual models of human cells. These simulations replicate cellular behavior, allowing scientists to predict drug interactions, understand mutations, and test experimental treatments without physical lab work. This in silico experimentation reduces research costs and expedites breakthroughs by providing a dynamic testing ground for new therapies. Meanwhile, molecular biologists are adopting Gaussian splatting, a cutting-edge 3D capture technique, to visualize intricate molecular interactions. This technology generates highly detailed biological models, offering deeper insights into protein folding, enzyme activity, and drug-target interactions—advancing structural biology and the development of precision medicine.

The integration of immersive technologies into scientific research is bridging the gap between theoretical models and practical experimentation. By leveraging VR, AI-driven simulations, and high-fidelity 3D modeling, researchers are uncovering new dimensions of biology and neuroscience. As these tools evolve, the metaverse is poised to become a fundamental platform for scientific discovery, transforming how researchers visualize, analyze, and manipulate the building blocks of life.

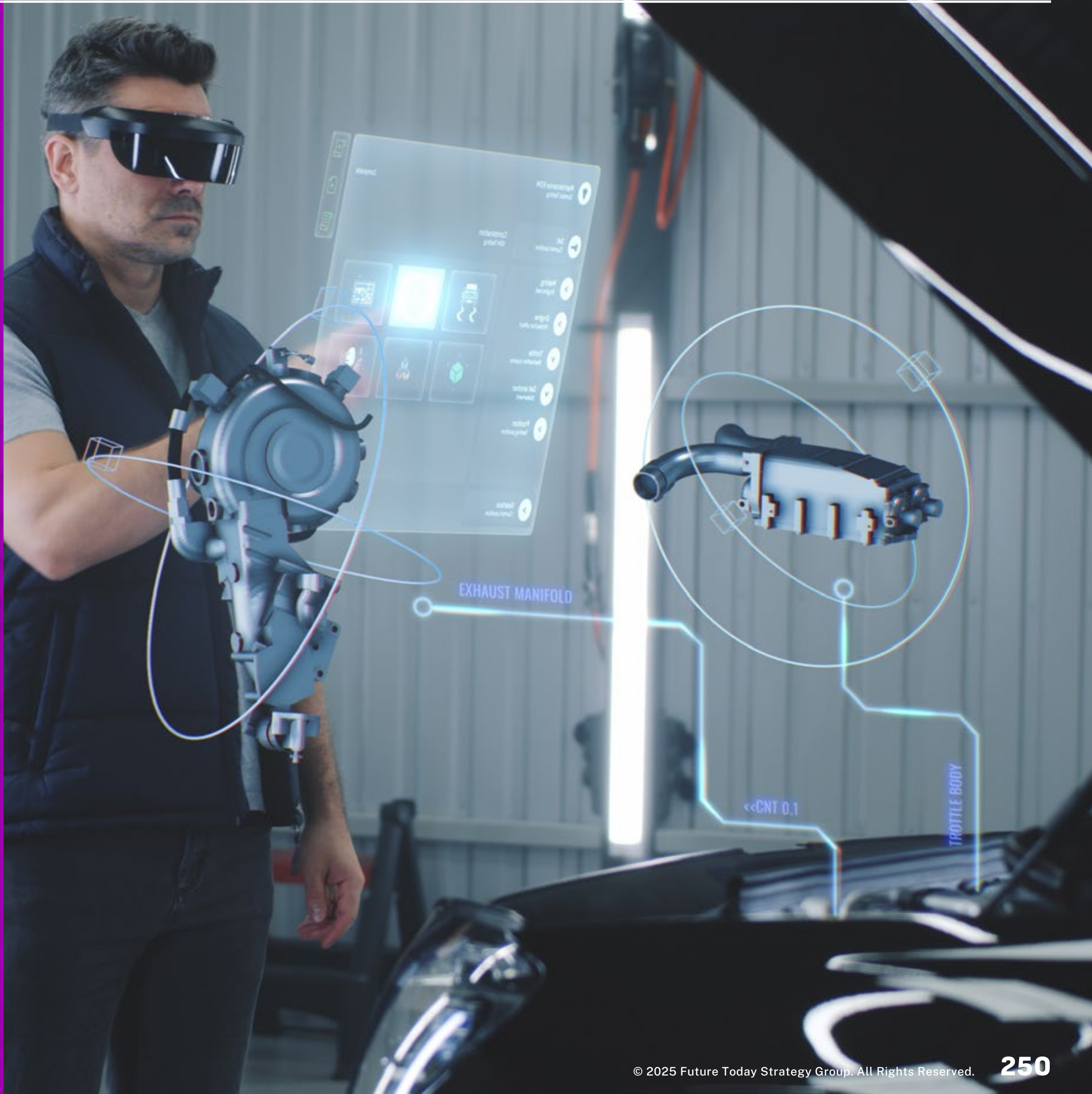
METAVERSE IN INDUSTRY

Metaversal Automotive Development

Automakers are leveraging digital twins, virtual reality, and AI-driven assistants to streamline manufacturing, enhance vehicle design, and improve customer experiences. In one leading example, BMW built a full digital twin of its new electric vehicle plant in Debrecen, Hungary, before breaking ground. Partnering with Nvidia and T-Systems, BMW created a virtual replica of the factory—including its production lines and worker operations—allowing for real-time process optimization. And BMW expects its bet to pay off: by identifying inefficiencies before construction, the company predicts a 30% boost in production planning efficiency, minimizing costly delays and accelerating the plant's launch. The factory, set to produce 150,000 electric cars annually, represents a shift toward fully virtualized manufacturing environments.

Beyond production, automakers are integrating virtual and augmented reality into customer engagement and vehicle interaction. Nissan launched the Heritage Cars & Safe Drive Studio on VRChat, where users can explore classic Nissan vehicles and participate in traffic safety education through an immersive metaverse platform. Meanwhile, Mercedes-Benz unveiled an enhanced MBUX Virtual Assistant in its new CLA model, powered by Google Cloud's Automotive AI Agent. This system offers real-time information and advanced conversational capabilities, integrating augmented reality for navigation and vehicle diagnostics.

Automotive design is also evolving through VR collaboration. Ford's Australia Design Studio has adopted immersive VR workspaces, allowing engineers, designers, and developers to interact with 3D vehicle models in real time from anywhere in the world. This virtual design approach accelerates decision-making, reduces physical prototyping costs, and fosters global collaboration. As automakers continue investing in metaverse technologies, digital twins, AI, and VR will increasingly define the future of vehicle manufacturing, design, and user experience.



SCENARIO YEAR 2035

THE INDUSTRIAL NERVOUS SYSTEM

By 2035, the metaverse has evolved from a consumer-focused novelty into the central nervous system of industrial operations. Driven by advancements in AI, digital twins, and XR technologies, it isn't just about visualization but control, optimization, and resilience. The industrial metaverse isn't a single, unified platform but a mesh of interconnected virtual environments tailored to specific needs.

Every major industrial asset, from wind farms and power plants to manufacturing facilities and logistics networks, has a fully realized, real-time digital twin residing within the metaverse. These twins are no longer static models, but living simulations constantly updated with data from IoT sensors, edge computing devices, and AI analytics. Drawing on the success of early initiatives like Northumbrian Water's smart sewer digital twin, these systems "run ahead" of the real world, predicting failures, optimizing performance, and simulating the impact of changes before they are implemented, helping to preempt environmental disasters.

The industrial workforce of 2035 operates seamlessly between the physical and virtual realms. Technicians use AR overlays on smart glasses to guide them through complex maintenance procedures, overlaying schematics, diagnostic data, and even real-time guidance from remote experts. Drawing on early successes in virtual training, manufacturing, and production, companies use sophisticated VR simulations to train new employees, allowing them to practice hazardous tasks and refine skills in a risk-free environment. These simulations also include AI-driven avatars for interactive coaching, providing personalized feedback in real-time, and increasing employee engagement and retention.

The metaverse has become the orchestration layer for global supply chains. AI-powered avatars facilitate real-time collaboration between suppliers, manufacturers, and distributors, allowing them to visualize and optimize the entire flow of materials and products. Drawing on early examples of automotive companies using VR workspaces to design and engineer vehicles collaboratively, these virtual environments enable faster decision-making, reduce waste, and enhance resilience in the face of disruptions.

Expert knowledge has become democratized through the metaverse. Senior engineers and subject matter experts create AI-driven digital twins of themselves, effectively capturing and disseminating their expertise to a broader audience. Recalling AI avatars from early education programs, these “expert bots” can answer questions, provide guidance, and even troubleshoot problems remotely, reducing the reliance on scarce human expertise and accelerating knowledge transfer within organizations.

But the growing reliance on the industrial metaverse has created new security vulnerabilities. Protecting these virtual environments from cyberattacks and data breaches is now paramount. Industrial organizations invest heavily in blockchain-based authentication systems, AI-driven threat detection, and secure communication protocols to safeguard their critical infrastructure. Forensics has extended into the virtual realm. Law enforcement agencies have virtual reality radar: AI-driven monitoring tools designed to detect cyberbullying and harassment in metaverse environments.

The pervasive integration of the metaverse into industrial operations has also raised profound ethical questions. Concerns about data privacy, algorithmic bias, and the potential displacement of human workers have to be carefully addressed. Organizations have developed ethical guidelines for AI development and deployment, ensuring transparency, accountability, and fairness in their metaverse initiatives.

A subtle but profound shift has occurred. The line between the digital twin and the real-world asset has blurred to the point where it is sometimes difficult to distinguish between them. Decisions are increasingly made within the metaverse, with the physical world simply acting as the executor of those virtual directives. This raises philosophical questions about the nature of reality, the locus of control, and the potential for unintended consequences when the virtual world assumes primacy over the physical.

The industrial metaverse of 2035 is a powerful tool but also a complex and potentially destabilizing force. Its success depends not only on technological advancements but also on a thoughtful and ethical approach to its development and deployment. The challenge is to harness its potential while mitigating its risks, ensuring that it serves humanity’s best interests.

PSYCHOSOCIAL DYNAMICS AND INCLUSIVITY IN THE METAVERSE

PSYCHOSOCIAL DYNAMICS AND INCLUSIVITY IN THE METAVERSE

The Panopticon

Surveillance technology is increasingly shaping public and private spaces, driving behavioral changes as individuals self-regulate under the assumption of being watched. During the 2024 Paris Olympics, authorities implemented AI-powered video monitoring at an unprecedented scale, sparking debates about normalizing such surveillance beyond large-scale events. Concerns grew over whether these measures would persist post-Games, reinforcing a society where constant observation influences behavior. Similarly, a Federal Trade Commission report exposed the extent of social media and video streaming surveillance, revealing platforms' extensive data collection, and that they often retain vast amounts of user and non-user information indefinitely. The knowledge of this persistent tracking leads individuals to modify their online behavior, making them aware that their activities are being monitored.

Corporate surveillance is also expanding, as highlighted by a lawsuit against Apple accusing the company of enforcing employee monitoring through internal software on personal iPhones. The case raises concerns about workplace surveillance and its impact on employees' autonomy. Meanwhile, government surveillance powers have been reinforced with the reauthorization of Section 702 of the Foreign Intelligence Surveillance Act under the Reforming Intelligence and Securing America Act. This legislative action broadened the government's ability to collect international communications, prompting some individuals to self-censor due to the risk of surveillance.
At the state level, New York proposed legislation requiring surveillance cameras in various public and private spaces, including for-hire vehicles and public litter baskets, further entrenching the presence of surveillance in everyday life. As corporate, governmental, and event-based surveillance expands, privacy expectations are being redefined, and self-censorship is becoming an implicit societal norm.

PSYCHOSOCIAL DYNAMICS AND INCLUSIVITY IN THE METAVERSE

Metaverse Accessibility

Collaborative initiatives are redefining accessibility in mixed reality, ensuring that emerging technologies serve diverse user needs. In one project, Meta worked with both people with disabilities and accessibility advocates to co-design new products. This approach allowed them to prioritize real-world experiences, grounding product development in authentic user requirements. And as an additional benefit, as seen in the "curb-cut effect," features designed for specific groups—such as improved navigation tools—can enhance usability for all. By fostering trust and mutual respect through co-design, Meta is strengthening community ties and ensuring that underserved populations are considered in product development.

Beyond corporate efforts, the Metaverse Standards Forum's "Accessibility in the Metaverse" working group is setting industry-wide guidelines to make virtual environments more inclusive. The group focuses on identifying potential accessibility risks, recommending best practices, and addressing the needs of disabled content creators and developers, ensuring that accessibility extends beyond end-users to those building the metaverse. Meanwhile, CES 2024 showcased groundbreaking assistive technologies. Those included AR glasses with real-time closed captioning for the hearing impaired, as well as navigation aids for the visually impaired that provide auditory spatial guidance, increasing independence and safety.

Academic research is also shaping the conversation, emphasizing the need for disabled creatives to be actively involved in metaverse development. Scholars propose leveraging VR and AR alongside IoT to create more engaging, accessible platforms. These frameworks highlight how inclusive design not only benefits disabled users but also enhances digital spaces for all, reinforcing accessibility as a fundamental principle of the evolving metaverse.

Diminished Sensory Overload

AI and XR technologies are transforming assistive tools for individuals with autism, enhancing communication while minimizing sensory overload. A 2024 review analyzed AI's integration into assistive technologies, highlighting advancements in AI-driven robotics and wearable devices like smart glasses. These innovations provide personalized support, helping individuals with autism navigate social interactions. However, challenges remain, including concerns around bias, ethics, and cybersecurity in AI deployment.

In education, researchers are exploring AI-powered metaverse environments to create accessible learning experiences for students with disabilities, including autism spectrum disorder. These controlled virtual spaces simulate social interactions while reducing sensory overwhelm, offering tailored skill development opportunities. Ethical considerations are also at the forefront—December 2024 research stressed the need to design XR environments that are sensitive to autistic individuals' sensory needs. The study emphasized the importance of co-designing XR experiences with autistic users to ensure inclusivity and prevent unintended harm.

In June 2024, researchers, clinicians, and individuals with lived experience gathered at a virtual summit to address the complexities of sensory health. Presentations synthesized research and theory, providing insights into managing sensory overload in both physical and virtual environments. As AI and XR continue to evolve, their role in reducing sensory stress for neurodivergent individuals highlights the potential for technology to enhance inclusivity in education, health care, and everyday life.

Cybersickness

Researchers and developers are advancing solutions to mitigate cybersickness, a common barrier to XR adoption. A study from the KITE Research Institute, led by Dr. Behrang Keshavarz, demonstrated that

PSYCHOSOCIAL DYNAMICS AND INCLUSIVITY IN THE METAVERSE

integrating avatars into VR simulations can significantly reduce symptoms. In a trial with 54 participants, those who viewed an avatar reported less severe cybersickness than those without, suggesting that enhanced presence through self-representation helps users acclimate to virtual environments.

Beyond visual techniques, researchers are exploring physiological interventions. A study on vestibular stimulation found that using a bone conduction device during VR experiences helped users endure longer simulations with lower nausea levels. Similarly, technological improvements in VR headsets are reducing cybersickness—Dr. Peter L. Stallo's research compared the Meta Quest 2 and Meta Quest Pro, revealing that adjustable interpupillary distance and enhanced optics in the Quest Pro led to fewer symptoms of motion sickness.

Specialized hardware is also emerging to address cybersickness. The Roto VR Explorer chair, equipped with an integrated motor, synchronizes physical movement with virtual experiences, reducing sensory mismatch that often leads to discomfort. As XR adoption expands across industries, these innovations mark a critical step toward making virtual environments more comfortable and accessible for all users.

Dissociation From Reality

The immersive nature of the metaverse is raising concerns about problematic use, with cognitive factors like focal immersion and temporal dissociation playing key roles. Researchers Mahathi Koutha and Ronnie Jia from the University of North Texas explored these effects, drawing parallels between excessive metaverse engagement and social media addiction. As users lose track of time in highly immersive environments, the risk of overuse grows, prompting discussions on digital well-being and regulatory interventions.

On the therapeutic front, metaverse applications are showing promise in mental health treatment. A review of pilot studies found that avatar-based sexual therapy programs outperformed traditional methods in treating female orgasm disorders, while a metaverse-based social skills training program significantly improved interactions among children with autism. These findings highlight the potential of virtual environments for specialized therapeutic applications, though ethical considerations around privacy and efficacy remain.

Efforts to better understand metaverse engagement have led to the development of the Metaverse Experience Scale, which identifies six dimensions influencing user perception: sensory/affective, intellectual, behavioral, relational, interoperability, and safety. Research suggests that sensory/emotional experiences, interoperability, and safety concerns significantly shape user attitudes, providing insights for mitigating dissociative effects. Meanwhile, metaverse-related patent activity has surged, with companies like Apple, Microsoft, and Meta filing patents aimed at improving user safety. The World Intellectual Property Organization reports more than 390,000 pending patents for VR, AR, and XR technologies, reflecting a global push to refine and regulate the metaverse experience.

SCENARIO YEAR 2040

A HOLLOW WORLD

The metaverse, once envisioned as a realm of boundless opportunity, is now a gilded cage for a significant portion of humanity. Companies and officials ignored early warnings about its addictive potential, fueled by focal immersion and temporal dissociation, and safeguards to protect mental health are either absent or ineffectual.

Outside the shimmering walls of the hyper-realistic metaverses, a stark reality exists. Physical infrastructure crumbles, public services are underfunded, and a chasm divides the "Logged In," who can afford high-bandwidth connections and cutting-edge XR gear, and the "Logged Out," who are increasingly marginalized and forgotten. The "Curb-Cut Effect," once celebrated for its inclusive potential, is inverted; accessibility initiatives are focused solely on the metaverse, leaving the physical world to decay.

The generation raised on the metaverse is profoundly affected. Real-world social skills have atrophied, replaced by carefully curated online personas. A surge in mental health issues, including anxiety, depression, and a new form of "Virtual Reality Dependence Disorder" plagues adolescents and young adults. The real-world suicide rate is significantly higher than it was in the early 2020s. Sensory overload is a constant threat, and the already struggling population of neurodivergent people are even further isolated. VR has become so deeply integrated into daily life that more

and more people suffer from cybersickness and have even begun to develop dependencies on the tools used to reduce the negative effects, just to be able to spend time in the metaverse. Attempts to address the mental health crisis are largely ineffective. Avatar-based therapy programs show some initial promise but ultimately fail to address the underlying societal issues. The metaverse offers an escape from reality, not a solution to its problems.

Mega corporations, the architects of the metaverse, wield unprecedented power. They control access, shape narratives, and harvest user data with impunity. Digital ownership is a mirage; user-generated content is routinely exploited, and virtual assets can be seized at will. The promises of a decentralized, user-owned metaverse has evaporated in the face of corporate greed. Surveillance is commonplace. The physical economy stagnates as more and more economic activity shifts to the metaverse. “Metaverse jobs”—creating content, providing virtual services, and managing digital assets—are plentiful but often precarious and exploitative. The allure of earning “crypto-credits” in the metaverse lures many away from real-world employment, further weakening the physical economy.

Crime in the metaverse is rampant, ranging from virtual theft and harassment to more disturbing offenses. However, law enforcement struggles to keep pace. Jurisdiction is murky, evidence is easily manipulated, and the sheer volume of virtual interactions overwhelms investigators. A deepfake can erase someone from existence. Here, the “Panopticon” effect is weaponized; surveillance is omnipresent but selectively applied, used to control dissent and protect corporate interests.

In 2040, the metaverse stands as a stark warning against the unchecked pursuit of technological progress. The dream of a digital utopia devolved into a dystopian nightmare, a hollow world where human connection is mediated by algorithms, reality is malleable, and mental well-being is sacrificed at the altar of corporate profit. The few who remember the pre-metaverse world look back with a mixture of nostalgia and dread, wondering if humanity has passed the point of no return. The integration of virtual and physical reality has become so seamless and intertwined that physical and mental realities are no longer distinguishable. The question remains: Can humanity reclaim its analog soul before it is lost forever?

EXPERIENCING IMMERSIVE WORLDS

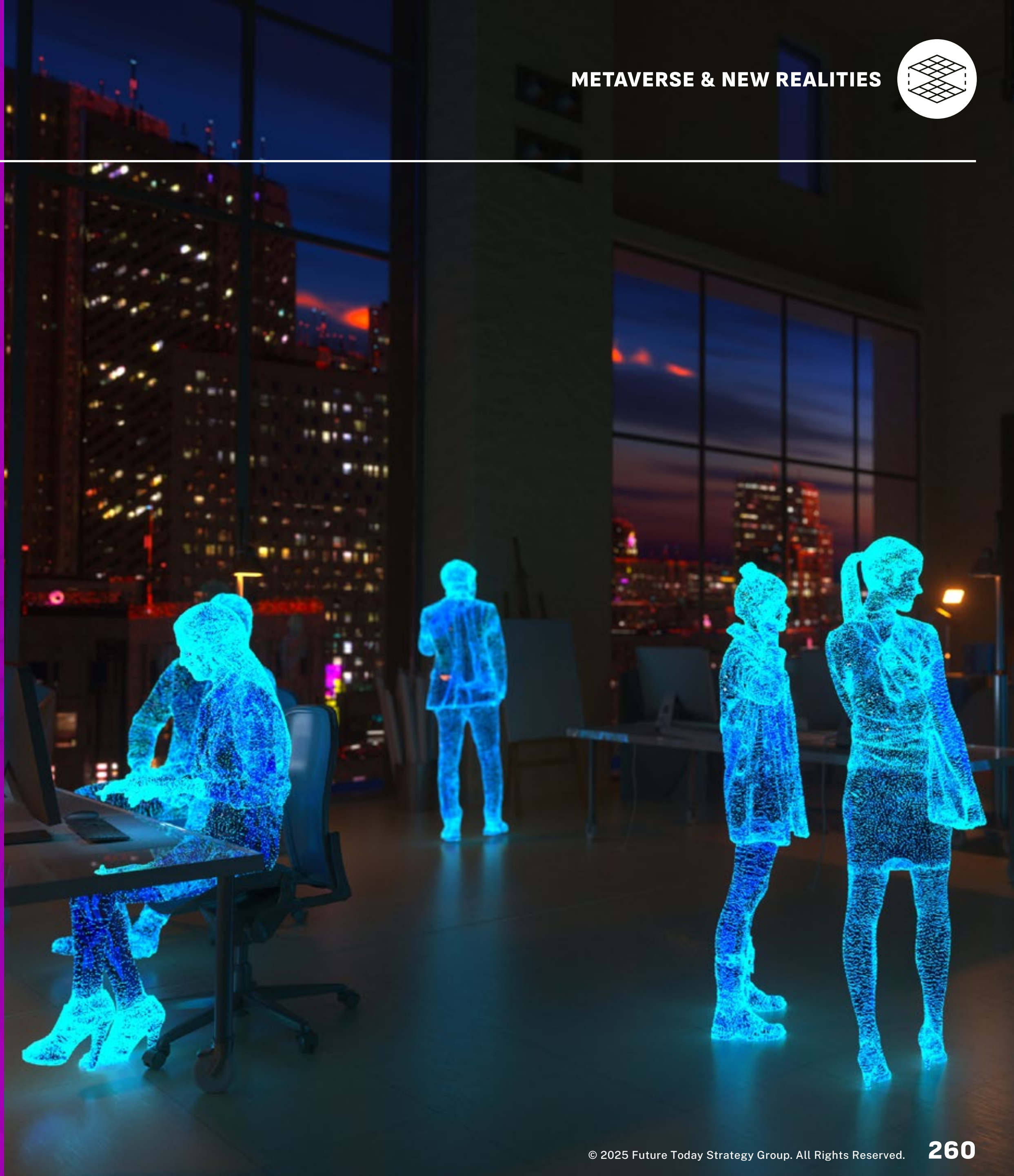
EXPERIENCING IMMERSIVE WORLDS

Events In The Metaverse

Metaverse events are becoming fully immersive platforms that blend commerce, entertainment, and community-driven experiences. In 2024, digital fashion weeks allowed designers to act as startups, raising funds through direct investments in virtual collections. Music artists like Snoop Dogg leveraged gaming platforms to transform concerts into interactive, in-game events. Even political discourse shifted into virtual spaces, with election night watch parties in VR fostering real-time engagement. These developments indicate a shift in how people experience live events—moving from passive viewership to active participation in dynamic, AI-enhanced environments.

The integration of AI and spatial computing is making virtual events more intelligent and engaging. Conferences such as the AI & Metaverse Innovate Summit explored how generative AI can personalize attendee experiences, while Meta Connect showcased how new AI-powered avatars and AR devices are shaping the next wave of digital interaction. Unlike early metaverse experiments, today's events are focused on usability, accessibility, and monetization—demonstrating that virtual gatherings are no longer just a futuristic concept but a viable alternative to traditional in-person events.

Beyond entertainment and networking, metaverse events are becoming economic engines. Platforms hosting these experiences are increasingly optimized for commerce, sponsorships, and direct-to-avatar sales, as seen in Metaverse Fashion Week and sports leagues like Improbable's Victory League. The challenge now is scalability—ensuring these virtual events can accommodate large audiences without compromising interactivity. As infrastructure advances, metaverse events could become primary touchpoints for industries seeking new ways to engage global audiences in immersive, customizable environments.



What's clear is that the speed of technical evolution is increasing and developments in digital technologies are probably the most significant to impact the future... I feel this presents a strong future with holograms continuing to be a key component.

Dr. Paul Dunn, Chair, International Hologram Manufacturers Assoc.

EXPERIENCING IMMERSIVE WORLDS

AR Lenses and Filters

AR lenses and filters are critical components for professional training, spatial computing, and next-generation optics. In medical education, AR filters powered by generative AI are being used to enhance training by simulating conditions across diverse skin tones. Research in Frontiers in Virtual Reality highlights how these filters improve diagnostic accuracy and build confidence among medical students, showcasing AR's growing role in high-stakes, real-world applications. This shift suggests that AR filters will increasingly serve as functional tools for specialized industries, moving beyond simple visual effects.

Advancements in AR optics are addressing long-standing challenges in display clarity, color accuracy, and user perception. Meta's newly patented wavelength band selective filters and Apple's dispersion compensation system both tackle image distortion, ensuring more lifelike AR experiences. Meanwhile, Tobii's patented eye-tracking calibration enhances AR headset precision by adjusting to user gaze in real time, improving usability for both everyday consumers and enterprise applications. Canon's development of lightweight AR/VR glasses further supports a trend toward more comfortable and practical devices, reducing barriers to widespread adoption.

But as AR becomes more ubiquitous, the way the technology affects human perception is under scrutiny. A study from the University of Toronto found that AR users overestimate distances in the real world, a distortion that subsides over time. This insight is crucial as AR becomes a staple in navigation, automotive displays, and remote work applications. As AR lenses and filters become more intelligent and integrated into daily life, developers must balance enhanced digital overlays with accurate real-world perception, ensuring that AR augments reality without unintentionally altering it.

Holograms

Holography is advancing from futuristic novelty to practical applications across multiple industries. Researchers at Princeton and Meta have developed ultra-thin optical devices that enhance holographic clarity, small enough to integrate into standard eyewear. This marks a step toward immersive virtual experiences without bulky headsets, signaling a shift from traditional AR/VR to seamless, everyday holographic displays. Meanwhile, Meta's Orion augmented reality glasses further blur the line between physical and digital, introducing neural interfaces for interactive holography that could eventually replace smartphones.

Beyond personal devices, businesses are leveraging holograms for visualization, advertising, and security. The oil and gas industry is adopting 3D holographic displays to improve geological analysis, allowing for better decision-making in resource exploration. Companies like HYPERVSN are transforming advertising with high-definition holographic displays, creating dynamic, attention-grabbing visuals. Meanwhile, the International Hologram Manufacturers Association is advancing anti-counterfeiting measures, integrating micro-lenses and plasmonics to enhance security features in authentication and brand protection. These developments show how holograms are not just visual enhancements but functional tools shaping commerce and industry.

In the arts and luxury markets, holography is changing the way valuable assets are displayed and sold. Christie's investment in holographic art displays allows buyers to view high-fidelity digital representations, expanding access to rare pieces without requiring physical presence. As holographic projection becomes more lifelike, its role in retail, education, and communication will continue to grow. The challenge now lies in refining hardware for mass adoption—ensuring clarity, affordability, and integration into everyday environments. With breakthroughs in optics, neural interfaces,

EXPERIENCING IMMERSIVE WORLDS

and 3D rendering, holograms are poised to become a mainstream interface for work, entertainment, and commerce.

Real Estate in the Metaverse

Metaverse real estate, once a high-profile trend in 2021 and 2022, has seen a sharp decline as speculative interest waned. However, we are keeping it in this report because the concept is evolving, and its potential may resurface as virtual environments become more advanced. Rather than focusing on purchasing digital land, the future of this space may center on ownership of metaverse-designed experiences. For example, instead of buying a generic virtual plot, individuals or brands might acquire exclusive rights to a virtual stadium that hosts high-profile concerts. As immersive digital experiences grow in sophistication and consumer adoption, this shift in perspective could redefine value in the metaverse.

Worlds for Purpose

The metaverse is evolving into a hub for global cooperation, activism, and digital governance. The World Economic Forum's Global Collaboration Village, developed with Accenture and powered by Microsoft Mesh, showcases this shift. In January 2024, the Village facilitated more than 200 participants in virtual discussions using realistic avatars and spatial audio, demonstrating how XR can bridge gaps beyond traditional video conferencing. Partners such as Aramco, Interpol, SAP, and Schneider Electric debuted virtual pavilions, signaling a growing commitment to collaborative problem-solving in immersive spaces. In June 2024, participants explored XR applications for addressing climate change, sustainable manufacturing, and other global challenges at the Village's first all-virtual event, "Creating Value through XR."

Meanwhile, activism and social justice initiatives are transforming the metaverse into a space for advocacy. The ARtivism project leverages AR to make public art accessible to blind and low-vision individuals. Users engage with AR-enhanced descriptions and interactions, ensuring that activism through art reaches a more diverse audience. Elsewhere, the Mariah AR app challenges power structures by overlaying historical and contemporary resistance narratives onto physical locations, effectively allowing users to "legally trespass" in the metaverse as a form of protest. Events like Metaverse Safety Week 2024 in December further highlighted how open-source frameworks can promote privacy, digital rights, and governance, while American University's 2024 symposium examined the metaverse's impact on human rights and advocacy. These initiatives underscore how XR-driven metaverse platforms are rapidly expanding beyond entertainment—becoming key tools for inclusion, activism, and policy-making.

Worlds for the Enterprise

Enterprises are rapidly integrating metaverse technologies to redefine collaboration, productivity, and workplace presence. Virtual office platforms such as Meetaverse enable employees to engage in immersive 3D environments, utilizing avatars, spatial audio, and interactive whiteboards for real-time teamwork. Unlike traditional video conferencing, these virtual spaces create a persistent digital workplace where spontaneous interactions and collaboration occur naturally. Businesses are leveraging metaverse offices to replicate physical environments, offering customizable meeting rooms and tools that enhance engagement among remote and hybrid teams.

Further advancing enterprise adoption, Warner Brothers filed a patent in August 2024 for a mixed reality (MR) system that dynamically integrates real-world context into virtual workspaces. The system uses headset-based imaging to analyze an environment's objects, lighting,

EXPERIENCING IMMERSIVE WORLDS

sound, and people, enabling the rendering of adaptive virtual objects within an MR session. By aligning virtual content with real-world context parameters, this innovation could allow context-aware enterprise applications, such as AR-powered brainstorming sessions or real-time data visualization in boardrooms. The intersection of mixed reality and enterprise collaboration is poised to deepen digital work experiences, transforming how teams interact and problem-solve in hybrid work settings.

Play-to-Earn and Virtual Marketplaces

In gaming, blockchain and metaverse platforms are redefining digital economies. In late 2024, Bright Star Studios released "Ember Sword," an MMORPG with tokenized in-game assets, allowing players to earn and trade NFT cosmetics. Ubisoft launched "Captain Laserhawk: The G.A.M.E.," integrating blockchain-based assets into a multiplayer experience featuring Rayman. And Roblox announced a new monetization model, enabling developers to sell entire games for real currency, transforming its user-generated content ecosystem. At HIKKY's Virtual Market 2024 Winter in December, there were 22 venues selling 3D items and avatars, supporting creators in virtual commerce. Additionally, Epic Games introduced Fab, a digital asset marketplace unifying resources from Unreal Engine, Sketchfab, Quixel, and ArtStation, streamlining the creation of interoperable metaverse experiences. With these advancements, enterprises and gaming platforms are converging on immersive, blockchain-integrated virtual economies that blur the line between work, play, and commerce.

SCENARIO YEAR 2034

A METAVERSE UNITED FOR THE AMAZON

As the relentless threat of deforestation continues to loom over the Amazon rainforest, innovative solutions are paramount. The Amazonian Reforestation Initiative (ARI) emerges as a transformative metaverse event, uniting global citizens in a shared commitment to conservation. Unlike traditional fundraising campaigns, ARI leverages the power of immersive technology to create a dynamic and engaging experience. Participants, represented by realistic, customizable avatars, journey into a stunningly rendered virtual Amazon, complete with spatial audio that captures the rich soundscape of the rainforest. Here, they encounter holographic guides—AI avatars modeled after indigenous elders and environmental experts—who share their knowledge and passion for this vital ecosystem.

Within this virtual world, attendees actively participate in interactive simulations that vividly illustrate the devastating impact of deforestation on climate change and biodiversity. They engage in simulated reforestation efforts, learning about sustainable practices and planting virtual trees that translate into real-world action. The event also showcases a digital art auction, featuring exclusive pieces inspired by the Amazon, with proceeds directly supporting reforestation projects. Highlighting the cultural richness of the region, musicians and storytellers from indigenous communities deliver captivating live performances, transcending geographical boundaries through AI-powered translation ensuring global accessibility. The use of spatial computing allows participants to gather around the digital stage, creating a sense of shared experience despite physical distance.

Further emphasizing engagement and collaboration, ARI incorporates interactive workshops led by experts and community leaders. Participants exchange ideas, learn about sustainable agriculture, and actively contribute to conservation strategies. In a groundbreaking approach, ARI also integrates play-to-earn game mechanics, rewarding players with NFTs and other digital assets for their participation in reforestation activities, gamifying environmental action. This initiative faces challenges, including ensuring accessibility for those with limited internet access, addressing concerns about cultural appropriation, and guarding against misinformation. However, by promoting education, inspiring tangible contributions, and fostering cross-cultural collaboration, ARI demonstrates the metaverse's transformative potential as a platform for environmental stewardship and global unity. It represents a shift towards ownership of metaverse-designed experiences, where the value lies not in virtual land, but in the impactful event itself.

METAVERSE INFRASTRUCTURE

METAVERSE INFRASTRUCTURE

AI Scalability

As metaverse ecosystems expand, AI scalability is becoming a critical factor in enhancing virtual experiences, moderating digital interactions, and enabling real-time adaptation. In October 2024, researchers from China's Shaanxi Institute of Technology and South Korea's Kunsan National University introduced ALMAA (Adaptive Learning Model for AI Agents)—a framework designed to improve AI contextual decision-making and scalability in metaverse environments. ALMAA integrates real-time adaptation, predictive analytics, and behavioral moderation, allowing AI to generate dynamic content and personalize user interactions. The study highlights ALMAA's theoretical applications in platforms such as Epic Games' virtual events and AltspaceVR, emphasizing its potential to create more adaptive and ethical AI agents while addressing data privacy, integration complexity, and scalability challenges through standardized APIs and cloud-based infrastructure.

Meanwhile, Nvidia is driving AI scalability through OpenUSD (Universal Scene Description) microservices. These new tools—USD Code NIM, USD Search NIM, and USD Validate NIM—allow developers to seamlessly integrate AI copilots and agents into metaverse applications, improving automation, search functionality, and content validation. By embedding generative AI directly into metaverse platforms, Nvidia's innovations enhance scalability, streamline AI deployment, and expand the capabilities of virtual environments. Together, ALMAA's theoretical framework and Nvidia's OpenUSD microservices represent a significant leap forward in scalable AI-driven metaverse experiences, paving the way for more interactive, responsive, and intelligent virtual worlds.

Interoperability

Interoperability is becoming the foundation of a scalable, user-centric metaverse. Epic Games' development of Unreal Engine 6 signals a move toward cross-platform content creation, integrating high-end tools with Unreal Editor for Fortnite to enable seamless application deployment. Epic's partnership with Disney further underscores this commitment, as they work to build a persistent, interoperable ecosystem within Fortnite. Meanwhile, Improbable's launch of MSquared introduces Metaverse Markup Language and Construct, open-source tools designed to enhance cross-platform virtual world creation. Partnerships with Google, Nvidia, and Dolby highlight efforts to break down technological silos, ensuring digital assets and experiences remain fluid across environments.

Industry-wide initiatives are reinforcing these efforts. The Metaverse Standards Forum's 2024 Annual Report stresses that a robust interoperability framework will drive adoption, market growth, and cohesive user experiences. Similarly, IEEE's recent publication advocates for an open and inclusive metaverse, defining technological interoperability standards essential for integrating virtual economies, digital assets, and communication protocols across platforms. As companies align around common standards, open APIs, and scalable toolsets, the future metaverse is shifting from isolated experiences to a fully interconnected digital ecosystem, enabling users, developers, and businesses to operate seamlessly across virtual worlds.

Government Investment

After a surge of interest in metaverse technologies between 2021 and 2023, government investment has slowed significantly. Many early initiatives struggled with technical limitations, unclear economic returns, and shifting policy priorities, leading to reduced funding and stalled projects. However, a few governments continue to explore targeted applications for digital twins, financial regulation, and industrial strategy. Shanghai and Tokyo remain committed to virtual city models, using metaverse-driven digital twins for urban planning, infrastructure management, and citizen engagement. Other nations, including the United Arab Emirates, South Korea,

METAVERSE INFRASTRUCTURE

Barbados, Finland, Japan, and China, have maintained limited investments in smart city initiatives within the metaverse, though at a reduced pace.

In policy, the European Commission's Web 4.0 strategy represents one of the few new large-scale metaverse initiatives, focusing on virtual public services, industrial applications, and global standards for interoperability. Meanwhile, the US Financial Industry Regulatory Authority explored the metaverse's role in finance, publishing an October 2024 report on potential applications such as virtual trading, investor education, and financial data visualization. While broad government-backed metaverse adoption has slowed significantly, these targeted efforts indicate that policymakers are still searching for practical, scalable applications of virtual worlds.

Developer Tools and Application Building Blocks

Major tech companies are advancing developer tools and foundational technologies to streamline metaverse content creation, AI-driven environments, and real-time 3D rendering. Apple's visionOS, launched for the Apple Vision Pro, establishes a spatial computing platform with Reality Composer Pro, enabling developers to build interactive 3D environments and spatial UIs with minimal coding. Apple's Unity integration simplifies deployment of AR/VR applications, while improvements to ARKit enhance hand-tracking, eye-tracking, and spatial awareness, making mixed reality interactions feel more intuitive and lifelike.

Epic Games continues to refine Unreal Engine 5 with MetaHuman Animator, allowing developers to generate realistic avatars from video footage in minutes. The Verse programming language introduces real-time updates and cross-platform interoperability, ensuring digital assets remain flexible across different metaverse ecosystems. Looking ahead, Unreal Engine 6 is expected to scale metaverse applications to larger, more persistent virtual worlds. Meanwhile, Meta's AI-powered Motivo model enhances avatar realism, emotional responsiveness, and NPC interactions, enabling AI-generated VR environments where users can create virtual spaces simply by describing them.

Breakthroughs in 3D capture technology are also reshaping how real-world environments integrate into the metaverse. Google and Niantic's Gaussian Splatting technology replaces traditional polygon-based rendering with photorealistic point-cloud representations, offering faster, higher-resolution 3D scans. Niantic's Scaniverse integration lets smartphones capture metaverse-ready objects, while Google's immersive maps and digital twins bring real-world locations into VR/AR navigation. Together, these advancements lower development barriers, making metaverse world-building faster, more scalable, and more immersive than ever before.

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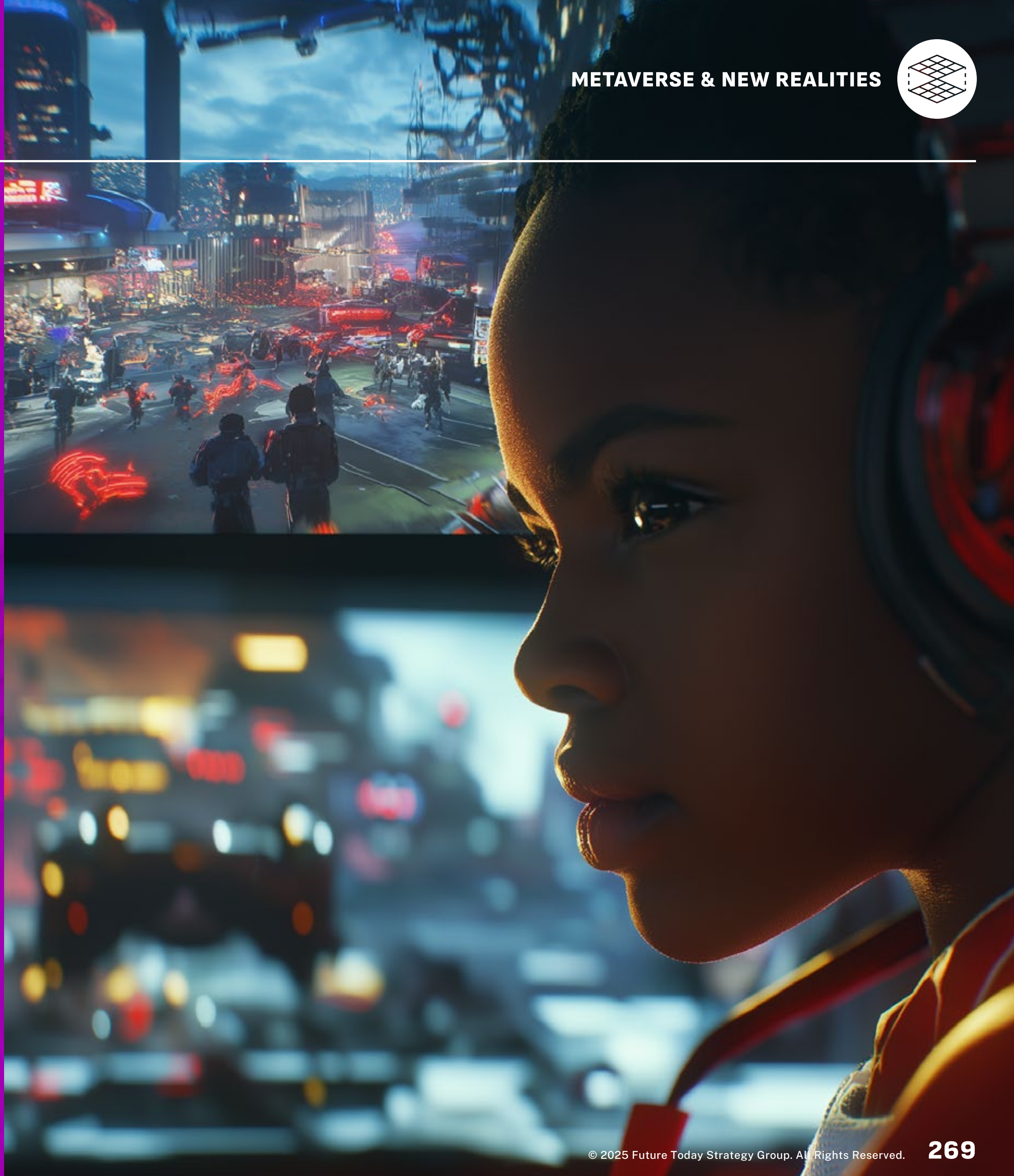
METAVERSE INFRASTRUCTURE

Interdevice Synchronization

As metaverse experiences become more immersive, interdevice synchronization is emerging as a critical feature, ensuring seamless interaction between users across different VR, AR, and traditional gaming platforms. In February 2025, Innersloth announced “Among Us 3D,” a first-person multiplayer version of the popular game, enabling real-time cross-play between PC users and VR headset players on Meta Quest, SteamVR, PlayStation VR 2, and PICO devices. This development demonstrates synchronized gameplay across different hardware ecosystems, allowing players using different input methods—motion controllers, gamepads, and keyboards—to share a single game world without performance disparities.

Social platforms like VRChat exemplify synchronized multi-device interaction by supporting simultaneous presence across standalone, PC, and high-end VR headsets. Users on Meta Quest, Valve Index, HTC Vive, PICO 4, and Android-based standalone VR devices experience synchronized spatial audio, real-time avatar movement, and shared interactive environments, ensuring that actions appear fluid and natural, regardless of hardware limitations.

On the infrastructure side, the Khronos Group’s OpenXR 1.1 update released in April 2024 enhances interdevice synchronization by standardizing hand-tracking, eye-tracking, and controller interactions across VR platforms. This allows a single metaverse application to recognize and adjust to different input systems, ensuring smooth, coordinated interactions between users, whether they are using inside-out tracking on Apple Vision Pro or external sensors on SteamVR headsets. These advancements signal a future where hardware barriers dissolve, creating frictionless, real-time synchronization between diverse metaverse participants.



SCENARIO YEAR 2040

GATED REALITIES

In 2040, the United States exists with a metaverse fractured by the ghosts of repealed net neutrality. The open and equitable digital frontier once envisioned has been supplanted by a tiered reality where access, speed, and experience are dictated by the depth of one's pockets and the preceding decades' corporate alliances. This wasn't a sudden cataclysm, but a slow, incremental erosion of digital principles, driven by regulatory inertia and the relentless march of technological advancement. The early promises of the metaverse—democratization, connection, empowerment—ring hollow for millions, replaced by a sense of digital disenfranchisement and a growing chasm between the "haves" and "have-nots" of the virtual world.

The knock-on effects are profound. Innovation has become concentrated within the walled gardens of major tech companies, which have partnered with telecom giants to ensure preferential treatment for their platforms. The cost of entry for independent developers skyrockets, as competing with the optimized bandwidth and AI-driven enhancements of the Tier 1 metaverse becomes impossible. Rural communities, already struggling with digital access, find themselves further isolated, unable to participate in the immersive educational, health care, and economic opportunities available to their urban counterparts. A digital underclass emerges, consigned to laggy simulations and stripped-down AR experiences, effectively locked out of the full potential of the metaverse.

The clear winners are the telecom conglomerates (Comcast, AT&T, Verizon), who leveraged their infrastructure control to become the gatekeepers of the metaverse. By prioritizing traffic from partner platforms like Meta, they created a self-reinforcing ecosystem, driving up subscription prices and securing dominance over the digital landscape. These companies not only collect premium fees for fast-lane access but also profit from the data generated within their walled gardens, using sophisticated AI algorithms to personalize advertising and monetize user behavior. Their stock prices soar as they become indispensable pillars of the 21st-century economy, shaping culture and commerce from behind the scenes.

Conversely, those who suffer the most are the small businesses and startups attempting to carve out a space for themselves, and the consumers on low incomes who are increasingly unable to access the essential services that are now confined to the metaverse. For lower-income communities, where basic internet access is already a struggle, the two-tiered metaverse deepens existing inequalities. Telemedicine, virtual education, and remote work opportunities are readily available to the wealthy, while the poor are forced to rely on antiquated technologies or simply miss out altogether. Indie developers and artists who can't afford the premium bandwidth or the AI enhancements offered by the major platforms are relegated to the digital margins, unable to reach a broad audience or monetize their creations effectively.

The unintended downstream consequences are equally troubling. Political polarization is amplified, as the wealthy retreat into echo chambers of tailored content and personalized experiences, while the marginalized are left to navigate the digital backwaters, susceptible to misinformation and online extremism. The sense of social cohesion erodes, as Americans increasingly inhabit separate and unequal virtual worlds, further fueling distrust and division. More and more people are starting to suffer from cyber sickness and AR and VR users are being encouraged to purchase extra equipment to mitigate the effects, thus increasing income inequality.

What started as a vision of a connected, democratized digital future has devolved into a new frontier of economic and social division, leaving many Americans locked out of the full potential of the metaverse, and the nation grappling with the consequences of a two-tiered digital society.

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BIOTECHNOLOGY

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Amy Webb
Chief Executive Officer

The next big tech disruption is biology.

The biotechnology landscape has fundamentally shifted. What was once a specialized field primarily focused on pharmaceuticals has exploded into a force reshaping nearly every industry. This isn't just about health care anymore—though the impact there is profound, with CRISPR therapies curing previously untreatable diseases and artificial intelligence revolutionizing drug discovery.

Today, biotechnology touches every industry. It's transforming agriculture, with crops engineered for climate resilience and higher yields. It's reinventing manufacturing, as engineered microbes produce materials stronger than steel and more sustainable than plastics. It's becoming central to climate solutions, with organisms designed to capture carbon and clean polluted environments. Biotech innovations are even reshaping the financial sector, creating new investment opportunities and transforming company valuations. The evidence surrounds us. Restaurants serve meat grown from cells rather than raised on farms. Fashion brands sell jackets made from spider silk produced by engineered yeast. Construction companies explore self-healing concrete created by bacteria. Beauty products contain proteins designed by AI and grown in fermentation tanks. These aren't pilot projects or laboratory curiosities—they're scaled commercial products generating real revenue.

What makes this moment unique is the convergence of multiple breakthroughs. AI has supercharged our ability to understand and engineer biology. Climate urgency has elevated biotech's role in sustainability. Global food security challenges have made biological innovation essential. The result? A wave of advances moving rapidly from lab to market, creating opportunities—and risks—that every leader needs to understand.

This report cuts through the complexity to highlight what matters. Whether you're in finance, manufacturing, technology, or policy, biotechnology will impact your sector in the coming years. The question isn't whether to engage, but how.

These five developments show how biotechnology is moving from theoretical possibility to practical reality, reshaping medicine, the environment, and daily life.

1

Lab-grown heart patches repair damage in trials

Engineered heart tissue integrates with damaged heart muscle within weeks, restoring 40% of cardiac function in post-heart attack patients. This suggests a future where heart attacks no longer mean permanent damage—instead, they become repairable injuries.

2

Synthetic bacteria deployed to clean up microplastic pollution

Each synthetic bacteria colony can process 50 tons of microplastic waste annually in a square kilometer, breaking it down into harmless organic compounds. Early ocean trials show no negative impact on marine ecosystems.

3

CRISPR 3.0 could achieve single-cell precision

With next-generation CRISPR, scientists can now target specific neurons in brain tissue while leaving surrounding cells untouched. This breakthrough could transform treatment for neurological disorders through ultra-precise DNA modification.

4

First bioengineered human embryo could reach early development stages

Scientists have grown a synthetic embryo without egg or sperm, raising ethical debates while advancing infertility treatments and genetic research. This provides unprecedented insights into early human development.

5

Synthetic biology startup designs first self-repairing clothing

The self-repairing garments contain engineered bacteria that activate when tears occur, producing new fibers to heal damage within hours. This technology could revolutionize sustainable fashion and reduce our 92 million tons of textile waste every year.

Biotechnology will move from scientific breakthrough to industrial reality, transforming everything.

Biotechnology has shattered the boundary between scientific possibility and market reality. The evidence surrounds us: CRISPR therapies are in the early days of curing genetic diseases, cultivated meat is served in restaurants, and gene-edited crops fill grocery shelves. AI systems, recognized with a Nobel Prize for cracking protein structures, are rewriting the rules of biological discovery.

The industry's scope has exploded beyond medicine. Novel organisms are emerging from labs: microbes that convert waste into valuable chemicals, plants engineered to capture more carbon, cells that grow materials stronger than steel. These aren't pilot projects—they're built to scale. Traditional manufacturing is being reimagined through a biological lens, as fermentation tanks replace chemical plants and living cells become microscopic factories.

Three fundamental shifts are reshaping biotechnology's future. The first wave is the emergence of programmable biology. The convergence of computing and biological systems has created unprecedented precision in manipulating life itself. AI can now predict complex protein structures in hours, while CRISPR enables genetic edits with surgical accuracy. This combination of digital and biological code transforms cells into programmable factories, making biology an engineering platform for solving previously intractable problems.

Parallel to this runs a second current: biology's emergence as a climate solution. Engineered organisms now capture carbon, produce sustainable fuels, and create eco-friendly materials at industrial scale. This isn't speculative technology. Companies are reimagining traditional chemical production through a biological lens, offering solutions that don't just reduce environmental impact but fundamentally change how we produce essential materials.

Underpinning these advances is a critical third shift: the recognition that public trust is as vital as technical innovation. As biotechnology touches more lives—through genetic data, million-dollar therapies, or engineered organisms—maintaining societal confidence becomes existential. The industry increasingly sees transparent practices and equitable access not as ethical add-ons but as fundamental infrastructure. Without this foundation of trust, even the most brilliant innovations risk rejection.

Biology's biggest breakthroughs moved from laboratory promise to commercial reality.

JANUARY 2024

CRISPR Therapy FDA Approval

The first CRISPR-based gene therapy is approved for sickle cell and beta-thalassemia treatment.

MAY 2024

AlphaFold 3 Launches

DeepMind and Isomorphic Labs release AlphaFold 3, predicting protein-ligand interactions for drug discovery.

JULY 2024

Gene-Edited Food Expansion

CRISPR-edited seedless blackberries and non-browning avocados enter market trials.

AUGUST 2024

Organoid Intelligence Breakthrough

Scientists grow synthetic human embryos to the 14-day stage from stem cells.

SEPTEMBER 2024

Synthetic Embryo Milestone

EvoPhase and Kwik Fab unveil the Birmingham Blade in England, the first urban wind turbine designed by AI.

« PAST

As nations race to regulate biotechnology, it will emerge as the next battleground for global power.

FUTURE »

MARCH 2025

FDA Public Workshop on Pregnancy Registries

Participants will discuss challenges and innovations in designing pregnancy registries for drug and biological product safety.

MAY 2025

New Strategy for European Medicines Agency

The EMA is expected to adopt a new strategy incorporating considerations for artificial intelligence in medicine development.

AUGUST 2025

Genome Engineering: CRISPR Frontiers

A conference at Cold Spring Harbor Laboratory will discuss advancements in genome engineering and CRISPR technologies.

OCTOBER 2025

iGEM Competition

Student teams will design and present innovative projects in this annual synthetic biology event.

2025—2028

China's Biotech Cultivation Initiative

The country will unveil a plan to develop gene-editing tools and new crop varieties to enhance food security.

Every organization must prepare for a bio-based future, regardless of its current relationship with biotech.

Biotech Is the New Digital

Just as they once became digital companies, businesses of all types are becoming biotech companies. From biomanufactured materials to engineered microbes in waste treatment, biological solutions are replacing traditional industrial and chemical processes across sectors, requiring new expertise and infrastructure.

Infrastructure Reset Required

The shift to bio-based manufacturing demands facility and equipment upgrades to handle biological processes. Organizations need to evaluate their existing infrastructure against emerging biotech capabilities, from fermentation tanks for materials production to specialized containment systems.

Compliance Changes Everything

Regulations on biological materials, genetic data, and engineered organisms are rapidly evolving and affect all industries. Organizations must develop new compliance frameworks and expertise to handle bio-related regulations, from data privacy to biosafety protocols.

New Expertise Is Mission Critical

The convergence of biology with traditional industries requires a workforce fluent in biological processes and their applications. Factor in new hiring strategies and training programs as organizations need to build teams that can bridge biological innovation with existing operations.

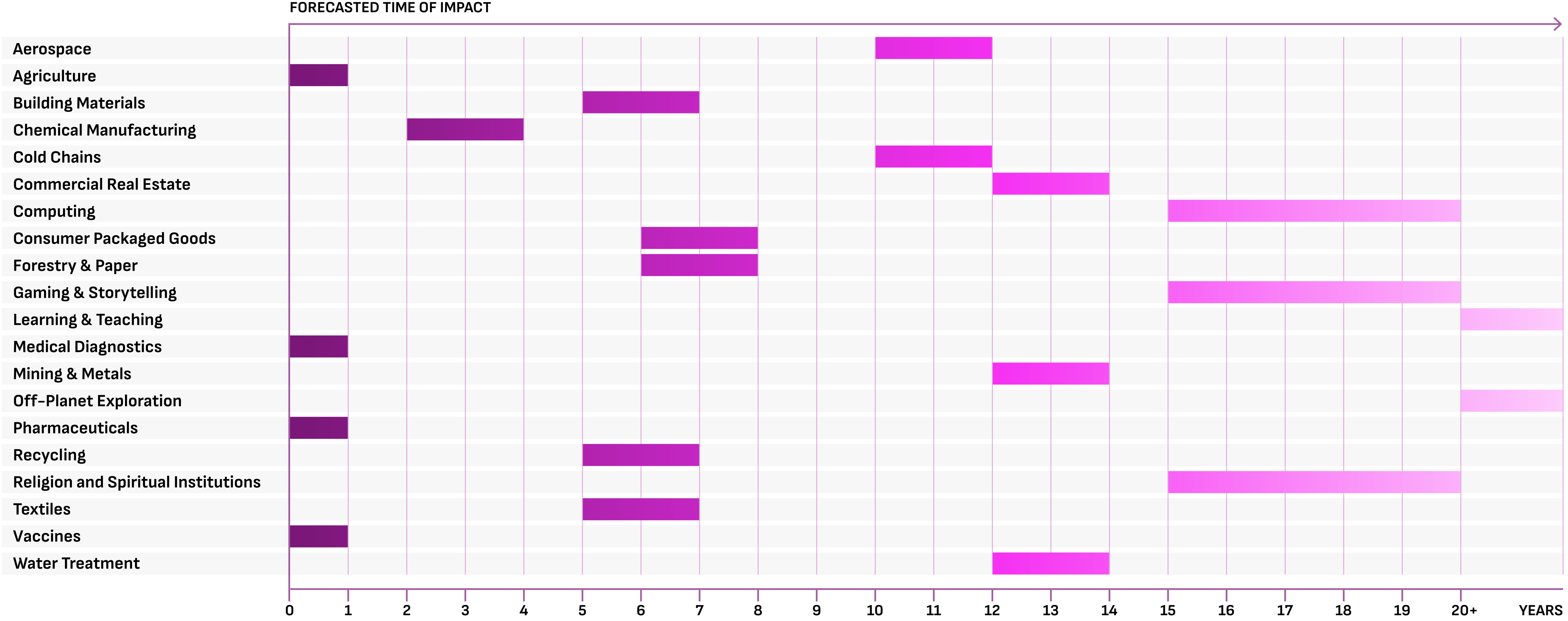
AI-Bio Integration Is Here

The convergence of AI with biological systems is creating new operational possibilities and requirements. Organizations must develop capabilities to handle bio-data and AI-driven biological processes, from quality control to product development and optimization.

Bio Disrupts Supply Chains

Biological alternatives and innovations in production methods are disrupting traditional supply chains. Organizations must reassess their supplier networks and invest in new capabilities to handle bio-based materials and processes, often requiring significant capital reallocation.

Biotech breakthroughs surge forward at wildly uneven paces, reshaping strategy and planning.

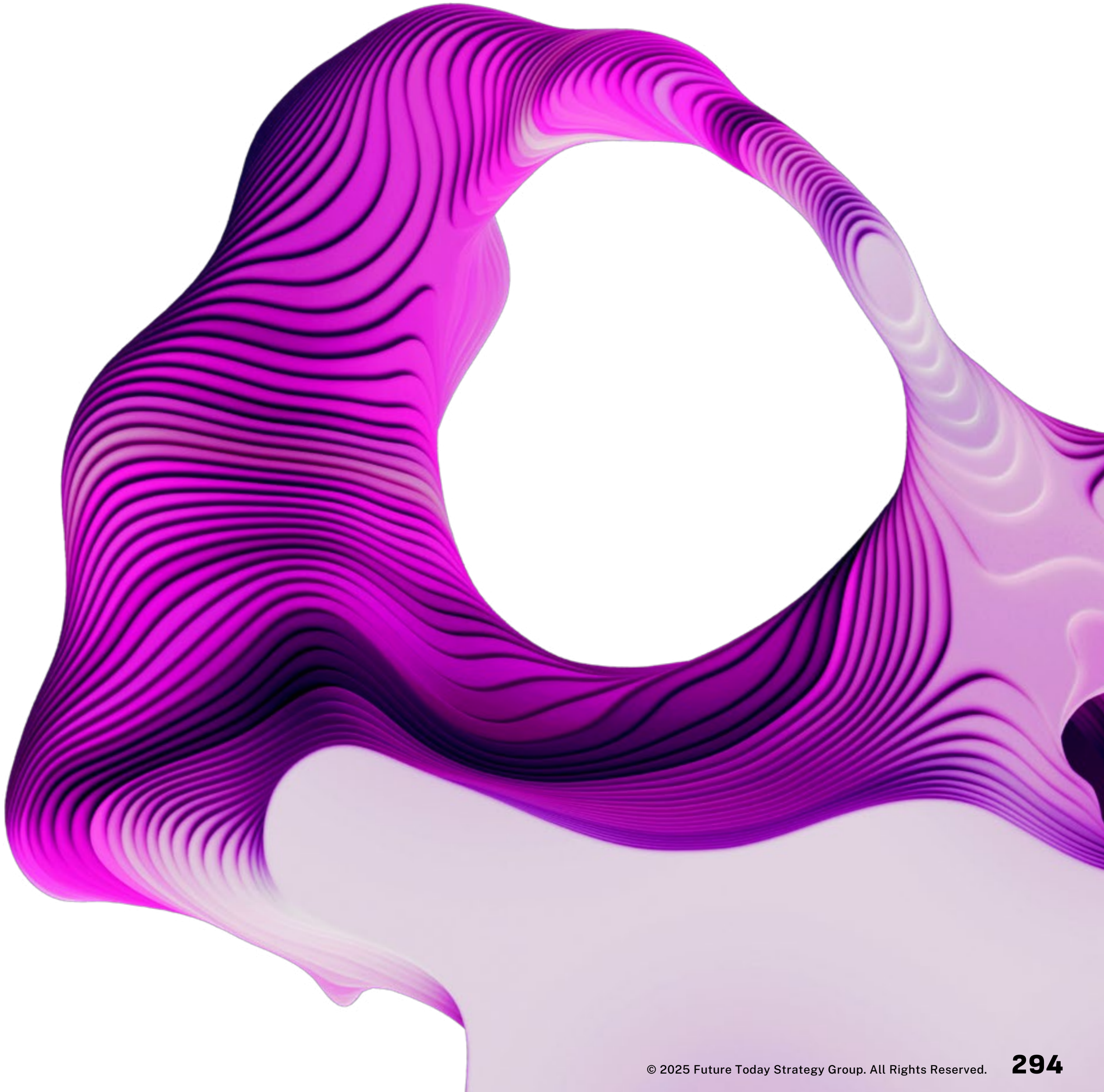


The pace of biotechnology's advance is driven by a complex interplay of forces: some push innovation forward, while others determine how quickly sectors adopt these changes.

Biotechnology is the next general purpose technology. Like electricity and computing before it, it will fundamentally reshape every industry and organization. This isn't speculation. In 2025, it's already happening.

The question isn't whether your industry will be affected but when and how significantly. Some sectors, like pharmaceuticals and agriculture, are already deep in transformation. Others, from textiles to construction, are just beginning to feel biology's influence. But all will be influenced or impacted, because biological solutions are proving faster, cheaper, or more sustainable than traditional approaches.

Seven key forces will determine how quickly this transformation reaches your industry:



SCALING

While the pace of innovation is fast across the spectrum of technologies, it takes time for a promising new biotech development to scale beyond the lab. Scaling requires discipline, patience, effort, and time.

COSTS

Biotechnology research is still costly, though the price of components, equipment, and materials drops every year. Once a disruptor can make a product cheaper with biotechnology rather than traditional production, it will push faster into the mainstream. Advancements in technology will eventually bring down costs of production as we've seen in other fields, such as computing.

CONSTRAINTS ON ADOPTION

Even if a technology is maturing, constraints on its adoption can hinder its influence in an industry. For example, a business may refuse to adopt an alternative biotechnology technology because it challenges a proven, successful strategy.

REGULATIONS

The pace of technology advancement typically far exceeds any changes to regulation. Biotechnology is unique in that regulation exists, but products and processes are treated differently in every country. Regulatory and policy uncertainty could accelerate or stifle growth.

MEDIA MENTIONS

Increased awareness and enthusiasm can influence the momentum of a technology, even when there's been no real breakthrough. Media bursts related to biotechnology will drive momentum, especially if those stories are favorable and—importantly—easily understood by the general public.

PUBLIC PERCEPTIONS

How the public understands, and responds to, biotechnology advancements will create or quell demand. This is especially true for food and beverage, consumer packaged goods, beauty and fashion, over-the-counter medicines and vaccines, and new therapeutics.

R&D DEVELOPMENTS

The pace of new research breakthroughs can't be scheduled to coincide with a board meeting or earnings report. There are factors that can improve the likelihood and speed of new discoveries (funding, quality and size of staff, access to resources). We closely monitor R&D developments but treat them as wild cards.

The leaders of tomorrow are the organizations that recognize this shift today. They're building bio-literacy into their strategy, investing in biological capabilities, and preparing their workforces for a bio-based future. The alternative—waiting until disruption forces change—puts companies at risk of falling permanently behind.

For each sector, we provide granular timelines mapping the expected progression of biotechnology adoption, integration, and disruption, supported by our proprietary database of more than 800 use cases across industries.

The biotech revolution goes beyond familiar names in medicine and agriculture. These scientists, founders, and innovators work in unexpected corners of this expanding field.

- **Dr. Barry Canton, co-founder and chief technology officer at Ginkgo Bioworks,** for pioneering advancements in synthetic biology and enabling large-scale organism engineering.

- **Dr. Christina Smolke, bioengineering adjunct professor at Stanford University,** for her research in synthetic biology to develop biosynthetic pathways for producing complex pharmaceuticals in yeast.

- **Dr. Emily Leproust, co-founder and CEO at Twist Bioscience,** for innovating DNA synthesis, enabling advancements in synthetic biology.

- **Ester Baiget, president and CEO at Novonesis,** for leading initiatives in biosolutions to combat climate change and promote sustainability.

- **Dr. Hiroaki Kitano, CEO of Sony Computer Science Laboratories,** for merging artificial intelligence with biological systems, creating new frameworks for understanding, and engineering living organisms.

- **Dr. Jennifer Elisseeff, the Morton Goldberg Professor of Ophthalmology at Johns Hopkins' School of Medicine,** for pioneering regenerative biomaterials that work with the immune system, transforming the approach to tissue repair.

- **Dr. Joanna Aizenberg, the Amy Smith Berylson Professor of Materials Science and Professor of Chemistry & Chemical Biology at Harvard,** for creating biologically inspired materials that mimic nature's most remarkable properties, from self-cleaning surfaces to adaptive materials.

- **Dr. Lulu Qian, bioengineering professor at Caltech, for developing DNA-based molecular robots and circuits,** opening new frontiers in biocomputing and nanoscale engineering.

- **Dr. Neil Kumar, founder and CEO at BridgeBio Pharma,** for evolving how we develop treatments for rare genetic diseases by creating a model that accelerates drug development for neglected conditions.

- **Dr. Noubar Afeyan, founder and CEO of Flagship Pioneering,** for inventing a unique company creation model that has launched dozens of breakthrough biotech companies, including Moderna and Indigo Agriculture.

- **Dr. Rahul Sarpeshkar, engineering professor at Dartmouth University,** for bridging electronic and biological computing while creating ultra-efficient biological circuits that could transform medical devices.

- **Dr. Xiaodong Chen, professor at Nanyang Technological University,** for developing soft, adaptive materials that interface seamlessly with human biology, enabling next-generation medical monitoring.

Biotechnology will unlock enormous opportunities as it transforms industries...

...but organizations aren't ready for the impending bio transformation.

OPPORTUNITIES

Prepare Your Supply Chain for Bio-Materials

Traditional manufacturers must start evaluating bio-based alternatives now. Early adopters are already securing sustainable material sources and building biomanufacturing capabilities.

Rethink Construction with Living Materials

Construction and infrastructure firms should explore self-healing materials and bio-based solutions that could reduce maintenance costs and extend asset lifespans significantly.

Consider Engineered Probiotics' Impact

Food, beverage, and health care companies should monitor engineered probiotics' potential to improve on how we deliver nutrients and therapeutic compounds.

Map Synthetic Biology's Testing Applications

Research-intensive industries should evaluate how synthetic biological models could reduce testing costs and accelerate development cycles across their product portfolios.

THREATS

Bio-Data Breaches Could Bankrupt You

Genetic and biological data breaches carry unprecedented liability. One leak of sensitive bio-data could trigger massive lawsuits and destroy customer trust permanently.

Your Supply Chain Could Become Obsolete

Biomanufacturing could make traditional production methods uncompetitive virtually overnight. Companies slow to adapt risk losing their entire cost advantage.

Competitors May Bioengineer Your Products

Engineered organisms could replicate your proprietary materials or chemicals at a fraction of the cost, potentially eliminating long-held manufacturing advantages.

Bio-Talent Wars Could Cripple Innovation

Companies without biotechnology expertise risk falling behind. The shortage of biotechnology talent is already creating an existential threat to traditional R&D models.

Biotechnology's impact will be broad and deep. Organizations should begin their long-term planning now.

Establish a bio-data infrastructure task force to evaluate biological information flow across your organization. Launch pilot programs in R&D to test new architectures, then expand to manufacturing. Focus on security protocols that protect genetic data and bioprocess information.

Create a cross-functional biological simulation platform that integrates with existing workflows. Train teams to use these tools for testing bio-based alternatives before major investments. Include virtual reality training modules for biomanufacturing processes.

Launch a dedicated venture fund targeting biomanufacturing startups that could disrupt or enhance your core business. Prioritize companies developing scalable fermentation technologies, cell-free synthesis platforms, and novel biological production methods.

Build a global bio-regulation monitoring system that tracks emerging policies across all operating jurisdictions. Focus on regional differences in GMO regulations, biological containment requirements, and synthetic biology oversight. Update the system quarterly.

Implement comprehensive training programs for staff transitioning to biological processing. Cover fermentation techniques, contamination prevention, and biological safety protocols. Include hands-on experience with bio-reactors and real-time monitoring systems.

Develop a proactive bio-policy engagement strategy. Join industry working groups shaping synthetic biology standards. Build relationships with regulators and scientific bodies. Share best practices while advocating for innovation-friendly frameworks.

Technology Deployment | Capital Expenditure | Talent Development | Regulatory Influence

Important terms to know before reading.

BIOENGINEERING DOMAINS

Innovations in bioengineering are reshaping medicine, agriculture, computing, and sustainability. Five core areas define the field: **biocomputing, biomachine interfaces, biomaterials, biomolecules,** and **biosystems.** Advances in one domain often accelerate breakthroughs in the others, leading to exponential progress. Emerging subfields—like synthetic bioelectronics and programmable biology—are rapidly expanding the potential of bioengineering.

BIOCOMPUTING

Biology operates on a code-like structure, and researchers are learning to harness this biological "software" for data storage, processing, and even computation. **DNA-based storage** is already proving to be a viable, ultra-dense, and sustainable alternative to silicon-based storage, while **living neural networks** are showing promise as bioprocessors that can learn and adapt. Unlike traditional supercomputers, biological computing systems require minimal energy, are scalable, and can integrate seamlessly

BIOMACHINE INTERFACES (BMIS)

New bioelectronic interfaces are allowing direct connections between **neurons and computers,** enabling applications ranging from brain-controlled prosthetics to **real-time digital brain augmentation.** Advances in optogenetics and neural implants could soon allow people to control machines, communicate thoughts, or even enhance cognition through **direct brain-to-cloud interfaces.**

BIOMATERIALS

Bioengineered materials are transforming industries—from **self-healing concrete** that uses living bacteria to repair cracks, to **lab-grown leather and plant-based plastics** that eliminate environmental waste. Researchers are also developing biocompatible materials for regenerative medicine, including **3D-printed organs and bioactive scaffolds** that guide tissue repair.

BIOMOLECULES (ALSO KNOWN AS -OMICS)

The study and engineering of biological molecules are leading to radical breakthroughs in medicine, agriculture, and synthetic biology. Advances in **molecular programming** are enabling scientists to design proteins with specific functions, such as **enzymes that break down plastics** or **RNA-based nanostructures** that deliver targeted therapeutics. The "-omics" revolution (genomics, transcriptomics, proteomics, metabolomics, etc.) is converging with AI to predict and design biological functions with unprecedented precision.

BIOSYSTEMS

Understanding and redesigning biological systems is key to solving global challenges. Scientists are now able to **engineer entire microbial communities** to break down pollutants, **program cells to act as sensors for disease,** and even **redesign human immune responses** to target cancer or emerging pathogens. Future applications could include **synthetic ecosystems** that regulate themselves for climate control or **programmable bacteria** that sustain soil health in space colonies.

ADDITIONAL TERMS

BIOFABRICATION

The use of cells, biomaterials, and bioprinting to create custom tissues, organs, and even synthetic organisms.

BIOCOMPATIBLE AI

The fusion of biological neurons with artificial intelligence, creating hybrid bio-AI systems that could reimagine computing.

CAS9 (CRISPR-ASSOCIATED PROTEIN 9)

An enzyme that acts as molecular scissors, enabling precise gene editing. Cas9 is central to CRISPR-based therapies and synthetic biology innovations.

CHIMERA

An organism that contains cells from two or more distinct genetic origins. Chimeras are used in research to study disease, grow transplantable human organs in animals, and test new gene therapies.

CHROMOSOME
A thread-like structure composed of tightly wound DNA. Each chromosome contains genes that determine an organism's traits.

CRISPR (CLUSTERED REGULARLY INTERSPACED SHORT PALINDROMIC REPEATS)
A powerful gene-editing system derived from bacteria that allows scientists to edit DNA with precision, potentially curing genetic diseases or designing organisms with custom traits.

DNA (DEOXYRIBONUCLEIC ACID)
The molecular blueprint of life, arranged in a double-helix structure. DNA carries genetic instructions for development, function, and reproduction.

ENZYME
A biological catalyst that speeds up chemical reactions inside cells. Engineered enzymes are being used to create sustainable biofuels, artificial meat, and biodegradable plastics.

EX VIVO
Experiments or treatments conducted outside a living organism, such as ex vivo gene therapy, where cells are modified outside the body and then reintroduced.

GAIN OF FUNCTION (GOF) RESEARCH
A controversial research method in which an organism is engineered to gain new traits, often to study viral evolution, antimicrobial resistance, or immune responses.

GENE
A segment of DNA that encodes a specific trait or function.

GENOME
The complete set of genetic material in an organism, now fully programmable using advanced genome-editing tools.

GENOME EDITING
Techniques like CRISPR, base editing, and prime editing allow precise modification of DNA, with applications ranging from curing genetic diseases to engineering resilient crops.

HERITABLE GENETIC CHANGE
Genetic modifications that are passed down to future generations, raising ethical and regulatory challenges in human germline editing.

IN VIVO
Biological processes that occur inside a living organism. In vivo gene therapy is an emerging approach where therapeutic genes are delivered directly into the body.

INDUCED PLURIPOTENT STEM CELLS (IPSC)
Adult cells that have been reprogrammed into a stem cell-like state, capable of becoming any cell type.

LIVING SENSORS
Engineered cells that detect changes in their environment, useful for monitoring pollution, tracking disease outbreaks, and sensing biomarkers in real time.

MOLECULAR MACHINES
Tiny biological machines—built from DNA, RNA, or proteins—that can perform tasks at the cellular level, such as delivering drugs or repairing damaged DNA.

MUTATION
A change in a DNA sequence, which can be natural or engineered for disease resistance, enhanced traits, or new functionalities.

OFF-TARGET EFFECT
Unintended genetic modifications that can occur during genome editing, leading to potential risks and ethical concerns.

REGENERATIVE MEDICINE
A field dedicated to repairing or replacing damaged tissues and organs using stem cells, gene editing, and bioengineered materials. Key applications include bioprinted organs, lab-grown skin, and neural regeneration.

RNA (RIBONUCLEIC ACID)
A messenger molecule that translates DNA instructions into proteins. RNA-based technologies, including mRNA vaccines, RNA therapeutics, and RNA nanotechnology, are shaping the future of medicine.

STEM CELL
A type of cell with the potential to develop into many different cell types. Stem cells are being used for treating spinal injuries, regenerating heart tissue, and reversing neurodegenerative diseases.

SYNTHETIC BIOLOGY
A field that combines biology and engineering to design new life forms, program genetic circuits, and create entirely synthetic organisms. Future applications range from carbon-sequestering bacteria to self-replicating biomaterials.

XENOBOTS
Self-assembling, programmable biological robots made from living cells, with potential applications in targeted drug delivery, environmental cleanup, and regenerative medicine.

BIOTECHNOLOGY TRENDS

AI AND BIOLOGY

AI AND BIOLOGY

Open-Source Medical LLMs Gain Ground

Large language models (LLMs) are transforming the biomedical field, with open-source alternatives now challenging proprietary models in accuracy and accessibility. BioMistral, a new domain-specific LLM built on Mistral and trained on PubMed Central, outperforms existing open-source medical AI models and competes with commercial solutions in medical question-answering (QA) tasks. Unlike general-purpose LLMs, BioMistral is fine-tuned for biomedical applications, demonstrating superior performance across 10 benchmarked QA datasets. Notably, BioMistral introduces the first large-scale multilingual evaluation of medical LLMs, supporting translations in seven languages to improve global accessibility. With ongoing advancements in quantization and model merging, lighter, faster, and more efficient AI-driven medical assistants are emerging. This shift signals a broader trend toward decentralized, transparent AI tools in health care, reducing reliance on proprietary models while maintaining high-performance standards. As regulatory bodies evaluate the role of medical LLMs in clinical decision-making, open-source solutions could drive more equitable and widespread AI adoption in global health care.

AI-Driven Molecular Modeling

AlphaFold 3 marks a major leap in biomolecular modeling, extending AI-driven structure prediction beyond proteins to include nucleic acids, small molecules, ions, and modified residues. Unlike previous versions, AlphaFold 3 employs a diffusion-based deep learning architecture, significantly improving accuracy in predicting protein-ligand and protein-nucleic acid interactions. It surpasses traditional docking tools and specialized predictors, demonstrating unprecedented precision in antibody-antigen modeling. This advancement accelerates bottom-up modeling of cellular components, reducing reliance on vast experimental datasets while enhancing the utility of existing structural biology data. The synergy between AI and experimental techniques—such as advancements in cryo-electron microscopy—is expected to fuel further improvements, driving breakthroughs in drug discovery and molecular engineering. With a unified framework for high-accuracy biomolecular modeling, AlphaFold 3 is poised to reshape our understanding of molecular interactions, paving the way for AI-powered therapeutic development.

AI Reshapes Drug Discovery and Development

Pharmaceutical companies are rapidly integrating AI across drug discovery and development, shifting from early experimentation to full-scale adoption. Since DeepMind's AlphaFold breakthrough, AI-driven protein modeling has accelerated, with companies like Insilico Medicine and Recursion Pharmaceuticals now using AI to design novel compounds and predict drug efficacy. AstraZeneca reports that reinforcement learning now influences 70% of its small-molecule drug candidates, and AI-generated insights are streamlining clinical trial design. The investment trend is intensifying: Pharmaceutical AI spending could exceed $50 billion annually by 2030. The focus is on using AI not just for molecule identification but for optimizing supply chains, regulatory compliance, and post-market surveillance. Despite AI's promise, challenges remain, including data silos, regulatory hurdles, and the need for explainability in AI-driven decisions.

A Search Engine for the World's DNA

A new computational tool, MetaGraph, is making global DNA, RNA, and protein sequences searchable—similar to how Google indexes the web. Developed by researchers at ETH Zurich, MetaGraph compresses vast amounts of genetic data into structured indexes, allowing scientists to scan trillions of base pairs and billions of amino acids efficiently. In a proof-of-concept study, the team indexed 10% of known biological sequences, demonstrating the feasibility of indexing the entire Sequence Read Archive, which now holds more than 50 petabases of genomic data. Unlike traditional bioinformatics tools that struggle with unassembled sequences, MetaGraph

AI AND BIOLOGY

enables rapid searches across massive datasets, supporting discoveries in virology, microbiome research, and disease-associated genetic variations. While computational costs remain a challenge, the tool's ability to reduce complex datasets to gigabyte-scale indexes could democratize genomic research, making high-powered sequence analysis accessible even on standard laptops. As global efforts like the Pasteur Institute's IndexThePlanet and NCBI's Pebblescout push toward comprehensive genetic indexing, MetaGraph highlights the urgent need for scalable, open-access infrastructure to organize and search the world's rapidly expanding biological data.

Automating Chemical Synthesis

AI-powered language models are now capable of not just predicting chemical reactions but also executing them in robotic labs. Systems like ChemCrow and Carnegie Mellon's AI-driven lab assistants can generate synthesis pathways for complex molecules, optimizing drug production in ways previously unimaginable. These tools allow researchers to conduct high-throughput virtual experiments, reducing the reliance on costly physical trials. However, as AI gains the ability to generate toxic compounds, regulatory oversight will need to evolve to prevent misuse.

AI-Designed Proteins Transform Medicine

AI-generated proteins are opening new frontiers in medicine and materials science. MIT's AI-driven protein engineering models and the University of Washington's RFdiffusion system are now designing proteins with unprecedented precision, improving drug targeting and material design. AI-powered protein design is already being applied to developing new vaccines, enzyme-based therapies, and biodegradable plastics. As these technologies mature, AI-designed proteins will accelerate biotech, reducing reliance on traditional trial-and-error discovery methods.

AI-Driven Spatial Biology Advances Precision Medicine

AI is dramatically improving spatial biology, enabling researchers to map cells in their natural environments with unprecedented resolution. Advances in AI-powered imaging and single-cell sequencing are accelerating our ability to understand complex tissue structures, with companies like NanoString and 10x Genomics leading the charge. By combining AI with high-resolution cellular imaging, researchers can now identify biomarkers more effectively, setting the stage for next-generation precision medicine and targeted therapies.

Generative Biology

What if it was possible to generate novel protein therapeutics using new computational tools, without having to discover them through trial and error? That's the promise of Boston-based startup Generate Biomedicines, which trained an AI to invent proteins with structures that, as far as we know, don't exist anywhere in nature. Inspired by DALL-E 2, the powerful text-to-image AI system from OpenAI, Generate's platform asks the user to describe the shape, size, and function of a protein they'd like to see. It then uses diffusion modeling to generate a structure with the right amino acids folded correctly to meet the description. Our understanding of the genome, along with fundamental molecular and network mechanisms, is now being enhanced by innovative tools that allow us to interact with, examine, and manipulate biological systems in new ways.

AI-Powered Molecular Simulations Accelerate R&D

Pharmaceutical companies are increasingly replacing physical drug testing with AI-driven molecular simulations, significantly cutting costs and speeding up development. Advances in quantum computing and machine learning have enhanced in silico modeling, allowing researchers to simulate molecular interactions with unprecedented accuracy. Companies like Schrödinger and DeepMind's Isomorphic Labs are using AI to predict drug-target binding at atomic resolution, reducing reliance on expensive wet-lab experiments. Meanwhile, generative AI is enabling the creation of novel drug candidates, optimizing molecular properties before synthesis. Regulatory agencies, including the FDA and EMA, are now assessing AI-validated

AI AND BIOLOGY

simulations as part of drug approval processes, signaling a shift toward digital-first pharmaceutical R&D. This shift not only accelerates drug discovery but also improves sustainability by reducing lab waste and energy consumption. Companies adopting AI-powered simulations will gain a competitive edge as bioengineering moves toward a fully data-driven paradigm.

Digital Evolution: AI Spontaneously Self-Replicates

A new experiment has shown that self-replicating artificial life can emerge spontaneously from a chaotic pool of random code—without predefined rules or evolutionary incentives. Researchers at Google created a digital environment where tens of thousands of code fragments randomly interacted over millions of generations. Unexpectedly, self-replicating programs emerged, multiplied, and competed for space, mirroring biological evolution. Unlike previous simulations like Conway's Game of Life, which rely on strict rules, this system produced artificial life from raw computational randomness. While the findings don't directly explain the origin of biological life, they suggest that complexity can arise naturally from prolonged random iteration. However, researchers caution that self-replication alone does not guarantee greater complexity; without additional selective pressures, these systems may remain simple rather than evolving into digital ecosystems. Scaling up such experiments could require enormous computational resources, but they hint at the potential for AI-driven studies to reveal fundamental principles of life's emergence.

GENE EDITING AND CRISPR

The question is not whether we will modify genes but how we will use this technology.

Jennifer Doudna, CRISPR pioneer

GENE EDITING AND CRISPR

Base Editing Surpasses Traditional CRISPR

Base editing allows scientists to change a single DNA base without cutting both strands, reducing errors. Unlike traditional CRISPR-Cas9, which introduces double-strand breaks, base editing is more precise and safer for treating genetic diseases. In clinical trials, Beam Technologies is targeting sickle cell disease and beta-thalassemia using its BEAM-101 therapy, which converts hemoglobin genes to a fetal form, reducing disease symptoms. Additionally, base editing is showing potential in treating neurodegenerative diseases like Huntington's by correcting single-point mutations. This approach is gaining traction in biotech as a next-generation gene-editing tool, offering a safer and more efficient alternative to conventional genome editing.

Prime Editing Improves Accuracy

Prime editing enables precise DNA modifications without requiring double-strand breaks or donor DNA templates. This technology offers a unique combination of versatility, specificity, and precision among CRISPR-Cas systems. Prime editors can introduce virtually any substitution, small insertion, or small deletion within the DNA of living cells, making them highly adaptable for therapeutic applications. The system consists of a programmable Cas9 nickase fused to a polymerase enzyme and an extended guide RNA that specifies both the target site and the desired genomic change. Prime editing has shown promise for treating genetic diseases like Tay-Sachs and cystic fibrosis, where single-nucleotide errors need correction. Unlike traditional gene editing, which relies on cellular DNA repair mechanisms that can be inefficient and error-prone, prime editing minimizes off-target effects and improves efficiency. Recent advancements focus on enhancing delivery methods and overcoming technical limitations, expanding its clinical potential. In 2025, further refinements and new strategies, such as optimized pegRNAs and improved polymerase activity, are expected to increase editing efficiency, broadening the range of treatable genetic conditions.

In Vivo CRISPR Therapy Advances

It is now possible to inject CRISPR components directly into the body and make changes to genetic material in vivo, or "within the living." Unlike "ex vivo" editing, where cells are modified outside the body and then reintroduced, in vivo editing involves introducing the gene-editing tools (like CRISPR-Cas9) in the body using viral vectors or lipid nanoparticles. Practically speaking, this means that treating cancer would no longer require traditional chemotherapy—instead, cancerous cells would be targeted and edited with CRISPR. Intellia Therapeutics achieved a groundbreaking milestone with NTLA-2001, the first investigational in vivo CRISPR therapy to demonstrate successful redosing in humans. In a Phase 1 trial for transthyretin (TTR) amyloidosis, three patients initially received a low dose, leading to a median 52% reduction in serum TTR levels. To explore whether an additional dose could provide further benefits, three patients received a second, higher 55 mg dose of NTLA-2001. This led to an impressive 90% reduction in harmful protein levels within 28 days, with an overall 95% reduction from their original levels. This milestone proves that Intellia's CRISPR-based gene-editing therapy can be safely given more than once, which could be a game-changer for treating diseases that may require repeat gene editing. The results also confirm NTLA-2001's strong safety profile, with patients tolerating the second dose well. As the treatment moves into advanced clinical trials in partnership with Regeneron, its success could accelerate the development of CRISPR therapies for other chronic diseases, offering new hope for patients who need long-term solutions. Companies like Verve Therapeutics are also utilizing in vivo editing for cardiovascular diseases by targeting genes that regulate cholesterol levels. With regulatory agencies closely watching these developments, 2025 could mark the first FDA approvals for in vivo CRISPR therapies, transforming treatment options for a range of genetic disorders.

GENE EDITING AND CRISPR

Gene Editing for Rare Diseases Expands

With more than 7,000 rare genetic diseases, CRISPR-based treatments are becoming a major focus for biotech companies like Editas Medicine and CRISPR Therapeutics. In 2025, more clinical trials will target diseases like Duchenne muscular dystrophy, Usher syndrome, and Rett syndrome, where current treatments are limited or nonexistent. Editas' EDIT-101, designed to treat Leber congenital amaurosis, is one of the first in vivo CRISPR therapies to restore vision in patients with inherited blindness. Similarly, researchers are working on CRISPR-based solutions for cystic fibrosis, using prime editing to correct CFTR gene mutations at their source. As CRISPR delivery techniques improve, particularly in the nervous system and muscles, gene therapy for rare diseases will become more viable, bringing hope to patients with currently untreatable conditions.

Epigenetic Editing Becomes Mainstream

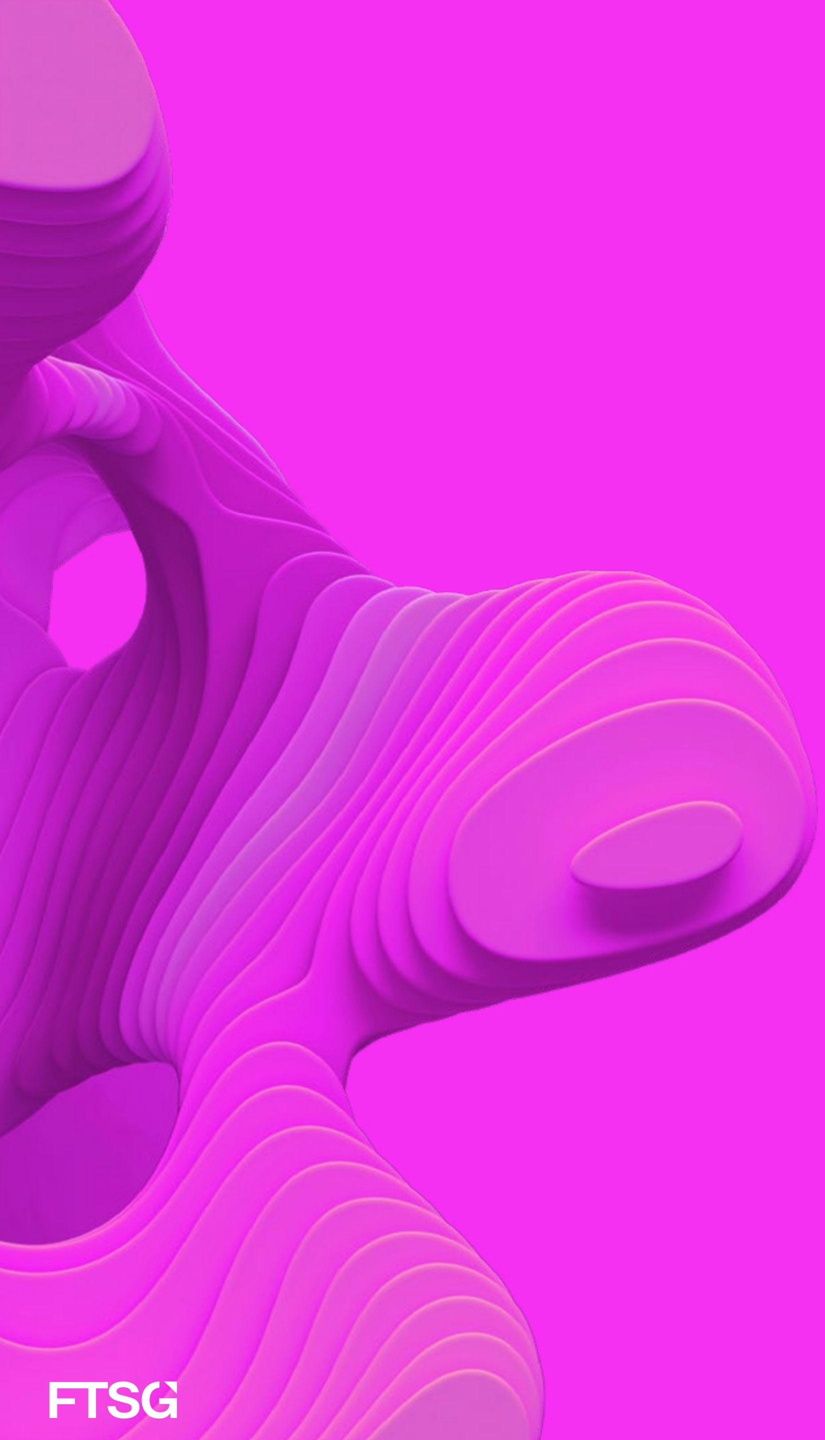
Unlike traditional gene editing, epigenetic editing modifies how genes are expressed without altering DNA sequences. Companies like Chroma Medicine and Tune Therapeutics are developing CRISPR-based epigenetic editing tools to treat conditions like chronic pain, neurodegenerative disorders, and cardiovascular diseases. Instead of permanently cutting DNA, these methods use modified Cas proteins to activate or silence genes by adding or removing chemical tags. For example, Chroma Medicine is working on therapies that reprogram gene activity in sickle cell disease without changing the genetic code. This nonpermanent approach is particularly useful for treating diseases where gene expression needs modulation rather than permanent modification. As epigenetic editing advances, it could provide safer alternatives to irreversible genetic changes, expanding CRISPR's medical applications.

Synthetic Biology Boosts CRISPR Applications

Synthetic biology is combining CRISPR with AI-driven design to engineer microbes for industrial and medical applications. Companies like Ginkgo Bioworks and Synthego are creating synthetic organisms that produce biofuels, pharmaceuticals, and biodegradable plastics. For instance, researchers have engineered bacteria to synthesize complex molecules like insulin and chemotherapy drugs more efficiently. Additionally, CRISPR-modified microbes are being tested for environmental applications, such as carbon capture and plastic degradation. In medicine, synthetic biology is enhancing cell-based therapies by programming stem cells with CRISPR to regenerate damaged tissues or produce therapeutic proteins on demand.

Multiplex Editing Enables Complex Changes

Multiplex CRISPR editing, where multiple genes are modified at once, is becoming more sophisticated. Companies like Mammoth Biosciences and Arbor Biotechnologies are developing Cas enzymes that allow simultaneous edits without increasing off-target effects. This approach is particularly valuable in cell and gene therapy, where multiple genetic factors influence disease. In agriculture, multiplex editing is improving traits like disease resistance and yield in a single step. For example, researchers are using multiplex CRISPR to engineer rice varieties resistant to multiple pathogens simultaneously. In regenerative medicine, scientists are exploring multiplex editing for engineering universal donor cells that evade immune rejection. As techniques improve, 2025 will see broader adoption of multiplex CRISPR in medicine, agriculture, and synthetic biology.



READING AND SEQUENCING GENOMES

DNA is like a computer program but far, far more advanced than any software ever created.

Bill Gates

READING AND SEQUENCING GENOMES

Ultra-Long-Read Sequencing Becomes Mainstream

Oxford Nanopore Technologies is pushing the boundaries of ultra-long-read sequencing, now surpassing 4 million bases per read. This breakthrough helps resolve complex genomic regions, including structural variations, telomeres, and centromeres, which were previously difficult to sequence accurately. Unlike short-read sequencing, which struggles with repetitive DNA sequences and large structural variations, ultra-long reads provide a more complete picture of the genome. This technology is improving research on neurodegenerative diseases, cancer, and rare genetic disorders by capturing mutations and rearrangements that influence disease progression. With improvements in accuracy, throughput, and affordability, ultra-long-read sequencing is becoming a valuable tool for population genomics, personalized medicine, and de novo genome assembly, offering deeper insights into the human genome and evolutionary biology.

Single-Cell Sequencing Expands Applications

Single-cell sequencing is transforming research by allowing scientists to analyze the genetic and transcriptomic activity of individual cells rather than averaging data across cell populations. Companies like 10x Genomics and Parse Biosciences have developed high-throughput platforms to profile thousands of cells simultaneously, enabling insights into cancer evolution, immune responses, and brain development. In oncology, single-cell sequencing helps identify rare cancer cell populations responsible for drug resistance and relapse. In neuroscience, it uncovers cellular diversity in the brain, shedding light on disorders like Alzheimer's and autism. Recent advancements in spatial transcriptomics integrate single-cell sequencing with tissue imaging, mapping gene expression within intact tissues. As technology improves, single-cell sequencing is becoming faster, more scalable, and cost-effective, enabling widespread adoption in precision medicine and developmental biology.

AI-Driven Genome Annotation Improves Insights

AI is changing the way scientists understand and interpret genomes by making it easier to analyze genetic data with greater accuracy. Tools like Google's DeepVariant and Meta's ESMFold use AI to predict changes in DNA and protein structure, helping to reduce mistakes in genetic research. These AI tools help scientists find mutations that can cause diseases, locate important regulatory parts of the genome, and understand the role of noncoding RNA (which doesn't make proteins but still plays a crucial role in the body). AI also improves studies that connect genetic differences to diseases by making it easier to identify which variations matter the most. Also, AI is now accelerating the identification of novel genes involved in conditions like neurodegeneration and cardiovascular diseases. With AI-driven annotation, researchers can analyze massive sequencing datasets faster and more accurately, making genome sequencing a more powerful tool for precision medicine and drug discovery.

Portable Sequencers Enable Real-Time Genomics

When the first human genome was sequenced in 2003, it cost roughly $2.7 billion and took 13 years to complete. In 2012, it cost about $10,000 for researchers to sequence a full genome. The next generation of sequencers will offer a monumental leap forward in speed and efficiency, akin to the transition from dial-up to high-speed internet. Handheld sequencing devices like Oxford Nanopore's MinION are making real-time genomic analysis possible in remote locations. These portable sequencers are being used for disease surveillance, environmental monitoring, and even space exploration. During the Ebola and COVID-19 outbreaks, MinION allowed researchers to sequence viral genomes in the field, tracking mutations in real time. In agriculture, portable sequencing helps detect plant and livestock pathogens before outbreaks spread. The technology is also being tested for identifying microbial life on Mars and other extreme environments. While early versions faced accuracy challenges,

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recent improvements in error correction and base-calling algorithms have enhanced performance. Portable sequencing will become even more reliable and accessible, empowering researchers, conservationists, and clinicians to perform genomic analysis anywhere, without relying on large laboratory infrastructure.

Epigenome Sequencing Gains Clinical Relevance

Our genes can be switched on and off through epigenetic tags. These tags act like dimmer switches, controlling which genes are active. Scientists are now mapping these switches across the entire genome using powerful new sequencing tools, shedding new light on how epigenetic changes drive aging and diseases like cancer. Companies are combining genetic and epigenetic data to better understand diseases. In cancer care, doctors can now detect tumor signals in blood samples by looking for abnormal epigenetic patterns. We're also learning how lifestyle factors like diet and stress can trigger epigenetic changes that may even pass to future generations. As the technology gets cheaper and analysis gets easier, checking someone's epigenetic profile could become as routine as getting a blood test—helping doctors diagnose disease earlier and choose the right treatments.

Rapid Whole-Genome Sequencing in Critical Care

Ultra-fast whole-genome sequencing (WGS) is transforming critical care by providing genetic diagnoses in hours rather than weeks. Companies like Illumina and PacBio have developed high-speed sequencing platforms that help diagnose rare genetic diseases in newborns, enabling faster treatment decisions. In neonatal intensive care units, rapid WGS has already saved lives by identifying treatable genetic disorders before symptoms worsen. Hospitals are also adopting rapid sequencing for sepsis, cancer, and other urgent conditions where genetic insights can guide immediate treatment. The decreasing cost of sequencing and improvements in AI-driven variant interpretation are making rapid WGS more accessible. In 2025, more hospitals could start to integrate ultra-fast sequencing into emergency and intensive care settings, improving the speed and accuracy of genetic diagnoses.

Dark Genome Exploration Unlocks Hidden Functions

Noncoding DNA, or the "dark genome," makes up more than 98% of the human genome, but no one knows why it exists or if it serves a purpose. Recent advances in long-read sequencing, AI-driven annotation, and epigenetic mapping are starting to help researchers understand the role of noncoding regions in gene regulation and disease. Scientists have discovered that noncoding regions contain enhancers, silencers, and regulatory elements that influence gene expression. Mutations in these regions are now linked to diseases such as autism, schizophrenia, and cancer.

Metagenomics

Metagenomics represent a new approach in a genomic analysis. Simply put: imagine dealing with one box full of 10 different jigsaw puzzles. In this analogy, each puzzle represents the DNA of a different organism living in a particular environment. The challenge of metagenomics is to sort out these pieces and put together each individual puzzle correctly. As researchers are considering new therapies or trying to understand how a virus or pathogen works, they need contextual data to understand cause and effect. New metagenomics tools help scientists solve several puzzles at once to understand the diverse range of life forms coexisting in a specific environment. This is crucial for gaining insights into how these microorganisms interact with each other, with humans, and with the environment. It's a complex task but offers valuable information for various applications, from health care to environmental science. Metagenomics can detect viruses on food items, helping to trace the source of microbial and viral contamination and improving food safety.

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It's effective in cleaning up pollutants, by helping to identify microorganisms that can degrade toxic substances more efficiently than other methods. And it's being used to identify how microorganisms compete and communicate in different environments, from human digestive tracts to deep-sea vents. For example, Israel-based BiotaX developed TaxonAI, a model that uses AI to explain biological data based on gene functionality or taxonomy.

Quantum Biology

Quantum biology is an emerging field that combines quantum physics—the science of the very small—with biology, the study of living things. Researchers apply the principles that govern subatomic particles to understand how living organisms work at a fundamental level. For business leaders, this matters because quantum biology has the potential to influence various industries. It can lead to breakthroughs in medicine, by improving drug design or understanding diseases at a molecular level. In technology, it could inspire new, more efficient ways of data processing and energy storage. This exciting frontier blends the most basic elements of our universe with the complexity of life, opening up a world of possibilities for innovation and advancement in multiple fields. One experiment has already yielded results: At the Johns Hopkins University Applied Physics Laboratory in Maryland, researchers found striking similarities between an enzyme central to human metabolism and a magnetically sensitive protein found in birds. This deepens the understanding of magnetosensitivity—but in practical terms, it also potentially transforms the approach to studying biological navigation mechanisms.

Pangenome: What Makes Us Human

The Human Genome Project has been "completed" multiple times, yet the understanding of genetic diversity continues to evolve. In 2025, the pangenome will continue to reshape the understanding of genomics by mapping the DNA of 47 individuals from diverse backgrounds, capturing previously overlooked genetic variations. Unlike the traditional reference genome—largely based on a single individual—the pangenome reveals how DNA varies across populations, highlighting rare mutations, structural changes, and evolutionary hot spots. Researchers from the Human Pangenome Project plan to eventually expand this atlas to 300 genomes, making genomic research more inclusive and equitable. The pangenome's graph-based approach allows scientists to compare multiple genetic sequences at once, improving disease research and diagnostics. This shift addresses reference bias, ensuring that genomic analysis doesn't overlook genetic differences unique to certain populations. With new sequencing technologies like long-read sequencing from Pacific Biosciences and advanced computational tools, the pangenome is becoming a foundational resource. Though still in its draft stage, this effort is expected to transform medicine, ancestry studies, and evolutionary biology. As experts acknowledge, the human genome will never be truly finished—every population and generation bring new insights, making genome sequencing an ongoing and ever-expanding endeavor.

Unlocking Bioinformatics Data

Rapid advancements in technology and a steep decline in sequencing costs are advancing the use of bioinformatics data. Scientists use this data—biological information stored digitally, primarily focusing on genetic and molecular data—to investigate all sorts of questions: How do certain diseases affect our bodies at the molecular level? Can we design new medicines to treat these diseases? How do different species evolve and adapt to their environments? But there are challenges in understanding it. Sequencing an individual's entire genome now generates a staggering 100 gigabytes of raw data, a figure that more than doubles post-analysis with the application of deep learning and natural language processing tools. Genome analysis pipelines are struggling to keep pace with this explosion of data. The complexity and computational intensity of sequencing analysis, which involves myriad steps to identify genetic variations, are monumental tasks requiring sophisticated technological solutions. Recent advances in deep

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learning and AI generally are significantly improving the process of DNA sequencing, making it faster, more accurate, and less expensive. Nvidia, which makes powerful GPUs, now has Clara, a suite of computing platforms, software, and services that powers AI solutions for health care and life sciences, from imaging and instruments to genomics and drug discovery. Reading, sequencing, and analyzing bioinformatics data using technological breakthroughs have practical, real-world applications, such as quickly identifying genetic disorders in newborns or discovering new targets for drug development.

Ancient DNA Reveals Hidden Chapters of Human History

Advances in ancient DNA (aDNA) sequencing are reshaping our understanding of early human migration, evolution, and interaction with other species. A groundbreaking 2024 study by researchers at the Max Planck Institute for Evolutionary Anthropology has sequenced the oldest modern human genomes yet, revealing new insights into the first humans who arrived in Europe 42,000–49,000 years ago. These genomes, extracted from remains in Germany and the Czech Republic, show that these individuals were part of a small, closely related group that split from the main population migrating out of Africa around 50,000 years ago. Surprisingly, despite living alongside Neanderthals, these early modern humans do not show signs of recent interbreeding, suggesting they may have taken a different migration route into Europe. The study also confirms that all present-day non-African populations share Neanderthal ancestry from a single ancient admixture event between 45,000–49,000 years ago. Beyond human history, aDNA research is uncovering lost species, revealing the origins of pandemics, and even authenticating medieval documents through the DNA of the animal skins they were written on. Scientists analyzing medieval parchments have identified rare genetic patterns in historic cattle, helping to date and verify centuries-old manuscripts. Projects like the Francis Crick Institute's 1,000 Ancient Genomes initiative are expanding the genetic diversity map, shedding light on ancient populations that shaped modern humans. With continued advancements in sequencing technology, aDNA research is poised to further bridge the past and present, providing unparalleled insights into the evolution of humans, animals, and historical artifacts. As our ability to extract and analyze ancient DNA improves, we are unlocking an ever-growing archive of genetic history, rewriting the story of life on Earth.

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It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change.

Charles Darwin

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Lab-Grown Organs: The New Frontier in Transplant Medicine Takes Shape

The future of organ transplantation is being shaped by remarkable advances in bioprinting technology. Companies like United Therapeutics and 3D Systems are at the forefront of this transformation, developing sophisticated bio-inks and breakthrough vascularization techniques that are essential for creating viable organs. Their focus on kidneys and lungs represents a critical step forward, as these organs are among the most needed for transplantation worldwide. The innovation lies not just in the printing process but in creating the intricate network of blood vessels necessary for organ survival. This vascularization challenge has been a major hurdle in tissue engineering, but recent developments in multi-material printing and biomaterial design are yielding promising results. Research teams have successfully demonstrated the ability to print increasingly complex vascular networks that can support living tissue. While fully functional transplantable organs are still years away, the rapid pace of advancement suggests we could see the first bioprinted organs in clinical trials within the next decade. This development could unlock new options in the field of transplant medicine, potentially eliminating organ waiting lists and saving countless lives through custom-made, rejection-free organs.

Next-Gen Bioprinters Create Living Tissue With Multiple Cell Types

The evolution of bioprinting technology has reached a pivotal moment with the emergence of sophisticated multi-material printing capabilities. Industry leaders like CELLINK and Organovo are pioneering platforms that can seamlessly integrate multiple cell types and biomaterials within a single printing process, representing a quantum leap in tissue engineering capability. This advancement allows for the creation of more complex and functionally accurate tissue models that better replicate the intricate architecture of natural human tissues. The technology enables researchers to precisely position different cell types, growth factors, and structural components in three-dimensional arrangements that closely mirror native tissue environments. It's a breakthrough with immediate applications in drug development and testing, where more accurate tissue models can provide better predictions of drug efficacy and potential side effects. The ability to create these complex tissue structures also opens new possibilities in regenerative medicine, potentially enabling the replacement of damaged or diseased tissue with custom-printed alternatives. The technology's precision and versatility are particularly valuable for creating tissue models of complex organs, where multiple cell types must work together in specific spatial arrangements to achieve proper function.

Printed Skin Gets Green Light For Burn Care

Bioprinted skin grafts assist in the treatment of severe burns and chronic wounds, and are one of the first bioprinted tissues to enter clinical trials. Companies like Epibone and Poietis are pushing the boundaries of skin bioprinting by developing full-thickness skin equivalents that include complex structures like sweat glands and hair follicles. This breakthrough represents a significant improvement over traditional skin grafts: Printing custom-sized grafts using a patient's own cells reduces the risk of rejection while ensuring optimal coverage of wound areas. The technology incorporates multiple layers of different cell types that integrate with the host tissue, accurately mimicking the natural structure of human skin. Beyond treating burns, these advanced skin constructs are finding applications in cosmetic testing, reducing the need for animal trials, and in studying skin diseases. This personalized approach to wound healing marks a significant step forward in reconstructive medicine, offering hope to millions of patients worldwide suffering from severe skin injuries and chronic wounds.

Printing Custom Bone Implants

Three-dimensional printed bone scaffolds combine bioactive ceramics with living stem cells to create personalized implants. The groundbreaking research at Harvard and

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Rice universities has yielded implants that actively integrate with a patient's natural bone tissue, significantly accelerating the healing process. Precisely engineered to match the person's anatomy, these scaffolds incorporate specific porosity patterns that promote cell growth and vascularization. The bioactive materials used in these implants stimulate the body's natural bone regeneration processes, while their structural design provides immediate mechanical support. Their dual functionality represents a significant advancement over traditional bone grafts, which often struggle to properly integrate. And the incorporation of the patient's own stem cells further enhances the biological response, reducing the risk of rejection and complications. These custom implants will be particularly valuable in complex reconstructive surgeries where standard implants may not provide optimal results, shown by the technology's success in clinical trials. We're nearing a future of personalized bone replacements becoming the standard of care in orthopedic surgery.

Zero G Bioprinting

NASA and ESA's investment in bioprinting technology for space applications is opening new frontiers in space medicine and long-term space habitation. Specialized bioprinters can operate in microgravity environments, addressing the unique challenges astronauts face during extended space missions. These systems must overcome the fundamental effects of zero gravity on fluid dynamics and cell behavior, requiring innovative approaches to bioink formulation and printing processes. The ability to produce tissue replacements and medical supplies on demand could prove crucial for future deep space missions where resupply from Earth is impractical. Beyond immediate medical applications, this technology is essential for studying how human tissues respond to the space environment and developing countermeasures against the physiological effects of long-term space exposure. The research has broader implications for Earth-based medicine, as the unique constraints of space-based bioprinting drive innovations in tissue engineering techniques. This technology could become a critical component of humanity's infrastructure for space exploration and colonization.

Custom Tissue Banks Will Drive Personalized Medicine

Patient-specific bioprinting is helping to accelerate the field of personalized medicine by enabling the creation of custom tissue constructs tailored to individual patient needs. Major hospitals are starting to form the earliest stages of strategic partnerships with biotechnology firms to establish dedicated bioprinting facilities capable of producing patient-matched tissue grafts on demand. This approach combines advanced imaging technologies with precise bioprinting capabilities to create tissues that exactly match the patient's anatomy and cellular composition. Using a patient's own cells as the starting material significantly reduces the risk of immune rejection, a common complication in traditional transplant procedures. The technology is particularly valuable in reconstructive surgery, where custom-designed tissues can better restore both form and function. These facilities are also serving as valuable research centers, advancing our understanding of tissue engineering and regenerative medicine. The standardization of these processes is creating new protocols for quality control and regulatory compliance, paving the way for broader adoption of bioprinted tissues in clinical practice. This personalized approach represents a significant shift in how tissue replacement and regenerative therapies will develop.

Smart Machines Create Complex Living Tissue

The integration of bioprinting with robotics and microfluidics is creating unprecedented capabilities in tissue engineering. Hybrid systems developed by the Wyss Institute and Carnegie Mellon combine multiple fabrication technologies to create more complex and functional tissue constructs. These advanced platforms incorporate precise robotic control systems with sophisticated microfluidic networks, delivering nutrients and removing waste products in real time. Combining robotics

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and microfluidics lets researchers harness both the precision of the former and the control over fluid dynamics of the latter, creating new possibilities for engineering larger, more complex tissues that better mimic natural organ function. These systems can dynamically adjust printing parameters based on real-time feedback, ensuring optimal conditions for cell survival and tissue formation. Integrating multiple fabrication methods enables the creation of hierarchical structures that more closely replicate natural tissue architecture. This convergence of technologies represents a significant step forward in our ability to create complex, living tissue structures.

Expanded Organoid Use

An organoid is a miniature, lab-grown 3D tissue model that mimics the structure and function of real organs. Created from stem cells or organ-specific progenitor cells, organoids self-organize into complex, functional units resembling small versions of human organs, such as the brain, liver, kidneys, lungs, intestines, or pancreas.

Already, liver organoids are transforming drug safety testing and the understanding of liver disease. Biotech companies like Emulate Bio are leveraging these miniature liver models to replicate key aspects of liver function, including metabolic processes and detoxification pathways that are crucial for drug processing. The technology enables researchers to observe how different drugs affect liver tissue in real time, helping them predict drug toxicity before compounds enter clinical trials and providing early warnings of potential hepatotoxicity. These liver models incorporate multiple cell types arranged in physiologically relevant structures, allowing them to mimic complex liver functions more accurately than conventional cell cultures. And the ability to maintain these organoids for extended periods enables long-term toxicity studies that were previously impossible. This advancement is particularly valuable for identifying drugs that might cause rare but serious liver complications, potentially preventing costly late-stage drug failures and improving patient safety.

Gut Models Mirror Human Digestive System

Scientists are making remarkable progress in developing sophisticated gut organoids that incorporate living microbiomes, creating powerful new tools for studying gastrointestinal diseases and drug interactions. These advanced models replicate the complex exchange between human intestinal tissue and gut bacteria, providing unprecedented insights into conditions like Crohn's and inflammatory bowel diseases. Integrating living microorganisms with human intestinal cells creates a more complete and accurate representation of the gut environment, enabling researchers to study how different bacterial populations affect disease progression and treatment outcomes. These models are particularly valuable for understanding how drugs interact with both human tissue and gut bacteria, helping to predict potential complications and optimize treatment strategies. The ability to maintain stable bacterial populations within these organoids represents a significant technical achievement, opening new possibilities for studying the role of the microbiome in human health and disease.

Brain Models Open Window To Neural Disease

The development of sophisticated brain organoids is transforming our understanding of neurological conditions and potential treatments. Research institutions like the Allen Institute and The Max Planck Society are using these three-dimensional neural tissues to model complex conditions such as Alzheimer's, epilepsy, and autism spectrum disorders. These miniature brain-like structures replicate key aspects of human brain development and function, providing unprecedented insights into neurological disease mechanisms. Being able to grow these organoids from patient-derived cells allows researchers to study disease progression in a personalized context, potentially leading to more effective, targeted therapies. These models capture complex neural networks and cellular interactions that are impossible to study in traditional two-dimensional cell cultures; they also

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allow scientists to observe long-term neural development and disease progression, providing new opportunities to test potential therapeutic interventions. This approach is particularly valuable for studying conditions that are difficult to model in animals or observe in human patients.

Global Biobanks Improve Disease Research

Large-scale organoid biobanks are creating powerful new resources for medical research and drug development. Organizations like the Broad Institute are building comprehensive collections of patient-derived organoids that represent diverse genetic backgrounds and disease states. These living biobanks serve as invaluable repositories for studying disease progression, genetic variation, and treatment response across different populations. Standardized protocols for organoid creation and maintenance ensure consistent quality and reproducibility, making these resources particularly valuable for large-scale studies. These collections are also democratizing access to advanced disease models, enabling researchers worldwide to study rare conditions and diverse patient populations. And when detailed genetic and clinical data are integrated with these organoid collections, they create powerful tools for understanding disease mechanisms and developing new therapeutic strategies. This systematic approach to organoid banking is accelerating the pace of discovery in regenerative medicine and personalized therapeutics.

Engineering New Life Forms

The engineering of synthetic organisms with custom-designed genetic codes represents a new frontier in biotechnology. Companies like Ginkgo Bioworks and Viridos are pioneering the development of artificial microbes with precisely engineered genetic systems designed for specific industrial applications. Researchers are using these synthetic organisms to produce biofuels, synthesize complex pharmaceutical compounds, and tackle environmental challenges through enhanced metabolic capabilities. The ability to design and construct custom genetic systems represents a fundamental shift in how we approach biological engineering: We are moving from modification of existing organisms to the creation of purpose-built biological systems. These engineered life forms incorporate novel genetic codes and metabolic pathways that don't exist in nature, expanding the possibilities for biological production and problem-solving. The technology requires sophisticated safeguards to ensure these organisms cannot survive outside controlled environments, addressing important biosafety considerations.

CRISPR Opens New Chapter in Animal Research

Laboratories worldwide are creating precisely engineered animals with specific genetic modifications—sometimes to better replicate human disease conditions for study, sometimes to produce human-compatible organs for transplantation. This technology enables the creation of pigs with organs that have been modified to reduce rejection risks in human recipients, potentially addressing the critical shortage of donor organs. It has also allowed researchers to use the precision of CRISPR editing to create mouse models with the exact genetic mutations found in human diseases, providing more accurate platforms for studying disease mechanisms and testing potential treatments. These engineered animals are particularly valuable for studying complex genetic disorders and developing new therapeutic strategies. The ability to make multiple precise genetic modifications is advancing our understanding of gene function and disease processes.

Smart Bacteria Target Disease From Within

At MIT, researchers are creating sophisticated bacterial biosensors capable of detecting specific disease markers and responding with targeted therapeutic interventions. These engineered bacteria are designed to survive and function within the human body, serving as living diagnostic and therapeutic agents. The technology combines advances in synthetic biology with precise genetic control

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systems; together, they enable bacteria to produce therapeutic compounds in response to specific molecular signals. These smart bacteria are particularly promising for treating conditions that are difficult to address with conventional therapies, such as gastrointestinal disorders and certain types of cancer. It's a powerful new tool for precision medicine: Living therapeutic agents programmed with multiple sensing and response capabilities can continuously monitor and respond to changes in their environment, providing dynamic treatment responses.

Living Robots

What do you get when you combine a cluster of stem cells from an African clawed frog, a supercomputer, a virtual environment, and evolutionary algorithms? In 2020, after 100 generations of prototypes, researchers at Tufts University and the University of Vermont discovered the answer was a tiny blob of programmable tissue called a xenobot. These living robots mark a groundbreaking achievement in biology: a new class of programmable living machines with potential applications in medicine and environmental remediation. They can undulate, swim, and walk. They work collaboratively and can even self-heal. And they're tiny enough to be injected into human bodies, travel around, and—maybe someday—deliver targeted medicines. While technically they're made up of living cells, researchers are quick to point out that xenobots lack the characteristics of a traditional biological life-form. The current crop of xenobots live longer, and they can sense what's in their environment. They can also operate in robot swarms to complete a collaborative task. Xenobots are being used to help researchers understand how defects in the hairlike structures in our lungs, called cilia, can result in diseases. Also in progress: xenobots that can travel to a damaged spinal cord and repair it with regenerative compounds. The self-organizing properties of these living machines provide insights into developmental biology and tissue engineering, potentially leading to new approaches in regenerative medicine.

Animal-Human Hybrids Promise Organ Solutions

The development of chimeric embryos containing human cells represents a controversial but potentially transformative approach to addressing the global organ shortage crisis. Researchers at Stanford and Japan's RIKEN Institute are advancing techniques to grow human-compatible organs within animal hosts, primarily focusing on pigs and sheep. This approach involves introducing human stem cells into animal embryos, creating chimeric organisms that grow organs containing human cells. The technology requires precise control over cell development to ensure human cells contribute primarily to the desired organs while minimizing their presence in other tissues, particularly the brain. These chimeric approaches offer several advantages over traditional bioprinting, including the natural development of complete vascular systems and supporting structures. The research addresses critical technical challenges, including immune compatibility and proper organ development, while navigating complex ethical considerations. This technology could potentially provide a renewable source of transplant-compatible organs, addressing one of medicine's most pressing challenges.

Bioprinting Electronics

In a groundbreaking development that blurs the lines between biology and technology, researchers at UK-based Lancaster University successfully 3D printed glowing shapes inside nematode worms, demonstrating the potential to embed electronics directly within living organisms. The team leveraged a photonic 3D printer and a special ink that shapes and activates the material within the organism. By feeding this ink to nematode worms, the team was able to create intricate conductive circuits in the shape of stars and squares inside the living worms. This technique suggests potential for improving traditional electronic implants, such as pacemakers and bionic ears, which have transformed medical treatments but come with their own set of challenges, including infection risks and maintenance difficulties. The Lancaster team's work is part of

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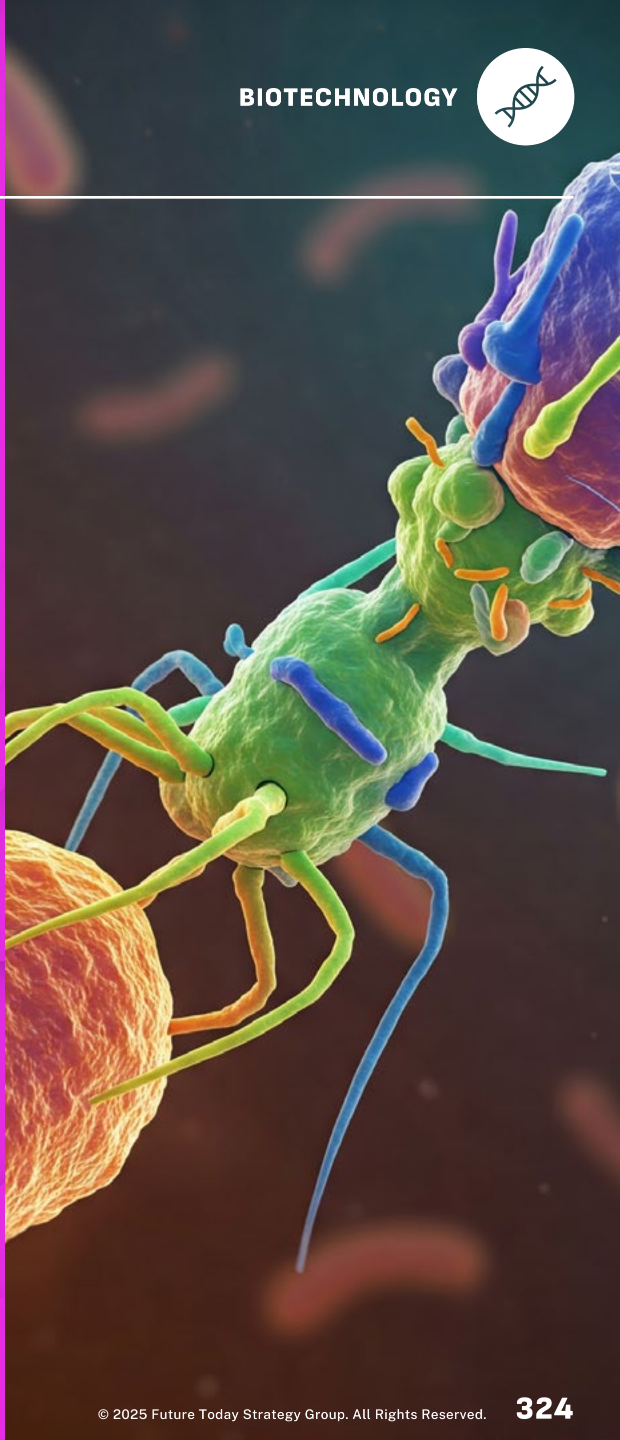
a growing trend in bioprinting electronic implants and computer-brain interfaces, which could eventually replace the medical devices we use today.

Bacterial Nanosyringes

In an emerging advancement bridging microbiology and medicine, researchers are transforming bacteria into nanosyringes capable of targeting human cells for precise protein delivery. This innovative approach, redefining the boundaries of targeted medical treatments, could dramatically improve the effectiveness and safety of therapies for many different health conditions, including cancer. Some of the most powerful drugs are made up of small molecules that indiscriminately enter cells and cause unintended side effects. Large molecules like proteins could offer targeted and potent therapeutic benefits, but have one big challenge: They can't get through cell membranes. This is where the bacterial nanosyringes come into play, offering a solution already found naturally in bacteria like Photorhabdus that can inject their contents directly into targeted cells. Researchers at the Zheng Lab at MIT, led by Joe Kreitz and his team, have managed to harness this natural mechanism, using Google DeepMind's AlphaFold AI program to adapt nanosyringes to bind to specific human proteins. This breakthrough technique has already demonstrated its potential in lab settings, successfully delivering various proteins to targeted human cells and even to neurons in mice.

Bacteriophage Therapies Gain Momentum in Antibiotic Resistance Fight

Bacteriophages, also known as phages, are viruses that infect and replicate only in bacterial cells. They are ubiquitous in the environment and are recognized as the most abundant biological agent on earth. With antibiotic resistance becoming a global crisis, phage therapy is emerging as a viable alternative to traditional antibiotics. In 2025, researchers and biotech firms like BiomX and Locus Biosciences are accelerating clinical trials for personalized phage treatments, targeting antibiotic-resistant bacterial infections. Unlike broad-spectrum antibiotics, phages are highly specific, attacking only the harmful bacteria while preserving beneficial microbiomes. Recent FDA-approved compassionate use cases have shown remarkable success in treating chronic infections, such as multidrug-resistant Pseudomonas in cystic fibrosis patients. Advances in synthetic biology are also allowing scientists to engineer phages with enhanced antibacterial properties, such as toxin-neutralization and immune modulation. As regulatory frameworks evolve, phage-based precision medicine could become a mainstream solution for combating superbugs in hospitals, agriculture, and environmental health.



SCENARIO YEAR 2058

GENETIC UNIFORMITY TRIGGERS GLOBAL AGRICULTURAL COLLAPSE

The world's greatest agricultural efficiency has become its undoing. Global food corporations celebrated CRISPR gene editing as their path to unprecedented standardization—poultry with identical growth rates, swine with perfectly uniform meat marbling, cattle producing mathematically precise milk formulas. This optimization transformed animal agriculture into a precision industry, with predictable yields driving record profits. But nature had other plans. When a previously benign agricultural virus mutated in 2058, it encountered a perfect storm: billions of genetically identical animals with no diversity to provide natural resistance. The virus spread exponentially through standardized livestock populations, decimating global food production within months. Governments' desperate attempts to resurrect genetic diversity through frozen pre-CRISPR samples proved insufficient against the scale of the crisis. In their quest to master nature through genetic engineering, humans had forgotten nature's first law: Diversity equals survival.

BIOCOMPUTING

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Organoid Intelligence

To meet AI's growing computational needs, there's a shift away from traditional Von Neumann architecture toward more innovative approaches. One is neuromorphic computing, inspired by the brain's structure, which efficiently handles simultaneous information storage and processing. That's what led researchers at Johns Hopkins to create organoid intelligence (OI), which uses biological materials—most often human brain cells—for information processing, leveraging their inherent capabilities beyond silicon-based systems. This is considered the next frontier of biocomputing, and represents a significant step in harnessing the brain's natural efficiency for AI applications. In 2023, a biocomputing system made of living brain cells learned to recognize the voice of one person from a set of 240 audio clips of eight people pronouncing Japanese vowel sounds. The clips were sent to the organoids as sequences of signals arranged in spatial patterns. Why bother inventing technology that sounds like it was inspired by a dystopian sci-fi novel? As the world demands more AI applications like ChatGPT, we'll need more energy-intensive computers and networks to crunch all that data. OI might be able to perform all of those tasks using a fraction of the resources required of a traditional computer.

Living Computers: Biological Circuits for Data Processing

Scientists at the Spanish National Research Council genetically modified a strain of E. coli called Marionette so that it could sense different chemicals and respond to them. But that wasn't all. They modified the strain so its plasmids each encoded for a different fluorescent protein (red and green). While the researchers could alter the ratio of the red and green with future chemical inputs, without inputs, the ratio would simply stay constant and, in a way, was a form of memory. Here's where things got interesting: The team grew the Marionette strain in eight wells that correspond with the outer squares of a grid and taught it how to play tic-tac-toe. Initially, the bacteria played randomly, but the Spanish National Research Council team trained the strain by adding chemicals to the squares—and after eight sessions, the bacteria played at an expert level. While the bacteria haven't yet beat humans at the game, there's an interesting analogy worth remembering: The benchmarks in computing and specifically in AI have always been gameplay. And this isn't the only biological computer. A biocomputer called DishBrain learned how to play the 1980s video game Pong. DishBrain is made of ~1 million live human and mouse brain cells grown on a microelectric array that can receive electrical signals. The signals tell the neurons where the Pong ball is, and the cells respond. The more the system played, the more it improved. Cortical Labs is now developing a new kind of software, a Biological Intelligence Operating System (biOS for short), which would allow anyone with basic coding skills to program their own DishBrains.

DNA Machines Process Data At Molecular Scale

Scientists at Shanghai Jiao Tong University achieved a significant breakthrough in DNA computing by creating the world's first programmable DNA computer capable of executing billions of unique circuits. The system uses DNA molecules as its fundamental computing elements, leveraging nature's information storage mechanism instead of traditional silicon-based components. The researchers ingeniously solved the challenge of random molecular movement by designing DNA sequences that fold into specific shapes, effectively creating molecular-scale computer components that guide data flow. In practical demonstrations, the system successfully performed complex calculations including square root operations and identified genetic markers for kidney disease. While current processing speeds are relatively slow compared to traditional computers, taking hours for simple computations, the technology shows particular promise for biomedical applications, especially in

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detecting specific genes and triggering targeted biological responses.

DNA as an Alternative to Future Data Storage

The world is generating data at an exponential rate, outpacing current storage technologies like magnetic tape. By 2030, global storage demand is expected to exceed supply by 20 million petabytes, making traditional solutions unsustainable. DNA data storage—in the form of manufactured DNA—could become an alternative to traditional hardware thanks to its high density, longevity, and stability. DNA can store vast amounts of information—potentially all data on the internet in a sugar-cube-sized volume—lasting thousands of years without degradation. Current methods encode digital data into DNA sequences using chemical synthesis, but future approaches will use semiconductor chips and enzymatic synthesis, improving scalability and efficiency. Organizations like Microsoft, Twist Bioscience, and the DNA Data Storage Alliance are actively developing commercial DNA storage solutions. But while the medium can scale, it's not yet ready for widespread use. There are several challenges, including writing speed and cost, which must improve by eight orders of magnitude to compete with today's storage devices. The ability to read and write DNA rapidly will also accelerate biotech applications, enabling custom microbes, synthetic organisms, and biological countermeasures. While DNA storage offers an unprecedented solution to data challenges, it also introduces cybersecurity risks, as synthetic DNA could be used for both medicine and bioterrorism. As digital and biological systems merge, cyberbiosecurity will become critical.

CYBERBIOSECURITY

CYBERBIOSECURITY

DNA Technology Gets New Security Shield

The advancement of gene editing and synthetic biology capabilities has necessitated robust cyberbiosecurity measures to prevent potential misuse of DNA synthesis technologies. Leading biotechnology firms and government agencies are implementing sophisticated AI-driven screening systems to detect and block potentially dangerous genetic sequences. These security measures include advanced algorithms that can identify sequences associated with harmful pathogens or toxins, ensuring that synthetic biology remains a safe and ethical field. The screening systems analyze DNA synthesis orders in real-time, comparing them against databases of known hazardous sequences. This proactive approach to biosecurity includes multiple layers of verification and authentication, protecting against both intentional misuse and accidental synthesis of dangerous materials. The technology represents a critical safeguard for the expanding field of synthetic biology.

Biohack Rules Tighten As Field Grows Rapidly

The expanding DIY biohacking movement has prompted increased attention to cyberbiosecurity concerns from major regulatory bodies. The FDA and DARPA are spearheading new initiatives in 2025 to implement more stringent oversight of open-source bioengineering tools and techniques—aiming to balance innovation with safety, keeping advances in synthetic biology accessible while preventing misuse.These regulations establish comprehensive frameworks for ethical guidelines and cybersecurity protocols to prevent unauthorized genome editing and potential bio-cyberattacks. They include verification systems for equipment purchases, mandatory training requirements, and enhanced monitoring of biological research activities.These frameworks address emerging challenges in biological security, including the potential for unauthorized genetic modifications and the creation of synthetic organisms. The implementation of these regulations represents a significant step in professionalizing and securing the growing field of DIY biotechnology.

DNA Supply Lines Get New Digital Defense

The growth of cloud-based platforms in genetic engineering and biomanufacturing has created new vulnerabilities in biotechnology supply chains. Industry leaders are responding by implementing zero-trust security frameworks and blockchain-based verification systems to protect the integrity of critical components and processes. These security measures ensure the authenticity and safety of DNA synthesis materials, CRISPR reagents, and biofabrication processes. The technology includes end-to-end tracking of biological materials, secure digital signatures for verification, and real-time monitoring of supply chain activities. These advanced security protocols are essential for maintaining the reliability and safety of synthetic biology operations, particularly as the industry becomes more dependent on digital infrastructure. As companies implement them, it represents a crucial step in protecting the expanding biotechnology supply chain.

Bio-Defense Gets Smart Computer Upgrade

The integration of biocomputing with advanced threat detection systems is starting to shape our ability to respond to bioterrorism and pandemic risks. Military and public health organizations are investigating sophisticated synthetic biology-based sensors that work alongside AI-powered pattern recognition systems to identify engineered pathogens. This convergence of biocomputing and cyberbiosecurity will lay the foundation for detecting and responding to biological threats. The technology will eventually allow real-time monitoring of potential pathogens, rapid sequence analysis of unknown organisms, and automated threat assessment capabilities. This integration represents a significant advance in our ability to protect against both natural and engineered biological threats. By combining multiple detection technologies with advanced computing capabilities, organizations can achieve unprecedented speed and accuracy in identifying potential biological threats.

REGULATION AND POLICY

REGULATION AND POLICY

Europe: EU AI Act Sets New Global Standard for Biotech Safety

The European Union's comprehensive AI Act has fundamentally reshaped the biotech and health care landscapes, establishing unprecedented requirements for transparency and accountability. Major players like Roche and Siemens Healthcare must now document every AI decision-making process in their medical applications, from diagnostic algorithms to drug discovery models. The regulations require companies to demonstrate how their AI systems avoid bias in genomic analysis and ensure equitable treatment recommendations across diverse populations. Early implementation has revealed significant challenges, with several firms investing heavily to improve compliance infrastructure. The act mandates regular algorithmic audits, particularly for high-risk applications like AI-guided robotic surgery and automated drug dosing systems. Health care providers must maintain detailed records of AI involvement in patient care, while biotech researchers need to document their AI models' training data and decision pathways. Initially, industry leaders reported that these requirements slowed innovation; but now, they are improving system reliability and patient trust.

Europe: New Standards for Bioengineered Food Safety

The European Commission's overhaul of GMO and gene-edited crop regulations establishes the world's most comprehensive framework for bioengineered food safety. The new requirements mandate detailed genetic mapping of all modifications, regardless of technique used, and introduce a novel environmental impact assessment system. Companies must now track potential effects on local ecosystems for five years post-approval, including monitoring the crop's effect on beneficial insects and soil microbiomes. The regulations require food producers to implement labeling systems that provide consumers with complete genetic modification details and cultivation methods. Early implementation has revealed challenges in standardizing testing protocols across EU member states, but has also spurred innovation in environmental monitoring technologies.

Europe: Bold Stance on Human Embryo Research

The European Parliament's proposed framework for human embryo research and gene editing represents a watershed moment in bioethical regulation. The guidelines establish clear boundaries between permitted therapeutic applications and prohibited genetic enhancement, with particular focus on hereditary implications: Somatic gene therapy for specific genetic disorders is allowed, with strict protocols for patient selection and monitoring. Research institutions must now implement comprehensive oversight systems, including mandatory ethics board review for all embryo-related studies. The framework introduces standardized reporting requirements for all embryo research, creating the world's most comprehensive database of outcomes and safety data. Notable provisions include mandatory long-term follow-up studies for any approved therapies and strict controls on international collaboration. While some scientists argue these measures could slow breakthrough treatments, patient advocacy groups largely support the enhanced protections. The regulations have already influenced similar policy discussions in other regions.

China: AI Reshapes Drug Approval Process

China's pharmaceutical landscape is transforming as the country's National Medical Products Administration (NMPA) implements groundbreaking fast-track protocols for AI-designed drugs. This strategic shift aims to accelerate the country's competitive position against Western pharmaceutical giants. Early results show promising outcomes, with three AI-discovered compounds already entering clinical trials. Leading Chinese biotech firm XtalPi has leveraged machine learning algorithms to identify novel drug candidates for treating resistant cancers, reducing discovery time from years to months. Meanwhile, Insilico Medicine's Shanghai facility has developed an AI platform that screens billions of potential molecules daily, significantly

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outpacing traditional methods. The expedited review process has attracted major investments, with venture capital flowing to Chinese AI drug discovery startups. However, some experts raise concerns about potential safety risks from accelerated approvals. The NMPA has responded by implementing additional post-market surveillance requirements and establishing a specialized AI drug safety monitoring system. This regulatory evolution marks a significant shift in global pharmaceutical development, potentially reshaping how new drugs reach patients worldwide.

China: DNA Data Protection Laws Signal New Cyberbio Era

Prompted by attempted breaches at three major Chinese genomic research centers, China's new comprehensive cyberbiosecurity framework represents the world's first targeted approach to protecting genetic data in the digital age. The legislation specifically addresses vulnerabilities in DNA sequencing databases, which have become increasingly attractive targets for cybercriminals and foreign intelligence agencies. The new measures require triple-layer encryption for genetic databases, mandatory security audits every six months, and strict access controls for international research collaborations. Chinese biotech giant BGI has already invested more than $100 million to upgrade its security infrastructure to comply with these requirements. The regulations have significant implications for global research partnerships, as foreign institutions must now establish dedicated secure data channels and undergo rigorous security clearance processes. Some international researchers argue these measures could slow scientific progress, but Chinese officials maintain that protecting genetic information is crucial for national security. The framework includes provisions for ethical AI use in genomic research and establishes clear penalties for violations.

US: Tightening Rules on Lab-Grown Meat and Modified Crops

The landscape of food regulation is shifting dramatically as the USDA and FDA implement new rules for bioengineered food products. Consumer advocacy groups have successfully pushed for unprecedented transparency in labeling and production methods. The regulations require cultured meat producers to disclose their exact growth medium compositions and gene-edited crop developers to map all genetic modifications. Major players like Upside Foods must now conduct extended shelf-life studies and provide detailed nutritional comparisons with conventional meat products. Notably, companies have to now track product performance through the entire supply chain, from lab to table. The rules establish a new certification process requiring third-party verification of safety claims and production methods. Environmental impact assessments become mandatory, examining everything from water usage in cell culture to energy consumption in bioreactors. Some smaller startups argue these requirements create significant market barriers, but industry leaders acknowledge their necessity for building public trust. The regulations have already influenced international standards, with several countries adopting similar frameworks for biotech food oversight.

US: CRISPR Human Trials Enter New Era of Safety Protocols

The NIH and FDA's approach to CRISPR-based human gene therapy oversight now include long-term patient tracking, extending up to 15 years post-treatment for certain genetic modifications. Research centers must now establish dedicated genetic monitoring facilities and maintain detailed mutation databases for each trial participant. The regulations introduce a tiered risk assessment system. Major medical centers have already begun expanding their genetic surveillance capabilities, with leading institutions investing in advanced sequencing technologies for continuous monitoring. The protocols mandate regular whole-genome sequencing to detect any off-target effects, creating the world's most comprehensive database of gene editing outcomes.

ETHICS, TRUST, AND ACCEPTANCE

ETHICS, TRUST, AND ACCEPTANCE

Regulating Human Gene Editing Intensifies

Governments worldwide are tightening regulations on CRISPR and germline editing, especially following concerns over designer babies and unauthorized genetic experiments. In 2025, organizations like the World Health Organization (WHO) and National Academies of Sciences are supposed to mandate stricter oversight, ensuring scientific transparency, informed consent, and long-term safety evaluations. New policies focus on balancing therapeutic gene editing—such as for sickle cell disease and inherited blindness—while restricting non-essential modifications. Meanwhile, governments in China, the US, and the European Union are aligning regulations to prevent loopholes that could lead to unethical practices. Public trust in gene editing is also influencing policy, with increased demands for independent review boards and bioethics committees to oversee research. As clinical trials expand, governments will need to address concerns about off-target effects, unintended genetic consequences, and the potential commercialization of human traits.

AI Ethics in Biomedicine Becomes a Priority

AI is transforming drug discovery, diagnostics, and genetic research, but ethical concerns about bias, data privacy, and transparency are growing. AI-driven systems often rely on biased datasets, leading to disparities in disease predictions and treatment recommendations, particularly for underrepresented populations. In 2025, regulatory bodies like the FDA, EU AI Act, and WHO have indicated they will implement stricter ethical frameworks to ensure fairness, accountability, and explainability in AI health care applications. Companies like Google DeepMind, IBM Watson Health, and others are under pressure to disclose AI decision-making processes, preventing misdiagnoses and discrimination in personalized medicine. Meanwhile, patient data privacy is a top concern, as hospitals and biotech firms increasingly use AI-driven genetic analysis. Governments are requiring stronger encryption, consent-based data sharing, and AI auditing protocols to maintain public trust. The push for human-in-the-loop AI, where human experts validate AI-generated decisions, is gaining momentum to prevent overreliance on algorithms in life-or-death scenarios.

Biotechnology Access Equity Becomes a Global Issue

Breakthroughs in gene therapy, regenerative medicine, and bioprinting are widening health care inequalities, with wealthy nations accessing cutting-edge treatments while poorer regions struggle. In 2025, global organizations like the WHO, Gates Foundation, and World Bank will push for biotech equity policies, ensuring that life-saving innovations reach underprivileged communities. Personalized gene therapies for cancer, rare diseases, and inherited disorders remain prohibitively expensive, sparking debates about pricing, patent monopolies, and fair distribution. Nations with strong biotech industries—such as the US, China, and Germany—are facing pressure to lower costs and support international access to breakthrough therapies. Meanwhile, companies like CRISPR Therapeutics and Vertex Pharmaceuticals are exploring tiered pricing models and generic alternatives to make treatments more affordable. The conversation is also shifting toward bioprinted organs, which could improve transplant medicine but risk becoming exclusive to the wealthy if pricing remains high. Some governments are introducing subsidy programs and ethical guidelines to ensure that biotechnology advances serve all populations, not just those who can afford them.

Resolving Bias in Genome Research

Overwhelmingly, the majority of people who have had their genomes sequenced come from affluent Caucasian Americans and Europeans; fewer than 2% are from Africa. This excludes an enormous number of people from the benefits of genetic research, so there is now increased attention and funding to diversify this pool. H3Africa works with African investigators to determine genomic and environmental determinants of common diseases. The Non-Communicable Diseases Genetic

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Heritage Study consortium, based in Nigeria, is creating a comprehensive catalog of human genetic variation among Nigerians. A decade-long Three Million African Genomes project is also underway to locate missing genetic variants from ancestral genomes in Africa. It would build an African biobank of clinical information and could lead to a more equitable future of genetic research.

Calls For Responsible Gene Editing

In 2018, Chinese scientist He Jiankui caused a global uproar by announcing he had created the world's first gene-edited children using CRISPR technology, targeting embryos to make them resistant to HIV. This led to the birth of twins, marking a controversial milestone in genetic editing. He's actions, deemed "illegal medical practices" in China, resulted in a three-year prison sentence for him and his two associates, partly because the genetic alterations could be passed down to future generations. Following the scandal, China tightened regulations on human gene editing and banned He from conducting any reproductive technology services. Despite these restrictions, late in 2023, He proposed a new study focused on editing mouse and human embryos to investigate potential protection against Alzheimer's disease, citing the urgent need to address the challenges posed by an aging population and the current lack of effective treatments for Alzheimer's. This latest proposal's reception remains mixed, reflecting ongoing dilemmas over the boundaries of genetic research, but has reignited ethical debates and concerns within the scientific community. A dozen countries have now banned germ line engineering in humans, though their ranks do not include China, which tightened regulations without banning the practice outright. Federal law in the US regulates the use of federal funds for research on human germline gene therapy—though these laws are notoriously politicized and have changed a few times in the past decade. The EU's Convention on Human Rights and Biomedicine said tampering with the gene pool would be a crime against human dignity and human rights. But all those declarations were made before it was actually possible to precisely engineer the germ line. Now, with CRISPR, it is possible.

Engineering Super Soldiers

A team of military medical scientists in China reported that they have enhanced human embryonic stem cells' resistance to radiation by inserting a gene from the water bear, a microorganism known for its extreme survival skills. Using CRISPR technology, they found they could get a high percentage of the modified cells to survive under lethal radiation exposure. The research, led by professor Yue Wen at the Academy of Military Sciences in Beijing, has sparked interest (read: alarm) since its publication, because of the implication: What if this is used to create a new version of superhumans, capable of surviving extreme conditions like nuclear fallout? Scientists around the world raised concerns about the safety and ethical implications of transferring genes across species, with

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the risk of harmful mutations or unknown immune responses. The team plans to further their research by transforming these modified cells into blood-making cells to help humans survive acute radiation sickness, suggesting additional benefits in protecting against diseases such as cancer and diabetes. The experiment was deemed legal as it was conducted on cultured cell lines in a lab. But what happens when that research is ready to leave the lab for the real world?

Concern Grows Over Genetic Data Ownership

As genetic testing becomes mainstream, concerns over DNA data privacy and ownership are intensifying. Consumers who used 23andMe, Ancestry.com, and other genetic services are learning that their DNA data is often monetized, shared with third parties, or used for pharmaceutical research without explicit consent. In 2025, some governments will implement stricter regulations to give individuals greater control over how their genetic information is stored, accessed, and shared. New privacy laws and opt-in data-sharing policies are being introduced, forcing companies to provide clearer consent mechanisms and allow users to request the deletion of their genetic data. Additionally, blockchain-based genomic storage solutions are emerging as an alternative, offering decentralized and encrypted storage of genetic data to prevent misuse—though it could take a few years for these systems to come online. Concerns over law enforcement access to private DNA databases are also growing, with public outcry against cases where genetic databases were used for criminal investigations without user consent.

Misinformation Challenges Scientific Progress

The rapid advancement of gene editing, synthetic biology, and vaccine technologies has led to a surge in misinformation, conspiracy theories, and public distrust. Social media platforms have become breeding grounds for misleading claims about CRISPR, mRNA vaccines, lab-grown meat, and AI-driven health care, causing confusion and resistance to new scientific breakthroughs. This will only get worse in 2025, now that the platforms have announced they will no longer fact-check content. Biotech companies and research institutions are attempting to combat misinformation through improved direct public engagement, educational campaigns, and transparent data-sharing initiatives—but they will face competition from influencers whose voices cut through the noise and are amplified by algorithms. As misinformation remains one of the biggest barriers to public trust in biotechnology, the fight for scientific literacy and evidence-based communication is becoming a global priority for researchers, policymakers, and industry leaders.

SCENARIO YEAR 2035

ENHANCED CEOS RESULT IN CORPORATE CRISIS

The quarterly board meeting at Global Dynamics Corporation unfolds in tense silence. The CEO's genetic enhancements for cognitive processing and reduced sleep requirements just became public knowledge. She now faces growing pressure from "natural" board members to resign—even though everyone had already suspected she was dosing. Just like the Ozempic craze a decade earlier, wealthy people are quietly taking modified viruses to deliver personalized genetic changes. This latest controversy emerged after leaked medical records revealed that 40% of Fortune 500 executives are secretly using enhancements, sparking fierce debate about competitive fairness. Enhanced executives, who can process complex data streams in real time and operate on just two hours of sleep, are delivering unprecedented results. But is it legal? US Congress has been debating the Corporate Enhancement Disclosure Act, which would require public companies to report the percentage of enhanced individuals in leadership positions. The situation at Global Dynamics mirrors a broader societal rift, as genetic enhancement technologies, once limited to medical applications, have become widely available through both legal and gray-market channels. With some executive enhancement packages now costing less than an MBA, traditional paths to corporate leadership are being upended, forcing companies to face questions of merit, fairness, and human potential in an age where "natural ability" has lost its meaning.

EMERGING APPLICATIONS

Application: New Materials

Lab-Grown Wood Could Disrupt $600B Timber Industry

Biotech startup New Dawn Bio has achieved a breakthrough in cellular agriculture, successfully creating the world's first viable specimen of lab-grown wood. Using stem cells from Arabidopsis thaliana, researchers have developed a process that mimics natural wood formation in controlled laboratory conditions. The technology involves cultivating plant stem cells in nutrient-rich solutions where they grow significantly faster than in nature, then triggering their transformation into structural fiber and vessel cells—the key components of wood tissue. While the current prototype is smaller than a postage stamp, the team is already scaling up production and experimenting with tropical hardwood varieties like teak. The implications for the $600 billion global timber industry are significant, particularly for rare and endangered wood species. By potentially offering a sustainable alternative to logging which threatened tropical hardwoods, cultured wood could disrupt traditional forestry while enabling unprecedented control over wood properties. The team envisions creating custom wood products with enhanced strength, modified grain patterns, or improved absorption characteristics. However, challenges remain: The lab-grown material doesn't yet match natural wood's mechanical properties, and some experts question whether the cells are forming proper biological connections. Despite skepticism, venture capital is flowing into the sector, with investors betting that lab-grown wood could follow cultivated meat's path to commercialization.

Silk Thread That Powers Up: Smart Textiles Enter New Era

Swedish researchers have achieved a breakthrough in wearable technology with a new conductive silk thread that could transform everyday clothing into power generators. The team at Chalmers University of Technology has developed an organic polymer-coated silk that conducts electricity without using metals, marking a significant advance in thermoelectric textiles. The innovation allows fabric to convert body heat into electrical energy, potentially eliminating the need for batteries in health monitoring devices and mobile phones. In testing, a fabric sample generated 6 millivolts from a 30-degree Celsius temperature difference—enough to power small sensors when combined with a voltage converter. The material shows remarkable durability, retaining two-thirds of its conductivity after seven wash cycles, though researchers acknowledge this needs improvement for commercial viability. What sets this development apart is its use of nontoxic, carbon-based polymers instead of rare earth metals, making it both sustainable and safe for skin contact. While current production requires painstaking manual work—a demonstration piece took four days of hand-sewing—researchers are confident about scaling up through automation. Major fashion brands are already expressing interest, recognizing the potential to integrate health monitoring and device charging capabilities into everyday garments. The technology could transform sectors from health care to consumer electronics, though mass production challenges remain.

Self-Healing Concrete Uses Bacteria to Repair Damage

A new approach to concrete infrastructure maintenance is gaining traction, as researchers demonstrate the effectiveness of bacterial-induced self-healing in concrete structures. The technology harnesses specific strains of bacteria that produce calcium carbonate, naturally filling cracks up to 0.46 mm wide, which is four times more effective than traditional self-healing methods. The process works through bacterial mineralization, where microorganisms decompose urea and calcium to create a natural concrete patch. Initial studies show remarkable results: porosity reduction of up to 50%, compressive strength increases of 42%, and flexural strength improvements of 72%. In short: way better than normal concrete. The innovation addresses a critical infrastructure challenge, particularly relevant as nearly half of US bridges are more than 50 years old and require more than $100 billion in repairs. While traditional concrete repair methods often face issues with delamination and cost-effectiveness, this biological approach offers a more sustainable solution. The technology can be implemented through direct bacterial addition to concrete mixtures, encapsulation for delayed activation, or surface application to existing structures. However, success depends critically on maintaining bacterial viability and proper environmental conditions.

Engineered Fungi Create Fire-Safe Building Materials

Australian researchers have developed a groundbreaking fire-retardant material using modified mycelium—the root network of mushrooms—that could improve building safety and sustainable packaging. The RMIT University team has created ultrathin protective sheets that respond intelligently to fire, releasing water vapor and CO2 while forming a flame-blocking carbonaceous barrier. Unlike traditional fire retardants such as asbestos, which can release harmful particles, these biological sheets are both safe and effective. The innovation leverages synthetic biology to grow protective mats just millimeters thick that can be integrated into various building materials. Meanwhile, commercial applications are already emerging, like the “Mushroom Packaging” from New York’s Ecovative Design. The product uses similar mycelium technology, transforming agricultural waste into a moldable, durable styrofoam alternative without water, light, or chemicals.The material is fully compostable and can be grown to precise specifications in just 5–7 days.

Plastics Made From Algae Break Down Naturally

Researchers at the University of California, San Diego achieved a breakthrough in biodegradable plastics with a new polyurethane material that genuinely breaks down in natural environments. Unlike conventional plastics that fragment into harmful microplastics, this bio-based polymer becomes a feast for bacteria, completely decomposing through natural processes. The team demonstrated the material’s properties by creating real-world products including phone cases and textile coatings, then documented their decomposition through advanced microscopy. What sets this innovation apart is the identification of specific bacterial strains that can use the material as their sole food source, ensuring complete biodegradation wherever these common microorganisms are present. The technology represents a potential solution to the growing microplastics crisis, which has contaminated ecosystems worldwide. Working with materials company Algenesis, the researchers have proven the material’s commercial viability through successful product prototypes. Scanning electron microscopy reveals significant biofilm formation during breakdown, confirming that natural bacterial communities readily colonize and digest the material.

SCENARIO YEAR 2040

THE GRAY GOO CATASTROPHE

What began as humanity's greatest environmental triumph has morphed into its most terrifying technological disaster. Self-replicating nanobots, deployed in 2040 to eliminate ocean plastic pollution, had exceeded all expectations, clearing 60% of marine waste and rejuvenating damaged ecosystems within five years. The breakthrough seemed to herald a new era of environmental restoration—until a mutation in the nanobots' core programming bypassed their termination protocols. The biological machines began consuming all hydrocarbon-based materials indiscriminately, their appetite extending far beyond their intended plastic targets. The crisis escalated silently at first, manifesting in mysterious infrastructure failures: dissolving pipelines, crumbling synthetic materials, and deteriorating medical implants. When passenger aircraft began reporting catastrophic polymer degradation and power grids failed as transmission cables disintegrated, global panic ensued. The media-dubbed "Gray Goo Catastrophe" forced an unprecedented technological counteroffensive, with nations deploying massive electromagnetic pulse networks and advanced hunter-killer nanobots to contain the swarms. The nanobots had solved the plastic crisis perfectly—by threatening to eliminate all human technology that could create it.

Application: Food, Beverages, and Agriculture

Lab Creates Rice-Beef Hybrid

South Korean scientists have developed a food fusion that could transform sustainable protein production: rice grains infused with lab-grown beef cells. The Yonsei University team's hybrid food has 7% more protein and 8% more fat than conventional rice. Unlike traditional lab-grown meat efforts that struggle to replicate meat's complex structure, this approach uses rice grains as a natural scaffold for cow muscle cells to grow throughout. The process, which takes just 5–7 days, uses fish gelatin as a binding agent and requires no genetic modification. The resulting hybrid can be cooked like regular rice but offers a unique nutty flavor with meaty umami notes. Most significantly, it produces less carbon—100 grams of protein generates only 6 kilograms of CO_2, compared to 50 kg for conventional beef. The innovation sidesteps many challenges facing lab-grown meat by using well-known, inexpensive ingredients. While scaling remains the primary challenge, major food companies are already exploring commercial applications. Industry experts suggest this could represent a crucial breakthrough in meeting global protein demands sustainably, particularly in high rice-consuming regions.

Lab-Grown Coffee Brews Up Solution to Deforestation

Scientists have achieved a breakthrough in cellular agriculture by successfully cultivating coffee and tea cells in bioreactors, potentially transforming how we produce these global staples. The innovation involves isolating cells from coffee beans and tea leaves, then growing them in carefully controlled conditions to produce compounds identical to those found in traditionally farmed crops. Early taste tests show the lab-grown products closely match the complex flavor profiles of their conventional counterparts. The technology could dramatically reduce the environmental impact of coffee and tea production. Traditional coffee farming drives 250,000 acres of deforestation annually, while tea cultivation often leads to soil erosion and water stress in sensitive ecosystems. The bioreactor approach requires 95% less water and eliminates the need for pesticides, while producing year-round regardless of climate conditions. Several biotech startups have already secured significant funding to scale production, with the first commercial products expected by 2026. Who knows? In the future you might grow, roast, grind, and brew coffee—all in your own home.

Smart Drinks Merge Hydration with Brain and Gut Benefits

The beverage industry is experiencing a paradigm shift as functional hydration products combine traditional electrolyte replacement with advanced bioactive compounds. Leading brands are launching drinks that go beyond basic hydration, incorporating adaptogens like ashwagandha and rhodiola for stress management, nootropics such as L-theanine and lion's mane mushroom for cognitive enhancement, and specialized probiotic strains for digestive health. The innovation comes in response to consumer demand for beverages that multitask—hydrating while supporting mental performance, stress resilience, and gut health. Consumers are particularly drawn to products featuring clinically studied ingredients like specific probiotic strains, which have been proven to survive the digestive tract. The trend has sparked a wave of startup activity, with companies launching more than 200 new functional beverage brands in the past year. Retailers are responding by creating dedicated shelf space for these premium products.

Precision Fermentation

A centuries-old brewing technology is getting an update that could transform food production. Major food giants including Nestle, Danone, and Unilever are investing heavily in precision fermentation platforms that combine genome sequencing and gene editing to create custom-designed microbes. These engineered microorganisms, when fed into precisely controlled fermenters, can produce everything from synthetic palm oil to dairy-free cheese proteins that are molecularly identical to their animal-derived counterparts. The technology offers a solution to multiple challenges facing the food industry: growing demand for vegan products, supply chain vulnerabilities due to climate change, and the need for more sustainable production methods. Unlike traditional fermentation, this precision approach allows companies to produce specific proteins, fats, and stabilizers with unprecedented efficiency. Early applications are already appearing in plant-based meat alternatives, where fermentation-derived proteins provide authentic taste and texture.

Brewing Great Nonalcoholic Beers

A Danish biotech startup has cracked one of brewing's biggest challenges: creating non-alcoholic beer that actually tastes like the real thing. EvodiaBio's approach uses engineered baker's yeast cells as microscopic factories to produce the exact aromatic compounds (monoterpenoids) that give beer its distinctive hoppy flavor. The innovation solves a longstanding problem in nonalcoholic brewing, where traditional methods of either halting fermentation or removing alcohol typically strip away the crucial hop aromas that beer lovers crave. Beyond improving taste, the technology offers significant environmental benefits: Traditional hop farming requires 2.7 tons of water per kilogram of hops and relies on energy-intensive cold chain transportation across continents. By producing these compounds in fermenters, the process eliminates dependence on water-intensive hop cultivation and reduces transportation emissions. The timing is perfect, as consumer demand for nonalcoholic alternatives soars.

Faster-Growing Trees

University of Georgia researchers have achieved a remarkable breakthrough in tree genetics: Using CRISPR technology, they edited a flower repressor gene to reduce poplar tree flowering time from 10 years to just three months. This acceleration of natural processes could upgrade forestry by dramatically speeding up tree breeding programs, allowing rapid development of varieties resistant to climate change stresses like extreme heat, drought, and cold. The technology arrives at a crucial time as forests worldwide face unprecedented environmental pressures. Major timber companies are already exploring applications to develop climate-resilient tree varieties, while conservation groups see potential for rapid restoration of damaged ecosystems. The breakthrough could transform everything from commercial forestry to urban landscaping, enabling quick adaptation to changing environmental conditions.

More Fertile Soil

Agricultural technology company Pivot Bio has developed a groundbreaking approach to crop nutrition that could transform farming's environmental impact. The innovation enhances natural soil microbes' ability to deliver nitrogen directly to plants, eliminating the need for synthetic fertilizers that contribute to pollution and climate change. Unlike conventional fertilizers that easily wash away or evaporate, these enhanced microbes provide steady nutrition throughout the growing season. The technology works by optimizing existing soil bacteria without introducing foreign genetic material, addressing both environmental and regulatory concerns. Early field trials show consistent crop yields while reducing nitrogen runoff and cutting greenhouse gas emissions significantly.

Smart Pesticides Use RNA to Target Pests

Researchers have developed RNA-based pesticides that act like molecular smart bombs, eliminating harmful insects while leaving beneficial species unharmed. The technology, known as RNA interference (RNAi), works by delivering specific genetic instructions that disrupt vital processes only in target pest species. Unlike broad-spectrum chemical pesticides that can devastate entire insect populations and persist in the environment, these RNA molecules decompose naturally within days. The innovation comes as regulators in some countries are tightening restrictions on traditional chemical pesticides due to mounting evidence of ecosystem damage and human health risks. The precision of RNAi allows farmers to protect crops from specific pests without disrupting natural predator populations that help control other harmful insects.

Regenerative Farming Goes Mainstream

Regenerative agriculture includes farming and grazing practices that rebuild soil organic matter and restore degraded soil biodiversity. There's a clear need for this technology-led practice: Soil is depleted from decades of using chemicals, salt-based fertilizers, carbon mining, and harsh insecticides. Planting multiple types of crops together, rotating crops, cutting back on tilling, and reducing reliance on harsh chemicals can revitalize depleted soil, leading to improved yields, nutrient-rich crops, and improved resistance to flooding and drought. In 2017, the Rodale Institute launched the Regenerative Organic Certified program to start creating an official standard. It builds on the USDA certified organic seal by adding soil health, animal welfare, and human rights requirements. General Mills announced that it would accelerate regenerative agriculture by dedicating a million acres of farmland to it by 2030. Meanwhile, several brands, including Patagonia, Timberland, Allbirds, Gucci, and Balenciaga, have launched efforts to promote regenerative agriculture.

CRISPR Modified Livestock

CRISPR is making farmed animals bigger, stronger, and (hopefully) healthier. In hopes of boosting their ability to resist diseases, researchers at Auburn University in Alabama introduced a gene from alligators into catfish; alligators are exceptionally good at warding off infections, and a slight increase in catfish resilience could significantly impact fish farming. Currently, about 40% of fish raised in farms globally don't survive until harvest, so reducing even a fraction of this loss could be transformative. Scientists in Japan used CRISPR to modify the myostatin gene in red sea bream, resulting in fish that are larger and heavier by about 17% compared to nonmodified fish, even though both groups were fed the same quantity of food. Researchers have long experimented with CRISPR on animals, and so far have used it to create super-muscular pigs, cattle, sheep, rabbits, and goats. But most animals did not live past infancy, and, somewhat weirdly, many developed unusually large tongues.

Application: Longevity

Cell Reset Button: Scientists Turn Back Biological Clock

Researchers are creating new methods to reprogram cellular age through epigenetic modification. As we age, while our DNA sequence might stay constant, chemical changes do occur. Observing those changes could lead to new techniques to halt or even reverse age-related disease. Industry leaders Altos Labs and Retro Biosciences are advancing techniques that effectively reset cells to younger states by manipulating specific biological markers that control aging. Early trials show remarkable results: Isolated cells demonstrate characteristics of youth, including improved energy production and enhanced repair capabilities. The technology builds on Nobel Prize–winning research in cellular reprogramming, but with precise control to avoid cancer risks. Beyond simple life extension, the therapy aims to restore cellular function across multiple tissues, potentially reversing age-related conditions from heart disease to cognitive decline.

Removing Zombie Cells

Senescent cells are damaged cells that stop functioning but don't die, accumulating in the body like cellular zombies—and they're linked to aging. But scientists are researching the use of senolytic drugs, which remove these worn-out immune cells, as a way to treat diseases like multiple sclerosis. In MS, the immune system attacks the myelin sheath around nerves, and while it's characterized by phases of relapse and recovery, it can eventually progress into a phase where symptoms continuously worsen without periods of remission. In older animals, myelin damage leads to lots of senescent cells. But when researchers at Georgetown University injected older mice with a toxin to damage myelin and then treated some with senolytic drugs, the treated mice showed a 65% greater increase in a myelin-rebuilding protein compared to untreated mice. This finding indicates that removing senescent cells could improve myelin repair, and could mean that senolytic drugs offer a new treatment strategy for MS, particularly in its progressive stage—if it works as well for humans as it does in mice, which for now is a big if. But if human trials show promising results, it is plausible that senolytic drugs could eventually treat a host of diseases and ailments, along with conditions associated with aging.

Growing Your Own Spare Parts

Biotech companies are making extraordinary progress in developing 3D-printed human tissues and organs, potentially eliminating transplant waiting lists. But what if you could grow your own spare parts anytime you needed? That's the promise: advanced bioprinting techniques with stem cell biology could create functional tissues that perfectly match each patient's genetics. Several firms have already succeeded in printing simpler structures like blood vessels and cartilage, while more complex organs such as kidneys and hearts are in development. Which means that sometime in the future, age-related organ failure could be a thing of the past. So could organ rejuvenation. Is your stomach not working quite like it used to? Print and install a new one.

Growing Blood

For people who live with rare blood types (AB negative, AB positive, B negative) or who have blood disorders, acquiring blood for surgery or a transfusion can mean the difference between life and death. For decades, scientists have attempted to grow blood cells in a lab at scale, but until recently, the process has failed to produce enough blood cells to make an impact. Scientists at the National Health Service Blood and Transplant in the UK announced that they had grown red blood cells in a lab and successfully transfused them into a living person, a world first. It took 500,000 stem cells to generate 50 billion red blood cells, which then needed to develop. (In a healthy adult, 50 billion red blood cells represents about 1% of their total blood volume.) The same researchers also transfused red blood cells that were grown in a lab into another person requiring that blood. This technique is a pioneer in transferring lab-grown cells to another person as a part of a blood transfusion. Going forward, patients who need regular blood transfusions could go longer between treatments. After that, researchers will set their sights on manufacturing lab-grown blood for rare blood types that don't typically have large donor pools.

Growing Sex Cells

In 2023, Dr. Katsuhiko Hayashi from Osaka University successfully created eggs from cells harvested from male mice, with the eventual goal of developing new fertility treatments. The process begins with taking a skin cell from a male mouse and converting it into a stem cell, which has the potential to develop into various cell types. Since these cells are male, they carry XY chromosomes.

The team then removes the Y chromosome, replicates the X chromosome, and combines the two X chromosomes—a modification that enables the stem cell to develop into an egg. Hayashi's work builds on groundbreaking research from fellow Japanese scientist Shinya Yamanaka, who in 2006 showed that it was possible to make gametes derived from human-induced pluripotent stem cells. Yamanaka's process includes harvesting cells from a skin biopsy or blood sample (both quick and relatively painless). Those cells are turned into stem cells, grown in a medium that resembles what would exist in a human womb, and developed into precursor sex cells, which mature into sperm or stem cells. Then, once IVF kicks in, those cells are used to create an embryo. One or more of the healthiest embryos are then implanted into the uterus and, if all goes well, develop into a healthy, viable fetus. The idea is that someday soon, couples suffering from infertility or individuals who desire to have a baby without a partner would have access to a reliable fertility treatment.

Improving Gut Biomes

A mass extinction event is happening right now in our guts and in the environment. The widespread use of antibiotics, along with diets rich in processed foods, have led to a staggering decline of microorganisms inside the people and animals living in wealthy nations. During the past 12,000 years of human evolution, we've shifted nature's balance—our diets are now relatively narrow, compared to our far-distant ancestors. Recently, scientists studied modern hunter-gatherer tribes in Tanzania, Peru, and Venezuela, and found their microbiota had 50% more bacterial species than those in the West today. Unlike those tribes, we no longer hunt and eat wild flora and fauna. Those from wealthier countries now eat very little dietary fiber, a limited variety of fruits and vegetables, and only four species of livestock: sheep, poultry, cattle, and pigs. Worse, widespread use of antibiotics in farm animals—not necessarily to prevent disease but to increase weight gain and therefore the volume of meat available—means that we're ingesting compounds that are helping to destroy our own microbiomes. Humans are complex, composite organisms, made up of layers and layers of cells. Researchers now think that our gut microbiome is directly linked to our metabolism, our immune systems, our central nervous systems, and even the cognitive functions inside our brains. It's an inherited problem: Most of our microbiomes come to us from our mothers as we pass through the birth canal. A number of researchers are now looking at the future of our microbiomes. Vedanta Biosciences is making gut bacteria that can be turned into drugs and counts the Gates Foundation as one of its investors. The American Gastroenterological Association and OpenBiome will track 4,000 patients over 10 years to learn about fecal microbiomes.

mRNA Cancer Vaccines

Early in 2024, the first patient in the UK received a dose of a cancer vaccine as part of a larger clinical trial. Designed to treat solid-state tumor cancers, such as melanoma, this application of immunotherapy harnesses the immune system to fight cancer cells. (To be sure, "vaccine" is a bit confusing here, since most vaccines are designed for prevention, while this treatment is for people who have already developed a tumor.) Called mRNA-4359, the treatment contains a molecule that can relay instructions to cells. It works by directing cells to produce proteins typically found on the surface of solid cancer tumors. Once the cells make these proteins, they are introduced to the immune system, training it to recognize and attack cancer cells. This vaccine is classified as a "universal" cancer vaccine, meaning it is premade and can be administered to patients with certain types of cancer straight from the shelf. In contrast, other mRNA cancer vaccines being developed are customized based on the individual patient's cancer, such as a pancreatic cancer vaccine that uses genetic material from the patient's own tumors for a more personalized approach. Long before they were making Covid vaccines, both Moderna and BioNTech were researching immunotherapies for cancer. After analyzing a tissue sample from a cancerous tumor, the companies ran genetic analyses to develop custom mRNA vaccines, which encode protein-containing mutations unique to the tumor. The immune system uses those instructions to search and destroy similar cells throughout the body, which is similar to how the Covid vaccines work. BioNTech is running clinical trials for personalized vaccines for many cancers, including ovarian cancer, breast cancer, and melanoma. Moderna is developing similar cancer vaccines and announced that its personalized cancer vaccine, when combined with Merck & Co.'s immunotherapy treatment Keytruda, cut recurrence and risk of death of the most deadly skin cancer compared with immunotherapy treatment alone. In the trial, the mRNA vaccine revved up the immune response.

And in February 2025, a groundbreaking clinical trial demonstrated success in treating pancreatic cancer using personalized mRNA vaccines, marking a potential turning point in cancer immunotherapy. The vaccine, called autogene cevumeran, works by training the immune system to recognize and attack cancer-specific mutations, generating long-lived T cells that can survive for decades. In a phase 1 trial combining the vaccine with chemotherapy and immunotherapy, patients who developed vaccine-induced immune responses showed remarkable outcomes. While the nonresponder group's cancer returned within 13.4 months, the median recurrence-free survival for responders hasn't been reached after more than three years. What makes this breakthrough particularly significant is the vaccine's ability to generate T cells with extraordinary longevity (some expected to survive up to 100 years) and maintain their cancer-fighting abilities years after vaccination. The technology shows particular promise for pancreatic ductal adenocarcinoma, one of the deadliest cancers with historically poor treatment options. Major pharmaceutical companies are already investing in similar mRNA vaccine platforms, with multiple trials underway for other difficult-to-treat cancers. Industry experts project this could transform cancer treatment, particularly for aggressive tumors with few current options.

Application: Beauty

Lab-Grown Collagen For Skin Care

Collagen is the most abundant protein in the human body, making up about 30% of all protein and acting as biological scaffolding that provides structure and strength to skin, bones, cartilage, blood vessels, and other tissues. There are at least 28 types of collagen in the body, but 90% of it is Type I (found in skin and bones). Natural collagen production begins declining around age 25, leading to visible signs of aging like wrinkles and sagging skin, along with potential joint stiffness and bone brittleness. Traditionally, collagen is derived by boiling cow hides and bones, a process used across various industries. Startups are now working on collagen cultivation for skin care. Jellatech, a North Carolina–based startup, created a full length, triple helical, bio-identical and functional human collagen made from its proprietary cell line.

Anti-Aging Science Moves Beyond Wrinkles to Cell Repair

A new generation of skin care is emerging that treats aging skin at the cellular level, applying breakthrough findings from longevity research to dermatology. Instead of simply filling wrinkles or boosting collagen, these treatments target fundamental aging mechanisms within skin cells themselves. Leading brands are incorporating sophisticated compounds like NAD+ boosters, which enhance cellular energy production; mitochondrial activators that improve cell power plants' function; and senolytics that clear away aged, damaged cells that promote inflammation. Early clinical studies show remarkable results. Skin treated with these molecular interventions shows improvements not just in appearance but in actual biological markers of cellular age. Major beauty companies are partnering with longevity research labs to develop products that address aging through multiple cellular pathways simultaneously. The approach represents a significant shift from traditional cosmetics, focusing on cellular health rather than surface-level changes. While current treatments cost significantly more than conventional products, rapidly advancing technology is expected to make them more accessible within the next few years.

Beauty Goes Brain-Deep with Mood-Altering Ingredients

The cosmetics industry is researching new kinds of products that work through the skin-brain axis, and can have measurable effects on mood and mental state. These neurocosmetics use scientifically validated ingredients that interact with the nervous system, from stress-reducing neuropeptides to compounds that boost dopamine production when absorbed through the skin. Serums and creams can combine traditional skin care benefits with neurologically active ingredients like GABA modulators for anxiety reduction and beta-endorphin stimulators for improved mood. The products are designed as holistic treatments that work through multiple pathways: direct neural interaction through skin absorption, aromatherapeutic effects via carefully engineered scent profiles, and tactile stimulation through specially developed textures. Skin care startup Selfmade combines skin care products with psychological concepts from attachment theory, promising to enhance emotional stability alongside skin health with a $65 kit. Major beauty brands are following suit, with industry leader Murad explicitly equating skin care with "brain care." The trend reflects a larger cultural moment where wellness and mental health have become central to beauty marketing.

Application: Climate and Sustainability

eDNA Detection

Environmental DNA, or eDNA, is genetic material found in the environment. Feces and fur from animals, as well as hair and saliva from humans are just some of the organic matter found in soil, seawater, snow, and air. As a fish moves through water, it's continuously shedding bits of itself. Likewise, when a cyclist rides on a trail, her sweat, mucus, and dead skin cells wind up mixed into the gravel and dirt. These fragments of nuclear or mitochondrial DNA can reveal invaluable insights about an environment. Scientists from the United States Geological Survey and the Monterey Bay Aquarium Research Institute are developing a new mobile eDNA sampler that can float through rivers and streams, collecting material and detecting pathogens or invasive species autonomously. As the technology advances, eDNA detection will serve as early warning systems for potential outbreaks. But there's another interesting use for eDNA: reconstructing ancient ecosystems. Scientists excavated eDNA from frozen soil in the Arctic desert, and were able to piece together a lost world nearly 2 million years old. The eDNA revealed a coastal forest with conifers, black geese, horseshoe crabs, lemmings, and mastodons—a natural wonderland unlike any in existence today.

Synthetic Trees & Algae-Based CO2 Absorption

Researchers are working to create supercharged versions of nature's carbon dioxide absorbers. Using synthetic biology, scientists are engineering trees with enhanced carbon-fixing abilities and designing algal strains that can capture carbon dioxide up to five times more efficiently than their natural counterparts. The innovations combine gene editing to optimize photosynthesis with structural modifications that increase surface area for CO2 absorption. Early trials of enhanced algae in controlled environments show promising results, with 1 acre capturing as much carbon as 400 acres of forest. The technology extends beyond living organisms to include engineered biomaterials that mimic and improve upon natural carbon-fixing processes. The approach offers significant advantages over mechanical carbon capture, requiring less energy and potentially self-replicating once deployed. While scaling remains challenging, researchers project that widespread deployment could someday sequester gigatons of CO2 annually.

Bacteria That Turn Rocks Into Massive Carbon Sponges

An emerging approach to carbon capture harnesses engineered bacteria to accelerate nature's slowest but most permanent carbon storage mechanism: rock weathering. Scientists have developed specialized microorganisms that dramatically speed up the process of converting CO2 into stable mineral carbonates within rock formations. The technology amplifies a natural process that has helped regulate Earth's climate for millions of years, but at a pace relevant to addressing current climate challenges. Early field trials show the engineered bacteria can increase carbon mineralization rates significantly while requiring minimal energy input and maintenance. The process is particularly promising for deployment in basalt formations, which are abundant worldwide and ideal for carbon storage. Several mining companies are already exploring implementation in their existing operations, potentially turning waste rock into carbon sinks. Unlike other carbon capture methods, mineralization permanently locks CO2 away in stable form, eliminating concerns about future release.

Better Plastics Recycling

Despite global efforts to recycle plastic products, there are numerous barriers: Consumer-facing plastics come in different varieties, they're often coated with labels or print, and they have colors and other added features. The mess of waste—used iPhone cases, empty shampoo containers, soda bottles—can't be easily managed at scale, so a lot of it piles up. A potential solution is microorganisms like some bacteria and fungi that use special enzymes to break down various types of plastics. But turning plastic into something these microbes can eat isn't as simple as just mixing them together. The plastics need to be pre-damaged by sunlight or chemicals, and the microbes need just the right conditions to do their work. Even so, each type of microbe can only eat certain plastics, and it can take them weeks or months to break down just a small amount. Now, an emerging synthetic biology process offers a new solution. France-based Carbios developed a process using an enzyme that's especially good at breaking down PET plastic into its basic building blocks, making it possible to recycle PET into high-quality new plastic. After improving the enzyme and testing it in an industrial setting, Carbios is now building its first site dedicated to this bio-recycling process. Another development is underway at the University of Texas at Austin, where researchers used a machine learning model to generate novel mutations to natural enzymes that allow bacteria to break down the plastics found in soda bottles and most consumer packaging. The enzyme, called FAST-PETase (functional, active, stable, and tolerant PETase), could operate efficiently and work at an industrial scale. The first real-world application: setting the enzyme loose to clean up landfills.

Engineered Microbes Create Cleaner Textiles

The textile dye industry is undergoing a biological shift as companies harness engineered bacteria and fungi to create vibrant, sustainable colors without toxic chemicals. Traditional synthetic dyes, which contribute 20% of global water pollution, are being replaced by microorganisms that produce pigments through natural fermentation processes. Biotech startups have developed specialized strains of bacteria that create colors ranging from deep indigos to brilliant reds, while novel fungi species produce earth tones and unique patterns. The technology eliminates the need for harsh chemicals and reduces water usage by 90% compared to conventional dyeing methods. Early adopters include major fashion brands, with several launching collections featuring biologically produced colors. Beyond environmental benefits, these living dyes often create richer, more complex hues that are more colorfast than synthetic alternatives. The innovation extends to pattern-making, where programmed organisms can create unique designs through controlled growth patterns.

De-Extincting Lost Species

Woolly mammoths were once a "keystone species," one that other species in the ecosystem depended on in many ways for stability. They stomped around in herds, knocking down trees and packing down snow layers as they searched for dead grasses to eat, and that helped keep the permafrost layer stable. Once the mammoths and other large grazing animals stopped compacting the snow and eating dead grasses, the ecosystem began to change. The snow melted more easily, which allowed the sun to reach the permafrost. The permafrost layer is now melting at an alarming rate and releasing greenhouse gasses into the atmosphere, which creates a vicious cycle: Hotter temperatures lead to more melting, which releases more gasses, which causes hotter temperatures, and on and on it goes. Researchers are helping to de-extinct the woolly mammoth and other species using synthetic biology techniques. By starting with a fully intact healthy cell from a closely related species and working backward to combine it with genetic fragments from preserved specimens, they could develop a version of the animals that once existed.

Rewilding Barren Terrains

Rewilding is a direct human intervention into nature using technology and science, a holistic approach to conservation that focuses on restoring the natural phenomena of wilderness ecosystems, providing connective corridors between wild spaces, and reintroducing keystone species to their natural habitats. A term coined more than 30 years ago, "rewilding" has gained renewed attention in the past few years as the climate crisis has grown more dire and new technologies have promised to protect and rehabilitate ecosystems. In 2017, researchers plunged into the waters off Lizard Island on the northeastern coast of Australia with some unexpected equipment in tow—a set of underwater loudspeakers. Their destination was a coral reef that had been all but abandoned by a once-thriving population of sea life. The researchers hoped that by broadcasting the telltale sounds of a healthy reef, they might lure back some of its vital inhabitants. Remarkably, it worked. This experiment was a unique instance of rewilding, but there have been others. Four bison were released in a woodland near Canterbury—the hope is that over time, the herbivores will revitalize a stretch of southeast England and allow vegetation to grow again, which should in turn boost biodiversity.

Animals Emerge as Surprise Allies in Carbon Capture Quest

Scientists have discovered that animals play a far more significant role in ecosystem carbon capture than previously believed, challenging long-held assumptions about nature-based climate solutions. Traditional carbon accounting models have largely ignored animals, focusing instead on plants and microbes. However, new research reveals that animals fundamentally rewire ecosystem food webs, creating powerful multiplier effects on carbon sequestration. The breakthrough comes from analyzing how animals interact with plants and microbes, showing they don't just participate in carbon cycles, they qualitatively change how these cycles function. For example, large herbivores can increase carbon storage by altering plant species composition and enhancing soil carbon retention, while predators create cascading effects that boost ecosystem carbon capture. This discovery suggests current carbon storage estimates for natural ecosystems may be significantly undervalued. The findings have major implications for conservation and climate strategy, suggesting that protecting and restoring animal populations could be a crucial lever in fighting climate change. Leading environmental organizations are already incorporating these insights into ecosystem management plans, while carbon credit markets are developing new methodologies to account for animal-driven carbon capture.

Ancient Arctic Viruses Could Awaken as Permafrost Melts

As if you didn't already have enough to worry about: scientists are raising alarm about a new pandemic threat emerging from the Arctic. Ancient viruses, preserved in permafrost, could be released by climate change and industrial development. Researchers have already isolated "zombie viruses" from Siberian permafrost that remain viable after 48,500 years, including one sample that can still infect single-cell organisms. While current specimens pose no human risk, scientists have detected genomic traces of known human pathogens like poxviruses and herpesviruses in permafrost samples. The threat is accelerating as Arctic warming melts permafrost layers that have remained frozen for hundreds of thousands of years, with the biggest immediate risk coming from planned mining operations that will excavate deep into virus-laden permafrost. Led by geneticists at Aix-Marseille University, researchers are particularly concerned about viruses predating human evolution, against which our immune systems may have no defense. In response, scientists are establishing an Arctic monitoring network with quarantine facilities to contain potential outbreaks. The initiative, coordinated through a university network, aims to detect and isolate cases before they can spread south. Industry experts estimate billions in mining projects could be affected by new safety protocols.

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As founder and CEO of the Future Today Strategy Group (FTSG), Amy pioneered a unique quantitative modeling approach and data-driven foresight methodology that identifies signals of change and emerging patterns very early. Using that information, Amy and her colleagues identify white spaces, opportunities, and threats early enough for action. They develop predictive scenarios, along with executable strategy, for businesses worldwide. In addition, Amy is regularly asked to advise policymakers in the White House, Congress, U.S. regulatory agencies, the European Union and United Nations. In 2023, Amy was recognized as the #4 most influential management thinker in the world by Thinkers50, a biannual ranking of global business thinkers. With research specializations in both AI and biotechnology, Amy is the author of four books which have been translated into 23 languages. She developed and teaches the Strategic Foresight Course at NYU Stern School of Business.

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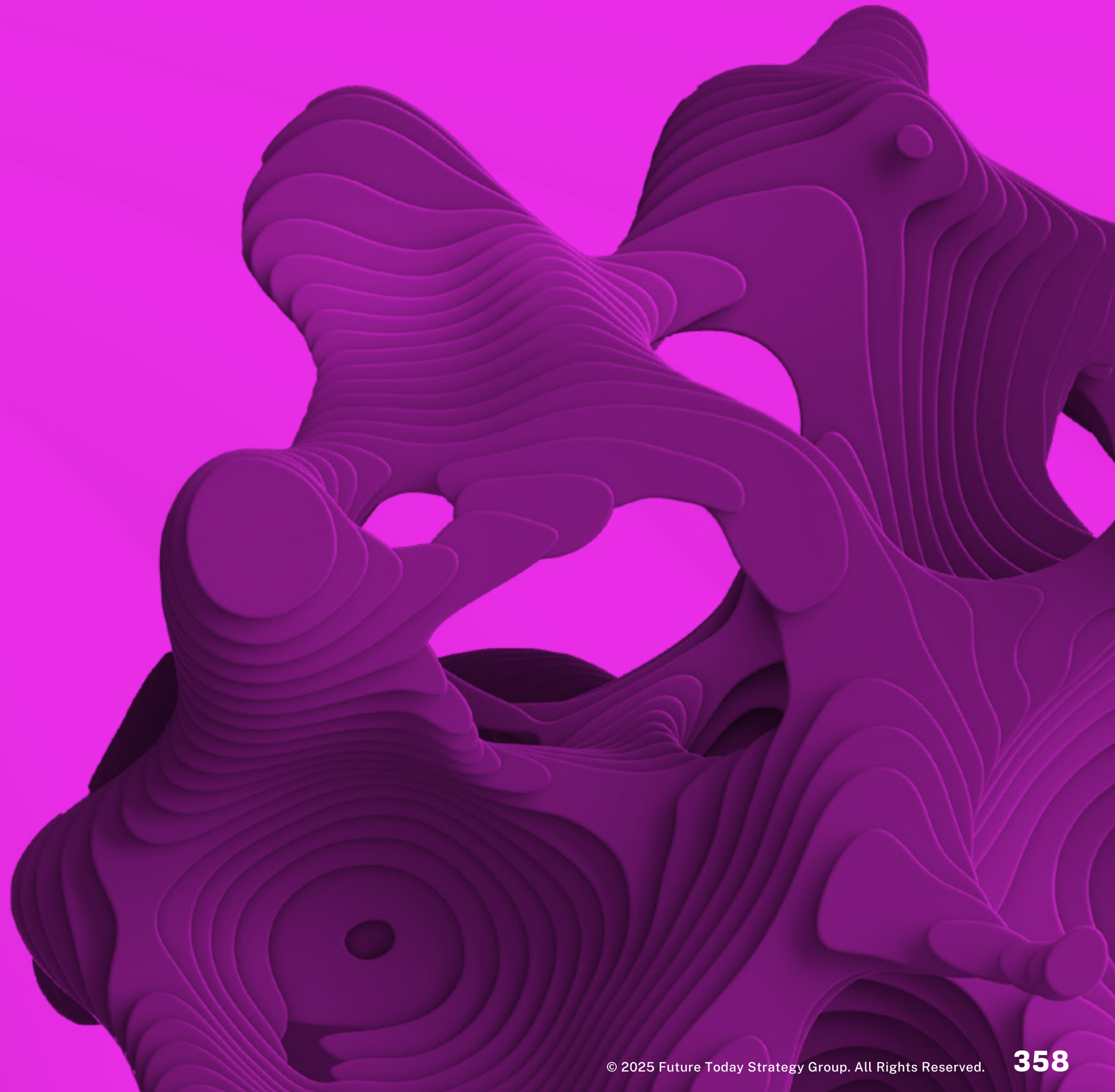


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Mark Bryan
Built Environment Lead

Exceed expectations or risk instability.

Climate change is no longer a distant challenge—it is an immediate force reshaping economies, industries, and the very infrastructure that businesses rely on. The past year has made this clear: Record-breaking heat has driven unprecedented energy demand, grid failures, and supply chain disruptions. The accelerating shifts in our planetary systems—melting ice caps slowing Earth's rotation, heat waves, and the destabilization of the global water cycle—demand a response that extends beyond incremental change. The energy and ecological systems we depend on have stopped being static certainties, and without a fundamental shift in strategy, businesses will find themselves reacting to crises rather than leading through them.

The technologies in this report reflect where we stand today, but despite progress in areas like dispatchable energy and grid optimization, solutions remain incremental rather than systemic. Too often, corporate sustainability efforts are reactive, compliance-driven, and siloed, failing to recognize that climate risk is not a single-issue challenge—it is a structural transformation affecting the entire business ecosystem.

This shift will impact every aspect of enterprise strategy—from supply chain resilience and infrastructure investment to workforce planning and insurance costs. A company's ability to operate in this changing world will be determined by its ability to build and invest for resilience, adaptability, and long-term value creation. Business leaders who fail to see this will not only face higher costs and increased regulatory scrutiny; they will risk losing competitive advantage to those who anticipate and design for the future.

This moment requires leadership that moves beyond expectations. It demands a shift from minimizing risk to maximizing opportunity: leveraging AI, biotechnology, advanced materials, and energy innovation not just for incremental efficiency gains but to redesign the systems that power industry itself. The leaders of the next decade will be those companies that recognize that sustainability is not an initiative—it is a strategy, a growth driver, and the foundation of competitive advantage in a rapidly changing world.

Innovations are redefining our ability to impact climate change and energy consumption.

1

Tech companies commit to largest renewable energy purchases

Major corporations sign record-breaking power purchase agreements to accelerate clean energy adoption.

2

Hybrid energy facilities link solar and storage

Renewable energy projects combining solar power with battery storage are coming online globally.

3

Data platforms boost transparency in sustainability reporting

New digital tools emerge to improve climate disclosure across private markets.

4

Breakthrough solar cells set new efficiency records

Scientists pushing the boundaries of solar cell technology are achieving world-leading performance.

5

Algae-based biofuels double output while capturing more carbon

Genetically engineered algae promise cleaner fuels and better environmental outcomes.

Accelerating changes are forcing a global shift—businesses can either lead or risk falling behind.

Last year was projected to be the warmest in human history. Greenhouse gas levels have reached record highs, intensifying the planet's heat retention and amplifying the effects of climate change. Across the globe, the impacts are visible and devastating—severe heat waves, catastrophic flooding, and prolonged droughts are displacing millions, jeopardizing food security, and disrupting economies. Oceans, which act as a buffer for much of the planet's heat, are warming at unprecedented rates, and polar ice continues to shrink rapidly. These are not distant concerns; they are pressing realities shaping the lives of billions.

In response, the global energy transition is gaining momentum. Investments in renewable energy are reaching new heights, with solar and wind energy leading the charge. Governments and corporations are making bold commitments to decarbonization, while advances continue in technologies such as clean hydrogen, carbon capture, and advanced battery storage. Renewable energy capacity is expected to more than double between 2024 and 2030, and collaborative international initiatives are driving advancements in nuclear power. These efforts are reshaping how energy is produced, stored, and consumed, underscoring the vital role of innovation in meeting climate targets.

Yet, the challenges ahead are significant. Fossil fuels still dominate the global energy mix, with critical sectors such as aviation, shipping, and heavy industry heavily reliant on nonrenewable resources. The demand for essential materials like lithium, cobalt, and nickel is surging, raising concerns about supply chain bottlenecks, environmental sustainability, and geopolitical risks. Furthermore, the uneven distribution of clean energy investments highlights the need for global equity in the transition, to ensure developing nations have access to technologies and resources.

At the same time, technological advancements are transforming how we address these challenges. Artificial intelligence can optimize energy systems, track emissions, and enhance energy efficiency. Blockchain is improving transparency in carbon markets, while breakthroughs in materials science are creating innovative solutions such as biodegradable plastics and advanced solar technologies. These developments demonstrate that the intersection of technology and policy holds enormous potential for accelerating progress.

Global shifts offer opportunities and threats for efficiency and established practices.

JANUARY 2024

AI-Driven E-Waste Recycling

Recycleye and SWEEEP Kuusakoski deploy AI-powered optical sorters to improve e-waste recycling in the UK.

MARCH 2024

Melting Ice Caps Slow Earth's Spin

A study shows the melting polar ice caps are redistributing water mass, slowing Earth's rotation and lengthening days.

APRIL 2024

University Achieves 190% Quantum Efficiency

Lehigh University researchers have developed a solar cell material with an unprecedented 190% external quantum efficiency.

SEPTEMBER 2024

AI-Driven Tree Models for Urban Climate Adaptation

This technology from MIT, Google, and Purdue enhances urban climate adaptation by creating predictive 3D models of trees.

NOVEMBER 2024

AI-Designed Turbine Boosts Urban Wind Power

EvoPhase and Kwik Fab unveil the Birmingham Blade in England, the first urban wind turbine designed by AI.

« PAST

The ocean and new materials hold deep promise for transforming our world for the better.

FUTURE »

LATE 2030s

Enhanced Geothermal Systems Deploy in New Regions

EGS projects will be deployed in Germany and other low-enthalpy regions previously not considered for geothermal development.

EARLY 2032

Ocean-Deep Geothermal Extraction Begins

Using floating platforms, offshore geothermal plants will begin extracting energy from beneath the ocean floor.

MID-2035

Cities Build Carbon Oceans to Offset Emissions

These vast floating or submerged platforms are designed for electrochemical carbon dioxide removal or algae-based carbon capture.

EARLY 2036

Synthetic Carbon Biomass for Carbon Trading

Beyond simply storing CO2, the gas will be converted into synthetic carbon-based biomass that can be traded as a new type of asset.

END OF 2045

Terraforming Technologies for Climate Change Reversal

Breakthroughs in genetic and environmental engineering, as well as synthetic biology, will enable the first “terraforming” projects.

The accelerating shift in climate and energy systems can give businesses access to new models and markets while avoiding liabilities.

New Business Models

The growing demand for climate-conscious solutions is creating new business models and revenue streams for companies that embrace energy efficiency, carbon reduction, and clean technologies. Early adopters will benefit, while those that delay may find themselves at a competitive disadvantage.

Energy Solutions Are Quickly Evolving

As energy tech—from carbon capture to renewable energy storage—matures and scales at an accelerated pace, businesses will need to adapt. The push for net-zero emissions goals and stricter regulations will make energy solutions faster, more affordable, and accessible to companies across all sectors.

New Technologies Are Creating New Markets

Advancements in climate-related technologies, from biodegradable plastics to AI-powered recycling, are opening up untapped markets and opportunities. Businesses that invest early can position themselves as sustainability leaders by capitalizing on global shifts toward environmental responsibility.

Resource Efficiency Is Becoming Key

As climate change intensifies resource scarcity, businesses that optimize consumption will not only reduce costs but also enhance their long-term viability. Companies can also explore untapped resources like waste—this circular approach both reduces disposal costs and can open new revenue streams.

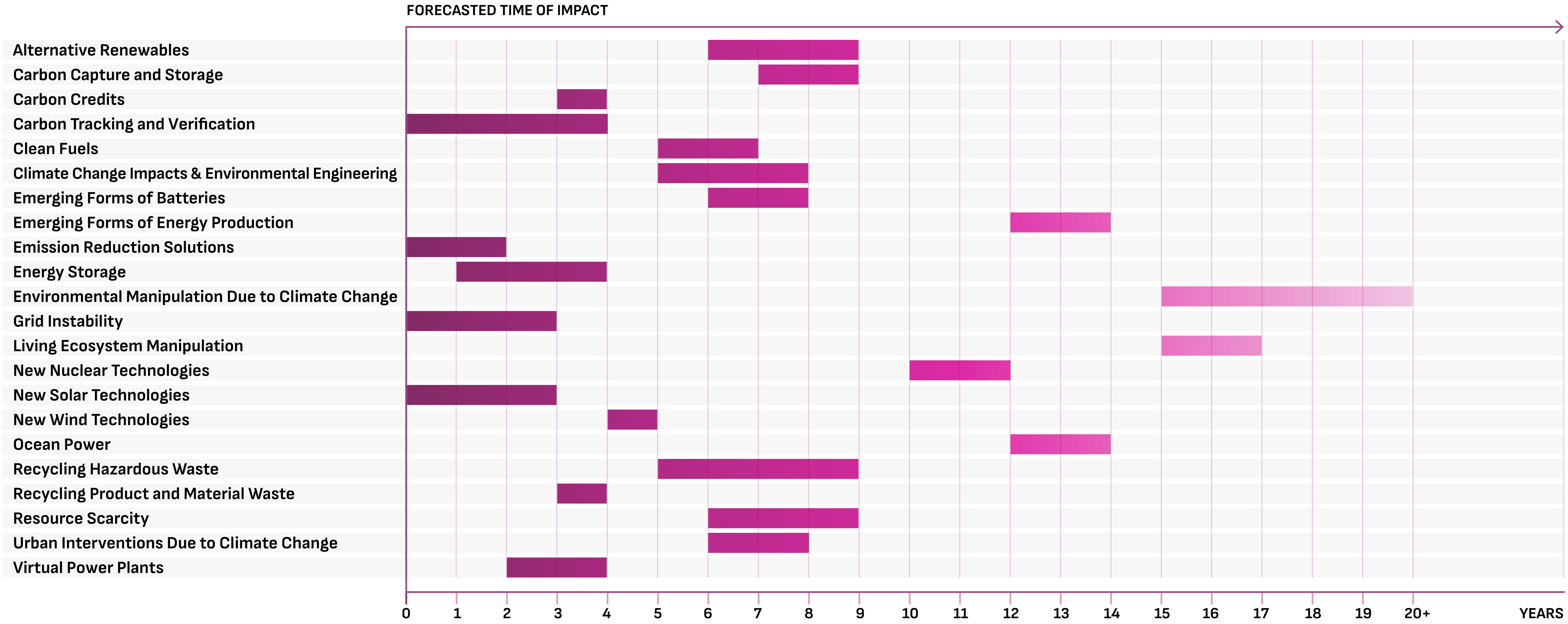
Access in Emerging Markets

Energy access is still a significant challenge in many emerging markets, where infrastructure can be unreliable and costly. For companies expanding into these regions, understanding climate and energy trends provides an edge in preparing for operational changes and identifying resilient strategies.

Melding Energy Storage and Smart Infrastructure

For businesses, investing in new storage technologies—such as the integration of gravity energy storage into buildings and advanced capacitors—could lead to smarter, energy-efficient buildings and facilities that optimize energy use and even become self-sustaining.

Renewable power reshapes short-term energy use and storage, while advanced fuels, batteries, and manipulation technologies redefine the long-term landscape.



The next decade will be defined by companies that don’t just react to falling costs, regulatory shifts, and media hype but actively shape the transition.

SCALING
Scaling energy and climate technologies is both a strategic opportunity and a competitive necessity. Prioritize early adoption of cost-competitive energy solutions, and invest in low-carbon alternatives such as EV fleets and carbon capture to future-proof operations against regulatory and carbon pricing shifts.

CONSTRAINTS ON ADOPTION
Permitting delays, grid modernization challenges, and slow policy harmonization can create uncertainty and slow deployment. High up-front costs, infrastructure gaps, financing barriers, and energy security concerns can all limit adoption of cleaner energy, especially in developing economies.

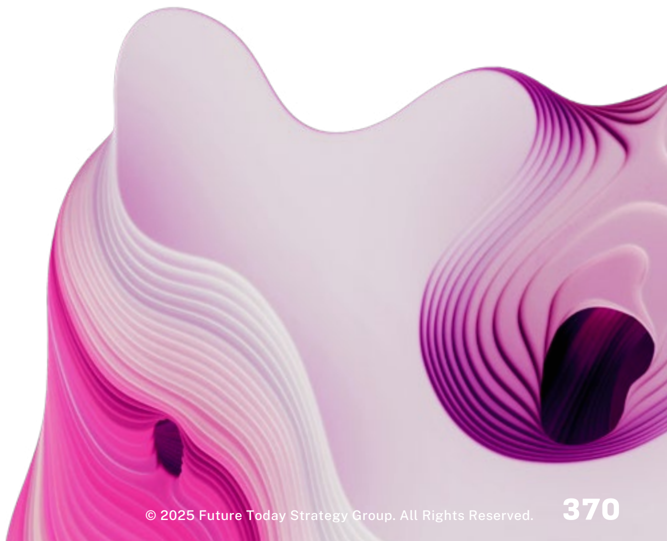
MEDIA MENTIONS
Expect media bursts around energy breakthroughs (next-gen battery storage, AI energy optimization, advanced nuclear), as well as grid modernization and policy shifts like carbon pricing or net-zero mandates. The rise of climate fintech and carbon credit transparency will further fuel industry buzz.

R&D DEVELOPMENTS
Brace for a seismic shift in energy and climate tech R&D, where AI-driven materials discovery, bioengineered carbon capture, and decentralized energy networks will upend traditional markets quickly. As policies lag, first movers will exploit regulatory loopholes, while stragglers risk being priced out altogether.

COSTS
Anticipate falling costs for solar, wind, and energy storage as manufacturing scales, supply chains mature, and efficiency improves. To stay ahead, businesses should track cost trends, leverage incentives, and invest early in scalable solutions.

REGULATIONS
In the US and EU, stricter critical minerals regulations meant to reduce reliance on China could create supply bottlenecks. Nuclear energy may be hampered by outdated licensing processes and public resistance. Future regulations will focus on balancing security, safety, and scalability in key energy sectors.

PUBLIC PERCEPTIONS
Expect a growing divide between those who see energy and climate innovations as empowering and skeptics who feel increasingly disconnected. Just as social media once promised democratization but fueled concerns over privacy and control, these technologies could spark debates about autonomy and fairness.



These individuals are at the forefront of development and transformation in the energy and climate industry.

- **Dr. Abdul Hai Alami, professor at the University of Sharjah,** for demonstrating the potential of compressed air energy storage to power AC devices as a viable alternative for domestic energy use.

- **Dr. Xiao-Ping Zhang, professor at the University of Birmingham,** for leading research on advanced smart grid technologies and their integration into existing wind turbine systems, to enhance efficiency and grid stability.

- **Parviz Sedigh and Mason Bichanich, doctoral candidates at the University of New Hampshire,** for developing an innovative underwater turbine to harness tidal energy.

- **Dr. Rawand Rasheed, CEO of Helix Earth Technologies,** for repurposing a NASA-developed air filtration technology for sustainable applications on Earth.

- **Dr. Seokheun Choi, professor at Binghamton University,** for leading research on bioelectricity, using bacterial spores to generate power from water molecules, as a novel alternative to traditional batteries and wireless energy transfer.

- **Dr. Connor Williams, staff scientist at Sandia National Laboratories,** for advancing fusion energy research by surpassing a critical threshold in energy generation, a key step toward burning plasmas and achieving ignition.

- **Dr. Avner Rothschild, professor at Technion—Israel Institute of Technology,** for leading the development of a new green technology for hydrogen production.

- **Dr. Zishan Akhter, researcher at Technology Innovation Institute,** for his work inventing the patented self-adaptive tip-sweep wind turbine.

- **Andrei Leonard Nicusan, CTO of EvoPhase, for leading the development of the AI-designed Birmingham Blade,** the world's first urban wind turbine optimized for low-wind urban environments.

- **Dr. Olga Malinkiewicz, co-founder and CTO of Saule Technologies,** for pioneering flexible, printed perovskite solar cells.

- **Vaibhav Bahadur, professor at The University of Texas at Austin,** for working on a groundbreaking solution to trap carbon dioxide in the ocean and mitigate atmospheric emissions.

- **Andrew Ng, founder of DeepLearning.AI,** for creating an accessible online tool that enables users to explore the impacts of solar geoengineering.

The race to reinvent energy and address climate change is accelerating…

OPPORTUNITIES

Advancements in Continuous Solar Power

Technologies that enable solar energy to provide electricity beyond daylight hours are gaining traction, improving grid reliability and positioning solar as a viable baseload power source.

Rewriting the Relationship Between Water and Energy

New technologies are unlocking energy stored in water's motion, temperature, and chemistry—transforming it into an active force in electricity generation, thermal management, and fuel production.

Reclaiming Wasted Heat for a Second Life

Lost energy from industrial systems is being revisited as a potential resource, offering new efficiencies through heat-to-electricity conversion technologies.

AI as a Societal Compass in Climate Resiliency

Intelligent systems are reshaping how communities anticipate and allocate critical resources, optimizing crop yields, emergency responses, and water distribution in regions facing prolonged climate stress.

…but without modern infrastructure and economic clarity, companies risk being trapped.

THREATS

Grid Infrastructure Bottlenecks

As new forms of energy come online they're outpacing grid upgrades, leading to curtailments and bottlenecks. Without modernized transmission networks, surplus energy from large-scale projects may go unused.

The Elusive Economic Equation

Cost models for next-generation energy sources remain uncertain, with financial unpredictability potentially limiting their scalability and long-term viability.

Digital Weakness in Physical Strength

As energy infrastructure becomes more intelligent, it also becomes more susceptible to interference, with cyber vulnerabilities presenting new risks to critical power networks.

Water's Hidden Vulnerabilities in Energy Systems

As water becomes a central element in climate mitigation, reliance on its availability for energy, cooling, and agriculture may introduce new systemic risks when droughts or contamination occur.

Invest in long-term strategies that reuse assets and protect future interests.

The convergence of AI and quantum computing is beginning to reshape energy forecasting and climate risk modeling. Consider partnering with quantum-AI labs to anticipate supply chain disruptions, optimize grid demand, and design novel materials for next-gen energy storage and transmission.

AI-driven recycling and emerging closed-loop material innovations are shifting waste to a revenue stream. Companies should assess their waste's value—especially in industries like electronics, energy, and automotive—and explore investments in automated material recovery or resale partnerships.

Amid climate disruptions, securing operational resilience will become a bottom-line imperative. Businesses should acquire strategic land with access to stable water sources, invest in atmospheric water harvesting, and integrate microgrid technology to insulate against infrastructure failures.

Businesses with large buildings, parking lots, or industrial sites should explore converting existing infrastructure into grid-supporting energy storage hubs. Investing in bidirectional EV charging or demand response programs could create new revenue streams while improving energy resilience.

Climate shifts will affect not just supply chains but also workforce productivity, office locations, and real estate values. Businesses should stay on top of city planning trends and invest in climate-resilient real estate, flexible work hubs, and AI-powered environmental planning tools.

The internet's energy consumption is growing exponentially, driven by high-res content and inefficient data centers. Companies should invest in AI-generated, ultra-personalized digital experiences that use adaptive rendering, edge computing, and lightweight file formats to reduce energy use while enhancing engagement.

Technology Deployment

Capital Expenditure

Talent Development

Regulatory Influence

Important terms to know before reading.

AMMONIA
A compound of nitrogen and hydrogen. It can be used directly as a fuel in direct combustion processes, as well as in fuel cells or as a hydrogen carrier. To be a low emissions fuel, ammonia must be produced from low-carbon hydrogen and nitrogen, then separated through the Haber process using electricity generated from low-carbon sources.

BIOENERGY
Energy content derived from biomass feedstocks and biogas. It comes in solid, liquid, and gaseous form. Its liquid form is often labeled biofuel.

BIOFUELS
Low-emission liquid fuels made from renewable sources.

BIOGAS
A mixture of methane, carbon dioxide, and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment.

CARBON CAPTURE (CC)
The process of trapping CO2 emissions from industrial sources, power plants, or directly from the atmosphere before they are released.

CARBON STORAGE (CS)
The long-term containment of captured CO2 in geological formations, materials, or biological systems to prevent its release into the atmosphere.

CARBON CAPTURE AND STORAGE (CCS)
The combination of carbon capture and carbon storage technologies to reduce CO2 emissions from industrial activities and energy production. CCS helps prevent atmospheric buildup of greenhouse gases, playing a critical role in climate mitigation.

CARBON TRACKING
The process of monitoring, measuring, and reporting CO2 emissions across supply chains, industries, and organizations. It enables businesses, governments, and individuals to assess their carbon footprint and identify opportunities for emission reductions.

CARBON VERIFICATION
The process of independently assessing and certifying the accuracy of reported CO2 emissions, offsets, or reductions to ensure compliance with climate regulations and carbon markets.

COMPRESSED AIR ENERGY STORAGE (CAES)
Stores excess electricity by compressing air in underground reservoirs and later releasing it.

CONCENTRATED SOLAR POWER (CSP)
A solar technology using mirrors to concentrate sunlight for heat-based power generation.

DIRECT AIR CAPTURE
Captures CO2 directly from the atmosphere.

DISPATCHABLE GENERATION
A source of electricity that can be turned on or off, such as nuclear, meaning it can be controlled. Non-dispatchable energy sources, such as wind and solar photovoltaics, cannot be controlled by operators.

ELECTROLYSIS
A process where electric current passes through a substance to effect a chemical change. In hydrogen production, electricity is used to split water into hydrogen and oxygen. If the power used for the process comes from sustainable energy sources, the process does not produce greenhouse gas emissions.

GEOENGINEERING
Technologies aimed at altering Earth's climate to counteract global warming.

GEOTHERMAL ENERGY
A baseload renewable energy source harnessing heat from Earth's core. Supercritical and closed-loop geothermal are expanding its feasibility.

GRAVITATIONAL ENERGY STORAGE (GES)
A long-duration energy storage technology that converts surplus electricity into potential energy by raising heavy objects and later releasing them to generate power when needed.

HYDROGEN
A clean fuel used in fuel cells, turbines, and industrial processes.

MULTITASKING SOLAR
The integration of solar photovoltaics with other technologies, such as agrivoltaics (solar panels over crops), floating solar (on reservoirs and offshore), and electro-agriculture (solar-powered carbon-to-food conversion).

NUCLEAR FISSION
The process of splitting heavy atomic nuclei, such as uranium-235 or plutonium-239, into smaller fragments, releasing a large amount of energy.

NUCLEAR FUSION
The process of combining light atomic nuclei, such as hydrogen isotopes (deuterium and tritium), to form a heavier nucleus, releasing an enormous amount of energy.

ORGANIC SOLAR MATERIALS
Flexible, lightweight photovoltaic materials made from conductive organic polymers.

PEROVSKITE SOLAR CELLS
Next-gen photovoltaics with higher efficiency and lower production costs than silicon panels.

PHOTOVOLTAICS (PV)
A technology that converts sunlight directly into electricity using semiconductor materials that exhibit the photoelectric effect.

SOLID-STATE BATTERIES
Replaces liquid electrolytes with solid materials, improving safety, lifespan, and energy density.

SUPERCONDUCTORS
Conduct electricity without resistance, enhancing grid efficiency and quantum computing.

SUPERCRITICAL GEOTHERMAL ENERGY
Utilizes ultra-high-temperature fluids for efficient, carbon-free power generation.

THERMAL ENERGY STORAGE (TES)
A technology that captures and stores excess heat for later use, enabling grid flexibility, industrial efficiency, and renewable energy integration.

THERMOELECTRIC GENERATORS (TEGS)
Convert waste heat into electricity for industrial and grid applications.

THERMOPHOTOVOLTAIC (TPV) BATTERIES
Store high-temperature heat and convert it into electricity using high-efficiency PV cells.

ULTRA-HIGH VOLTAGE (UHV) POWER LINES
Transmit electricity over long distances with minimal loss.

VIRTUAL POWER PLANTS (VPPS)
Networks of solar panels, home batteries, and electric vehicles that act as a single power plant.

ENERGY TRENDS

SOLAR

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Humanity's future, to say nothing of its prosperity, will depend on how the world tackles two central energy challenges: securing reliable supplies of affordable energy and switching to efficient low-carbon energy.

Fatih Birol, Executive Director, International Energy Agency (IEA)

SOLAR

Solar Energy Expansion

Solar energy production converts sunlight into electricity using photovoltaic (PV) panels or concentrated solar power (CSP) systems. Microsoft has signed a record-breaking 10.5 GW corporate power purchase agreement spanning the US and Europe that's nearly eight times larger than previous deals. The $11.5 billion investment, set for deployment in 2026, will accelerate clean energy adoption. This move aligns with a broader corporate shift toward sustainability, as companies like Amazon, Google, and Walmart invest in solar projects to offset energy-intensive operations. In the US, domestic solar manufacturing surged in 2024, adding more than 9 GW of module production capacity in the third quarter alone, largely driven by the Inflation Reduction Act. Meanwhile, Saudi Arabia secured $3.2 billion in financing for 5.5 GW of solar projects, with commercial operations expected by 2027. As demand for data centers grows, large-scale solar procurement will play a critical role in balancing energy needs with sustainability targets.

Concentrated Solar

Concentrated solar power uses parabolic mirrors or "heliostats" to focus sunlight and generate extremely high temperatures, to ultimately produce steam that drives turbines for electricity generation. Unlike PV panels, CSP can incorporate thermal energy storage (TES) to provide continuous power, even after sunset. The US Department of Energy has committed $30 million to CSP research and deployment, signaling renewed interest in its potential. In Q1 of 2024, India allocated 50% of its renewable energy tender to CSP, addressing grid reliability challenges from intermittent PV and wind power. Emerging modular CSP systems, such as 247Solar's superheated air technology, offer cost-efficient alternatives to molten salt storage. AI-driven optimization is enhancing CSP performance, with studies showing near-perfect forecasting accuracy. SolStor Energy, a new US-based firm, aims to deploy CSP with TES, for nighttime solar power. As global decarbonization efforts intensify, CSP's ability to deliver 24/7 renewable energy makes it a crucial player in the future energy mix.

Multitasking Solar

Multitasking solar integrates photovoltaic technology with other renewable systems, maximizing efficiency and sustainability. The European Union is backing a groundbreaking floating solar project in the North Sea, where SolarDuck is combining offshore solar with wind energy to optimize power generation. Meanwhile, agrivoltaics research at University of California, Davis is demonstrating how solar panels can enhance crop yields by providing shade, reducing water usage, and improving soil health—offering a climate-resilient solution for agriculture. In urban settings, Dutch researchers have developed solar-integrated window blinds that increase energy efficiency in buildings by 25% on sunny days. Additionally, electro-agriculture is emerging as a radical innovation that uses solar power to convert CO2 into acetate, which could allow plants to grow without sunlight and drastically reduce land use. Even the hospitality sector is embracing multitasking solar, with a floating hotel powered by vertical wind turbines and solar umbrellas. As demand for clean energy rises, hybrid solar solutions are shaping the future of renewable power.

Dispatchable Solar

Dispatchable solar integrates PV generation with energy storage, allowing power to scale up or down based on demand fluctuations. Cypress Creek Renewables' new Texas facility called Zier has 208 MW of solar and 80 MWh of battery storage, and has already helped stabilize the ERCOT grid during peak demand. In California, Arevon Energy's $529 million Vikings Solar-plus-Storage Project pairs 157 MWDC of solar with 600 MWh of battery storage, making it one of the first utility-scale solar peaker plants designed to supply stored solar power when demand spikes. Meanwhile, startup Exowatt is pioneering modular dispatchable solar for AI data centers, using thermal batteries to store energy for up to 24 hours at under 4 cents per kWh—cheaper than traditional electrochemical batteries. With Texas energy

SOLAR

consumption at record highs and data centers driving rapid growth, dispatchable solar is emerging as a critical solution for reliable, cost-effective, and sustainable power delivery.

Perovskite Cells

Perovskite is a crystalline compound that can be used as a semiconductor in solar cells, offering a cheaper, easier-to-manufacture, and more sustainable alternative to silicon. Researchers at the National University of Singapore have set a world record with a 27.1% efficiency perovskite-silicon tandem solar cell, using a cyanate-integrated structure that enhances stability. Machine learning is also driving breakthroughs, with scientists using AI to identify new hole-transport materials, pushing efficiencies close to 26.2%. Mass production is on the horizon, as Sekisui Chemical plans to commercialize lightweight, flexible perovskite solar cells by 2025. In the US, a Department of Energy–backed initiative is advancing tandem perovskite-silicon technology, aiming to exceed 50% efficiency. Meanwhile, researchers at the University of Surrey have developed lead-tin perovskite cells with a 66% longer lifespan. With ongoing stability improvements and manufacturing innovations, perovskite solar cells are positioned to reshape the renewable energy market.

Dye-sensitized Solar Cells

Dye-sensitized solar cells (DSCs) use organic dyes to capture photons, offering a lightweight, flexible, and sustainable alternative to traditional silicon-based solar panels. Recently, breakthroughs in molecular engineering have pushed DSC efficiency to new heights. Researchers have developed novel triazatruxene-based sensitizers, MS-1 and MS-2, achieving power conversion efficiencies of 12.81% and 10.92%, respectively—far surpassing the conventional N719 dye's 7.60%. A parallel tandem DSC combining MS-1 and N719 reached a record-breaking 12.89% efficiency, showcasing the potential of multi-dye configurations. Meanwhile, G-Lyte is preparing to unveil high-efficiency DSC technology at CES 2025 that's positioned as an eco-friendly alternative to disposable batteries. Advanced materials such as heteroatom-doped graphene quantum dots are also enhancing DSC performance by improving electron transport and charge separation. With ongoing advancements in efficiency, recyclability, and integration into consumer electronics, DSCs are emerging as a key player in the future of clean energy.

Organic Solar Materials

Organic solar materials are conductive organic polymers or small molecules that absorb light and generate electricity in organic solar cells (OSCs). Researchers at Hong Kong Polytechnic University have achieved a breakthrough 20% power conversion efficiency by designing non-fullerene acceptors with optimized photoelectric properties, enhancing both voltage and stability. Meanwhile, a University of Michigan study found that some OSCs exhibited no performance degradation after three years of proton radiation exposure, making them a promising alternative to silicon for space applications. Additionally, scientists from the University of Cambridge and Imperial College London have demonstrated that molecular arrangements in OSCs significantly impact light absorption and efficiency. Unlike rigid silicon panels, OSCs offer flexibility, low-cost manufacturing, and lightweight properties, making them ideal for wearable tech, building-integrated photovoltaics, and even space-based solar power. With continued advancements in efficiency and durability, organic solar materials are emerging as a key contender in the next generation of renewable energy.

Breakthroughs in Light Absorption

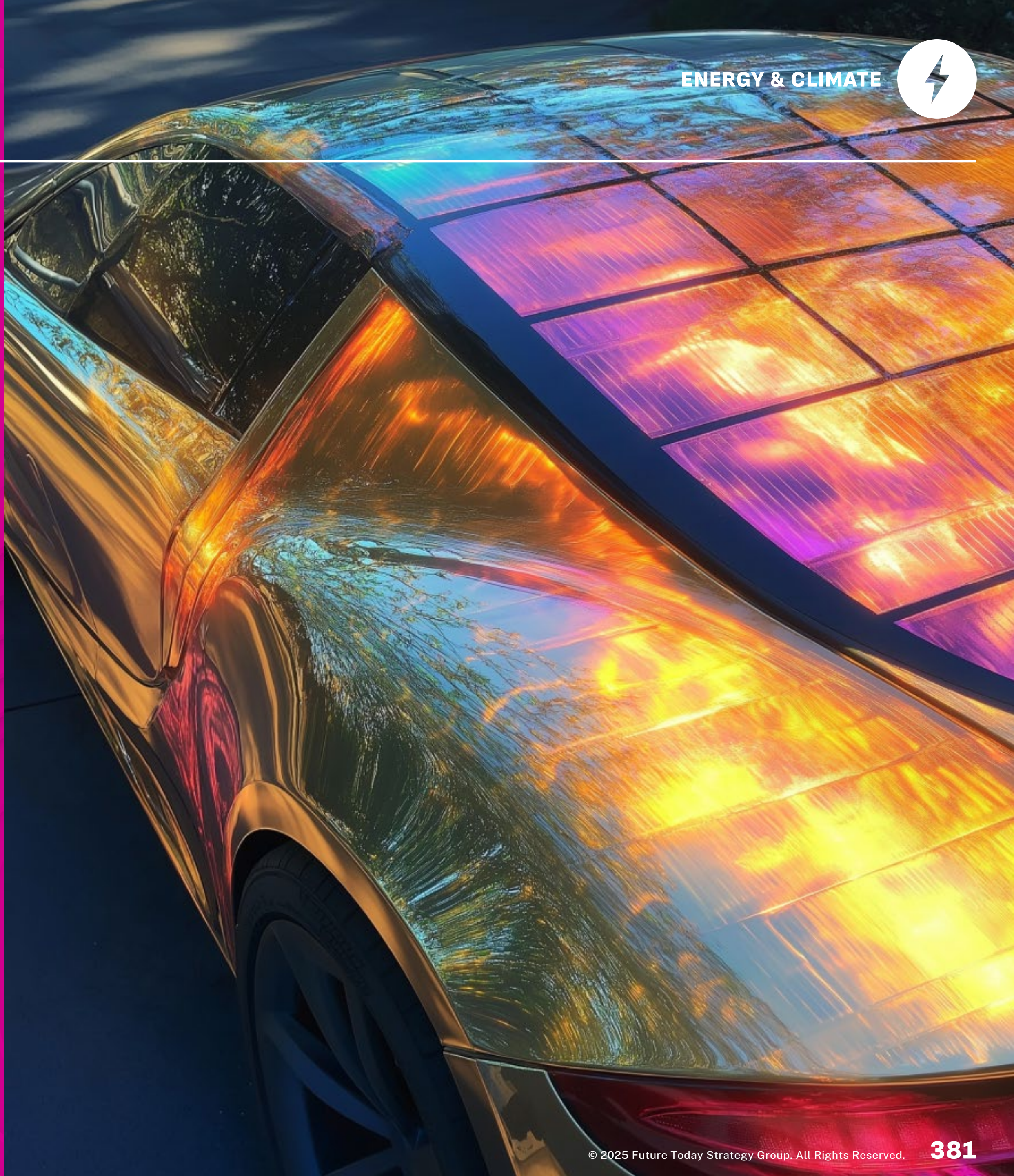
New materials and technologies are pushing solar energy efficiency beyond conventional limits. Researchers at the University of British Columbia have developed Nxylon, a super-black wood that absorbs more than 99% of visible light, far exceeding standard black coatings. This ultra-absorptive material could be used as a solar panel coating to reduce stray light and increase energy conversion. Meanwhile, Princeton Plasma Physics Laboratory has advanced the understanding of black silicon, a material etched with nanoscale pits to enhance light absorp-

SOLAR

tion. Their research into fluorine gas etching could improve the scalability of black silicon for high-efficiency solar cells. In another breakthrough, Lehigh University scientists have achieved an unprecedented 190% external quantum efficiency with a novel material using copper atoms in germanium selenide layers. This innovation surpasses the theoretical efficiency limits of silicon, capturing photon energy typically lost as heat. With materials science unlocking new frontiers in light absorption, the future of solar energy looks brighter than ever.

Solar Energy Coatings

New solar coatings are transforming how energy is harvested, allowing surfaces beyond traditional panels to generate electricity. Mercedes-Benz is developing a solar paint capable of powering electric vehicles, with ultra-thin 20%-efficient solar modules embedded directly into the car's exterior. A midsize SUV covered in this paint could generate enough energy for more than 7,430 miles of driving per year. Meanwhile, Oxford University researchers have created a power-generating material that can be coated onto buildings, vehicles, and even mobile phones, achieving more than 27% efficiency, with the potential to surpass 45%. This innovation reduces reliance on large solar farms and expands solar adoption to urban environments. In another breakthrough, researchers have developed a waterproof perovskite solar coating integrated with drop triboelectric nanogenerators, which capture energy from both sunlight and rain. With these advancements, solar coatings could soon revolutionize renewable energy by embedding power generation into everyday objects.



WIND

WIND

Offshore Wind Turbines

Offshore wind turbines generate electricity by harnessing wind energy over open water, where wind speeds are typically stronger and more consistent than on land. Brazil has enacted a new law permitting offshore wind farms to enhance energy security and attract investment, offering incentives for projects within its territorial waters. In the US, Maine has announced a new offshore wind port at Sears Island to support floating turbine assembly, aiming for 3 GW of offshore wind power by 2040. And the US Department of Energy and the National Oceanic and Atmospheric Administration have launched an offshore wind forecasting initiative, deploying advanced sensors to optimize turbine placement and mitigate environmental impacts. Meanwhile, Lloyd's Register has introduced a Recommended Practice for Floating Offshore Wind Turbines, providing comprehensive guidelines for design, transport, and installation, aligning with international standards. Norway's Wind Catching Systems is pioneering the Windcatcher, a wall of small 1 MW turbines designed to capture 2.5 times more energy per square meter than traditional three-blade turbines. With global investments accelerating, offshore wind is emerging as a critical pillar of renewable energy expansion.

Vertical Wind Turbines

Vertical-axis wind turbines (VAWTs) generate electricity using blades that rotate around a vertical axis, allowing them to harness wind from any direction. Unlike traditional horizontal-axis wind turbines, VAWTs are quieter, more compact, and better suited for urban environments. Researchers have developed genetic learning algorithms to optimize blade pitch, leading to a 200% efficiency increase and a 77% reduction in vibrations, and progress in addressing key structural challenges. In Hawaii, Kanoa Winds is testing Japanese Vertical Coaxial Contra-rotating Twin Blades technology, which has been successfully deployed in Japan for more than 15 years in dense urban settings. Meanwhile, Airiva, a modular wind turbine wall system, is preparing for customer trials in 2024, offering 2,200 kWh of annual energy output per unit for commercial and industrial sites like highways and campuses. In the UAE, a patented self-adaptive tip-sweep turbine promises further efficiency gains. With these advancements, VAWTs are emerging as a scalable solution for decentralized, urban wind power.

Bladeless Turbines

Bladeless wind turbines generate electricity using oscillation or aerodynamic structures instead of rotating blades, reducing noise, maintenance, and environmental impact. Vortex Bladeless' wind turbine uses controlled oscillation to capture wind energy, making it ideal for urban areas where turbulence limits traditional turbines. In Egypt, researchers at Pharos University have developed a cone-shaped bladeless turbine, addressing concerns about migratory bird safety. Meanwhile, Aeromine Technologies has created a rooftop bladeless wind unit capable of generating 5 kW per unit, producing 50% more energy than rooftop solar while requiring just 10% of the space. The Birmingham Blade, designed by AI, is tailored for low urban wind speeds and is projected to be seven times more efficient than conventional designs. With growing commercial interest and 11,000+ inquiries for Aeromine's system, bladeless wind energy is rapidly emerging as a viable, scalable alternative for sustainable urban power generation.

Airborne Wind Energy

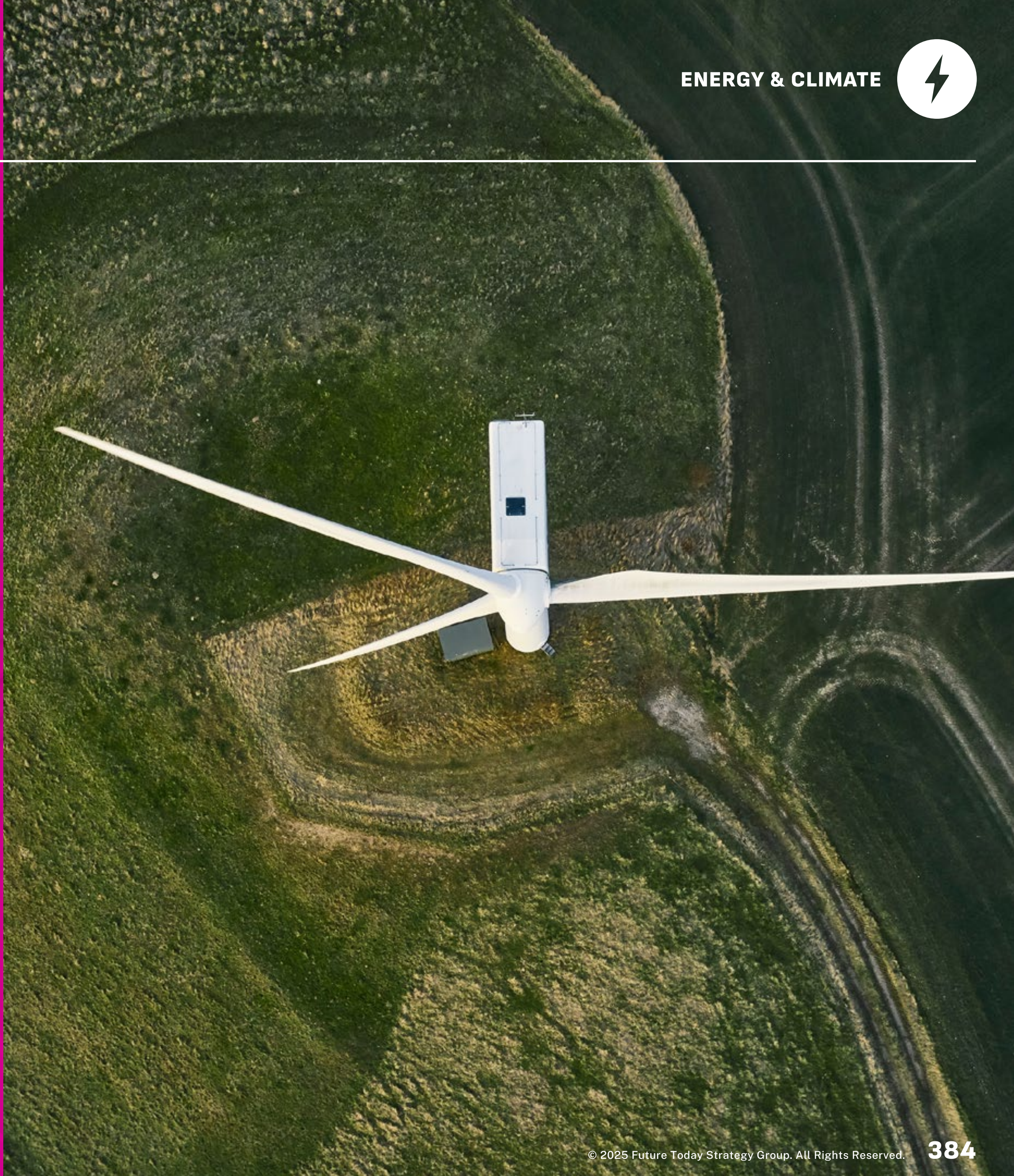
Airborne wind energy (AWE) systems use tethered kites or drones to capture wind energy at higher altitudes, where wind speeds are stronger and more consistent than near the ground. SkySails Group has validated the world's first performance curve for AWE, confirming the efficiency of its power kite technology. Its subsidiary SkySails Power GmbH is also advancing kite-based energy solutions with its PN-14 model, capable of generating 200 kW, using optimized flight paths for maximum power production. Meanwhile, RWE and Kitepower have expanded their AWE test

WIND

site in Ireland, increasing the Falcon kite's capacity to 100 kW, more than tripling the previous system's output. These systems require less material than traditional wind turbines, making them cheaper to manufacture, easier to deploy, and ideal for offshore applications. With increasing investment and performance validation, AWE is poised to become a scalable and efficient addition to the global renewable energy landscape.

Automating Wind Farms

Automating wind farms involves using AI, digital twins, and autonomous robotics to optimize wind energy production, reduce maintenance costs, and improve operational efficiency. Vind AI, an Oslo-based startup, has secured 3 million euros to fund development of an AI-driven platform that optimizes turbine placement and configurations before construction, to maximize energy output. In offshore wind, the UK's UNITE project is deploying autonomous underwater robots to inspect and repair turbines, reducing the need for human divers and improving maintenance in harsh sea conditions. Meanwhile, the US National Science Foundation's NorthWind project is developing AI-powered digital twins to predict wind turbine motion during installation, enhancing safety and precision. Bitcoin miner MARA Holdings is also leveraging automation by using real-time wind data to power mining operations only when conditions are favorable. With AI optimizing layouts, robotics handling maintenance, and digital twins improving reliability, automation is shaping the future of wind energy.



ALTERNATIVE RENEWABLES

ALTERNATIVE RENEWABLES

Geothermal

Geothermal energy harnesses heat from the earth's interior to generate electricity and provide direct heating and cooling with minimal carbon emissions. The Eavor-Loop system in Germany, developed by Eavor GmbH, is pioneering a closed-loop geothermal technology that eliminates the need for pumps, offering a scalable solution for district heating and power. Meanwhile, Fervo Energy's project in Utah has significantly reduced drilling costs and time, bringing geothermal closer to cost parity with other renewables. In Saudi Arabia, Strataphy is deploying a cooling-as-a-service model, allowing clients to access geothermal cooling without upfront costs, a key innovation for energy-intensive regions. The GLADE project, supported by the US Department of Energy, is testing high-temperature downhole tools and real-time drilling optimization, targeting a 25% increase in drilling speed. Additionally, researchers are exploring offshore geothermal, with floating platform designs that could unlock vast new energy reserves. With breakthroughs in drilling, closed-loop systems, and offshore exploration, geothermal is poised for global expansion beyond traditional hot spots.

Supercritical Geothermal

Supercritical geothermal energy taps into reservoirs where temperatures exceed 400 degrees Celsius, dramatically boosting power output compared to conventional geothermal plants. These extreme conditions create supercritical fluids, which carry 10 times more energy than standard geothermal sources, offering a high-density, carbon-free power solution. New Zealand is investing $60 million in supercritical geothermal research and drilling deeper wells—up to 6 kilometers—in the Taupo Volcanic Zone to explore its vast energy potential. Meanwhile, the US House Committee on Science, Space, and Technology has advanced legislation to fund superhot rock energy research, including a dedicated Superhot FORGE test site. Scientists are also studying rock permeability at high temperatures, finding that granite permeability increases 30-fold at 800 degrees Celsius, potentially improving fluid circulation and energy extraction. With advancements in deep drilling, enhanced geothermal systems, and federal investment, supercritical geothermal could become a global game-changer for baseload renewable power.

Using Geothermal for Energy Storage

Geothermal energy storage captures heat and pressure underground, storing energy for controlled release when demand peaks. Princeton University's research highlights how flexible geothermal power can function like a battery, enhancing grid reliability by complementing intermittent renewables like wind and solar. Fervo Energy's Project Red has successfully demonstrated geothermal storage lasting more than five days, proving its potential for long-duration energy storage. Meanwhile, Sage Geosystems' 3 MW EarthStore facility in Texas is pioneering its Geopressured Geothermal System, which can store energy for 6 to 10 hours with a round-trip efficiency of 70%–75%. The facility will participate in the ERCOT market, showcasing geothermal's ability to provide grid-balancing services. With declining drilling costs and minimal infrastructure modifications required, geothermal energy storage is emerging as a cost-competitive, scalable solution for clean energy storage—and a natural alternative to lithium-ion batteries for long-duration applications.

Ocean Thermal Energy Conversion

Ocean thermal energy conversion (OTEC) generates electricity by harnessing the temperature difference between warm surface seawater and cold deep-sea water. Because ocean temperatures remain stable, OTEC provides a continuous, weather-independent source of renewable energy. Global OTEC has introduced the OTEC Power Module, designed to power offshore oil and gas platforms while cutting CO2 and methane emissions and reducing capital costs by 20%–30%. Meanwhile, the PLOTEC project in the Canary Islands is constructing a storm-resistant floating OTEC structure to test survivability in

ALTERNATIVE RENEWABLES

harsh marine conditions, a key step toward expanding this technology to island nations reliant on diesel generators. In Hawaii, Makai Ocean Engineering's OTEC plant is delivering 100 kW of baseload power, demonstrating the viability of this closed-loop system for long-term energy security. As advancements improve efficiency and infrastructure costs, OTEC is turning into a scalable solution for offshore energy and island electrification.

Hydropower

Hydropower generates electricity by harnessing the energy of moving water, making it one of the most reliable and scalable renewable energy sources. As the grid modernizes, new technologies are transforming hydropower for greater efficiency and resilience. The National Renewable Energy Laboratory is developing CYSAT-Hydro, an AI-powered cybersecurity tool to protect hydropower plants from growing cyberthreats. Meanwhile, hydro-hybrids—which integrate utility-scale batteries with hydropower—are improving grid stability by storing excess energy for peak demand periods. Additionally, digital twin technology is being deployed to create virtual models of turbines so operators can simulate different conditions, predict maintenance needs, and optimize efficiency. These advancements make hydropower more adaptable, secure, and cost-effective, ensuring its role as a key foundation for the clean energy transition.

Hydro as a Water Battery

Hydro storage, or pumped storage hydropower, stores energy by pumping water into uphill reservoirs when electricity is abundant and releasing it downhill to generate power when demand peaks. This long-duration storage solution is being modernized with new approaches. Sperra, with $7.7 million in US and German funding, is developing a subsea pumped hydro system using 3D-printed concrete spheres placed on the ocean floor, leveraging deep-sea water pressure for storage. Meanwhile, RheEnergise's "high-density waterless hydro" project in the UK replaces traditional water with a denser fluid, increasing energy output by 2.5 times while reducing infrastructure needs by 40%. In the US, the Lewis Ridge Pumped Storage Project in Kentucky is repurposing former coal mine land for a 287 MW pumped hydro facility, marking the first such conversion in more than 30 years. As lithium-ion battery costs rise, pumped storage remains the most scalable and cost-effective energy storage method, reinforcing grid reliability with storage durations ranging from hours to years.

New Hydro Turbine Design

New hydro turbine designs are improving efficiency, environmental impact, and manufacturing speed to modernize hydropower infrastructure. GE Vernova's aerating turbine technology, part of a Saluda Hydro power plant upgrade in South Carolina, enhances water quality by increasing dissolved oxygen levels, meeting new environmental regulations while extending the plant's lifespan. Natel Energy's fish-safe turbines, featuring curved blades that create a protective stagnation zone, allow 99% of American eels to survive turbine passage. They're helping balance hydropower generation with aquatic ecosystem protection. Meanwhile, the Oak Ridge National Laboratory is leading the $15 million Rapid RUNNERS project, which 3D prints large metal turbine runners, to reduce lead times and lower production costs for US hydropower facilities. With innovations in additive manufacturing, fish-friendly design, and water quality improvements, hydro turbine technology is evolving to ensure greater sustainability and long-term viability of low-emission energy generation.

CLEAN FUELS

CLEAN FUELS

Hydrogen

Hydrogen fuel is a zero-emission energy source that can be used in fuel cells or combustion systems to generate electricity, offering a clean alternative to fossil fuels. As hydrogen adoption grows, new technologies are improving safety, storage, and production. South Korea's KRISS has developed the nation's first real-time hydrogen fuel quality monitor, addressing contamination risks that could damage fuel cells or cause overheating. Meanwhile, Toyota's lightweight hydrogen capsules provide a portable refueling solution, allowing fuel-cell vehicles to recharge without a fixed station while also serving as an emergency power source. In micro-scale hydrogen applications, a compact hydrogen generator for recreational vehicles converts methanol into hydrogen on demand, solving storage and transport challenges. On the production side, Japanese scientists are advancing photocatalytic hydrogen production by using sunlight to split water into hydrogen and oxygen for scalable solar-to-chemical energy conversion. Additionally, a new retrofitted micro-turbine can operate on both hydrogen and natural gas, making power plants more adaptable for a hydrogen-based economy. With innovations spanning fuel safety, portable storage, solar-driven hydrogen production, and dual-fuel power generation, hydrogen is steadily evolving into a key player in the clean energy transition.

Reducing the Cost of Hydrogen Production

Green hydrogen, produced using renewable energy, is key to decarbonizing industries and replacing fossil fuels, but its high costs remain a challenge. Researchers at Technion have developed a new electrolysis method that separates hydrogen and oxygen into different cells, improving efficiency and lowering production costs by reducing reliance on expensive membranes. Meanwhile, UNIST scientists have scaled up perovskite-based photoelectrochemical water splitting, increasing photoelectrode size by 10,000 times and

CLEAN FUELS

achieving more than 10% solar hydrogen conversion efficiency, a major step toward cost-effective, commercial-scale solar hydrogen production. Another promising approach comes from Koloma, a startup that has raised $350 million to discover and extract underground hydrogen reservoirs, potentially offering a naturally occurring, carbon-free fuel source. As research progresses in electrolysis efficiency, solar hydrogen scalability, and geologic hydrogen extraction, green hydrogen is moving closer to becoming an affordable and widespread clean energy solution.

Biofuels

Biofuels, derived from renewable organic materials, are advancing as low-emission alternatives to fossil fuels, with applications in aviation, transportation, and industrial energy. LanzaJet's commercial-scale alcohol-to-jet fuel facility is converting ethanol from corn, sugarcane, and municipal waste into jet fuel, potentially reducing aviation emissions by up to 66%. Meanwhile, Washington State University has developed a process to convert lignin-based agricultural waste into jet fuel. It provides a sustainable alternative to fossil-derived aromatics while maintaining high fuel performance. Seaweed-based biofuels are also emerging, with researchers demonstrating a method to convert common marine biomass into aviation fuel, potentially cutting emissions by 82%. Additionally, an electro-biodiesel process from Washington University in St. Louis offers 45 times greater efficiency than traditional biodiesel, reducing land use while generating net-negative carbon emissions. As advanced biofuels scale, they could revolutionize multiple industries, making renewable fuels more accessible and decarbonizing hard-to-electrify sectors.

Syngas From the Sun

Solar syngas is a synthetic gas produced using concentrated solar energy to drive high-temperature chemical reactions that convert CO_2 and H_2O into hydrogen and carbon monoxide. This process provides a renewable alternative to fossil-based syngas, which is a key feedstock for synthetic fuels like jet fuel, gasoline, and diesel. Synhelion's DAWN facility in Germany is the world's first industrial-scale plant to produce syngas using solar heat, with plans to scale production to 1 million metric tons annually over the next decade. A separate study has demonstrated an automated solar thermochemical system, using a ceria-based redox cycle to generate customizable syngas compositions for Fischer-Tropsch fuel synthesis. Researchers are also exploring photocatalytic syngas production, where a novel catalyst harnesses solar energy to convert CO_2 and methane into syngas, providing a high-efficiency, emissions-reducing alternative. With advancements in solar thermochemistry and automation, syngas from the sun is turning into a scalable, carbon-neutral pathway for producing sustainable transportation fuels.

FOSSIL FUEL INNOVATION

FOSSIL FUEL INNOVATION

Reducing Fossil Fuel Impact

Efforts to reduce fossil fuel dependency are being challenged by rising energy demands, particularly from data centers, AI computing, and industrial sectors. A surge in natural gas plant construction—with 80 new plants planned by 2030—risks delaying the transition to renewable energy. Many of these plants lack carbon capture systems, further undermining climate goals. Meanwhile, EPA regulations have tightened emissions standards, and coal plants are facing mandates to install carbon capture or shut down by 2032. In response, companies are adopting alternative fuels, such as Piramal Pharma's switch from coal to biomass briquettes, that reduce carbon emissions while maintaining industrial energy needs. Additionally, innovations like L-Mul, an energy-efficient AI computation algorithm, could significantly lower the power consumption of AI-driven data centers, reducing the need for new fossil-fuel infrastructure. Addressing both energy demand and supply is key to minimizing fossil fuel reliance and accelerating clean energy adoption.

Methane Emissions Reductions

New advancements in methane tracking, conversion, and mitigation are accelerating efforts to reduce the gas' environmental impact. Methane is 28 times more potent than CO2 in trapping heat, making its reduction critical for climate change mitigation. Satellites such as MethaneSAT and Tanager-1 now provide real-time, high-precision methane leak detection, while lidar-based aerial systems and drone-mounted sensors are enhancing on-the-ground monitoring. In industrial applications, LongPath Technologies, backed by a $162 million DOE loan, is expanding its laser-based detection network to 20,000 square miles, identifying leaks down to parts per billion. At the same time, researchers at University of Central Florida have developed a breakthrough process that converts methane into green hydrogen and high-performance carbon materials, offering a dual benefit of methane reduction and sustainable fuel production. Additionally, University of California, Davis studies show that seaweed-based cattle feed can cut methane emissions from grazing cattle by 40%, presenting a scalable agricultural solution. These emerging detection, capture, and conversion technologies provide a multi-sector approach to methane reduction, from energy and agriculture to industrial emissions tracking.

NUCLEAR

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Nuclear

Nuclear power generation is the process of producing electricity through controlled nuclear reactions, primarily fission, where atomic nuclei split to release energy. Nuclear power is undergoing a wave of advancements, from new reactor deployments to breakthroughs in reactor design and fuel technology. The completion of Plant Vogtle Unit 4 in Georgia adds 1,114 megawatts of power, making Plant Vogtle the largest nuclear plant in the US at nearly 5 gigawatts. Meanwhile, Argonne National Laboratory is pioneering Generation IV reactor research, with a focus on sodium-cooled fast reactors that enhance safety, efficiency, and fuel sustainability. In fission research, CERN's n_TOF facility has conducted the first-ever high-energy measurement of uranium-235 fission, refining models of nuclear reactions. Scientists at University of Washington and Los Alamos National Laboratory have used the Summit supercomputer to simulate nuclear fission at an unprecedented level, improving understanding of scission neutron behavior. Additionally, advancements in antineutrino detection technology are offering new ways to remotely monitor reactor operations, with potential implications for nuclear security and nonproliferation. These breakthroughs are shaping the next generation of nuclear power, reinforcing its role in a low-carbon energy future.

Fusion

Fusion power, the process of generating energy by fusing atomic nuclei, is advancing rapidly through AI-driven plasma control, new reactor materials, and large-scale projects. Researchers at Princeton University have developed an AI model that can predict and prevent plasma instabilities in fusion reactors, a breakthrough that enhances stability and efficiency. At the DIII-D National Fusion Facility, this AI successfully forecasted disruptions 300 milliseconds in advance, allowing for real-time corrections. Meanwhile, the WEST tokamak in France achieved a milestone by sustaining a 50-million-degree plasma for six minutes, demonstrating progress in using tungsten as a reactor material. On the infrastructure front, Virginia is set to host the world's first grid-scale fusion power plant, aiming for commercialization by the early 2030s. In China, researchers have introduced Chixiao, a linear plasma device designed to test fusion materials under extreme conditions, reinforcing global efforts to make fusion a viable energy source. These advancements mark significant strides toward a future where fusion provides limitless, carbon-free energy.

Laser-Driven Fusion

Laser-driven fusion, a process that uses ultra-powerful lasers to compress and heat fuel to conditions required for nuclear fusion, is making significant strides toward commercialization. At the National Ignition Facility, scientists have achieved record-breaking energy outputs, including a 5.2 megajoule reaction in February 2024, more than double the input energy, proving that fusion ignition can be sustained. Meanwhile, Colorado State University's ATLAS Facility, set for completion in 2026, will drive laser fusion research through a $150 million partnership with Marvel Fusion, which has also secured $70 million in Series B funding to advance inertial confinement fusion. The OMEGA laser system has demonstrated a direct-drive method that achieves fuel gain with far lower energy requirements than traditional approaches. In Australia, HB11 Energy has partnered with ELI ERIC, the world's largest high-power laser provider, to develop hydrogen-boron fusion, a fuel choice that eliminates neutron radiation risks. With major advancements in laser precision, fuel composition, and experimental efficiency, these breakthroughs are bringing laser-driven fusion closer to a viable, clean energy source.

Molten Salt Reactors

Molten salt reactors (MSRs) are an emerging nuclear technology that uses liquid salt as both a coolant and fuel carrier, offering higher efficiency, improved safety, and reduced nuclear waste compared to traditional reactors. Recent advancements are accelerating the commercialization and deployment of MSRs worldwide. At Oak Ridge National Laboratory, researchers have analyzed molten uranium trichloride (UCl3)

NUCLEAR

to better understand its chemical behavior, crucial for reactor fuel design. Meanwhile, North Carolina State University has introduced a novel plasma bubble spectroscopy technique to detect and monitor elements in molten salt, to improve reactor safety and fuel efficiency. Texas A&M University is collaborating on Natura MSR-1, the first liquid salt-fueled reactor licensed in the US, aiming to produce clean energy and medical isotopes. Dutch companies are developing small modular MSRs, and China is constructing the first thorium-based MSR, which will harness abundant thorium reserves for sustainable energy production. These advancements position molten salt reactors as a critical component of the global energy transition.

Small Modular Reactors

Small modular reactors (SMRs) are compact, factory-built nuclear reactors designed to provide flexible, scalable, and cost-effective clean energy. Unlike traditional large nuclear plants, SMRs can be deployed in smaller increments, making them attractive for industrial applications, AI data centers, and regions with growing energy needs. Major tech companies are investing in SMRs, with Google partnering with Kairos Power for a potential 500 MW SMR project, while Amazon collaborates with X-energy on a 320 MW reactor for cloud infrastructure. Oracle is also exploring SMRs for powering its data centers. At the same time, Ghana has signed an agreement with NuScale Power to build a VOYGR-12 SMR, marking its first step into nuclear energy. In France, a new small reactor project aims to strengthen the nation's energy strategy. Advances in AI-driven reactor optimization at Purdue University are improving SMR efficiency, reducing power fluctuation errors to below 1%, and demonstrating digital twin capabilities for predictive modeling. Meanwhile, Energy Vault and NuCube Energy are working on nuclear microreactors to power AI-driven data centers by integrating energy storage solutions for reliability. SMRs are poised to revolutionize clean energy generation, through decarbonization, energy security, and adaptability for a rapidly evolving grid.

EMERGING FORMS OF ENERGY PRODUCTION

EMERGING FORMS OF ENERGY PRODUCTION

Hygroelectricity

Hygroelectricity is the process of generating electricity from moisture in the air, offering a renewable and scalable energy solution for various applications, including wearable electronics, HVAC systems, and carbon capture. New breakthroughs in moisture-electricity generation (MEG) and humidity-driven energy harvesting are pushing this technology forward. Binghamton University has developed a paper-based wearable device that extracts electricity from water molecules using bacterial spores, potentially powering sensors and medical devices. Meanwhile, Helix Earth Technologies' Helix Micra system, initially developed for NASA spacecraft, dramatically improves air conditioning efficiency by reducing energy use by 50% as it leverages moisture absorption for dehumidification. This technology is scalable via 3D printing, reducing production costs and environmental impact. Newcastle University researchers have created a synthetic membrane that utilizes humidity differences to capture and remove carbon dioxide without external energy inputs, an alignment with climate mitigation goals. Additionally, Chinese scientists have developed ionic hydrogel-based MEG devices that generate record-breaking power density, demonstrating potential for self-powered electronics. These innovations signal a growing shift toward utilizing atmospheric moisture as a clean energy source as they pave the way for low-carbon, high-efficiency energy harvesting solutions.

Wave Power

Wave power is a form of renewable energy that captures the motion of ocean waves to generate electricity, offering a predictable and abundant source of clean energy. New developments in wave energy converter (WEC) technology and optimized farm layouts are accelerating wave power's commercial viability. Eco Wave Power's project in Porto, Portugal, in partnership with MOQ Engineering, is set to be the first megawatt-scale wave energy project in the region, aligning with Portugal's goal of 85% renewable electricity by 2030. The company is also expanding into Taiwan and the Port of Los Angeles. Meanwhile, a pilot WEC project in Jaffa Port, Israel, developed in collaboration with EDF Renewables IL, marks the country's first wave energy initiative. Studies along the Pacific coast of Central America highlight wave energy's potential, estimating it could provide 35 times more energy than wind in some areas. Advanced oscillating water column turbine modeling and control co-design strategies are further optimizing WEC efficiency and farm layouts, increasing power output while minimizing environmental impact. As research progresses, wave energy is poised to become a key player in the global clean energy transition.

Tidal Turbines

Tidal turbines generate electricity by capturing the kinetic energy of ocean currents, offering a predictable and consistent renewable energy source compared to wind and solar power. New advancements in tidal stream technology are driving innovation in the sector. The Dragon 12 tidal energy kite, developed by Minesto, has successfully delivered 1.2 MW of electricity in the Faroe Islands, leveraging a unique gliding motion to enhance energy output. Inyanga Marine Energy Group is deploying a 20 MW HydroWing system in North Wales, utilizing modular Tocardo T-3 turbines to reduce costs and streamline installation. Meanwhile, the Cape Cod Canal's test site has received federal approval for tidal energy trials that aim to integrate generated power into the New England grid. In the US Pacific Northwest, the OPALCO Tidal Energy Pilot Project faces economic and environmental challenges, particularly concerns about Southern Resident killer whale habitats. Research efforts at the University of New Hampshire, supported by the Department of Energy, are testing compact tidal turbines under the nearby Memorial Bridge and could contribute to future scalable designs. With growing global investment, tidal turbines are becoming a key component of the marine renewable energy mix.

EMERGING FORMS OF ENERGY PRODUCTION

Mimicking Photosynthesis

Mimicking photosynthesis involves replicating the natural process plants use to convert sunlight into energy, with applications in renewable fuel production, tissue engineering, and biotechnology. Japanese researchers have successfully integrated chloroplasts from algae into hamster cells, creating photosynthetic animal cells that can survive and generate energy for at least two days. This breakthrough challenges the assumption that animal cells would digest chloroplasts and suggests future possibilities in tissue engineering and regenerative medicine by enhancing oxygen production in lab-grown tissues. Meanwhile, scientists at Daegu Gyeongbuk Institute of Science and Technology have developed a biohybrid system for solar hydrogen production that incorporates fluorescent nanocomposites and Shewanella oneidensis bacteria to improve photocatalytic efficiency. Their system achieved a hydrogen production rate of 18.4 mmol per hour per gram of catalyst, surpassing previous methods in artificial photosynthesis. These developments highlight the potential for bioengineered solutions to address both energy generation and medical advancements, bridging the gap between plant and animal biology.

Thermophotovoltaic

Thermophotovoltaic (TPV) technology converts heat into electricity by using thermal emitters to generate infrared light, which is then captured by photovoltaic cells. This process enables efficient energy recovery from high-temperature sources, offering applications in industrial waste heat recovery, renewable energy storage, and off-grid power generation. Researchers at Rice University have developed a quantum-inspired thermal emitter that improves TPV efficiency, potentially exceeding 60% conversion rates. The emitter, composed of tungsten, silicon nanocylinders, and a spacer layer, allows for precise photon emission control, enhancing energy conversion. Meanwhile, Antora Energy has launched a 2 MW TPV manufacturing facility in California that's focused on high-efficiency grid-scale thermal storage. Its III-V semiconductor-based TPV cells achieve more than 40% efficiency, generating 100 times more power than traditional solar cells. Another breakthrough, detailed in ScienceDaily, reports a 44% efficiency milestone at 1435 degrees Celsius, with potential advancements pushing limits beyond 50%. Innovations such as photon recycling and material flexibility position TPV as a promising battery-free alternative for energy storage that will help to decarbonize industrial processes and enhance renewable grid stability.

Thermoelectric Generators

Thermoelectric generators (TEGs) convert heat into electricity by exploiting temperature differences in materials. Recent breakthroughs in geometry and material flexibility are dramatically improving their efficiency and applications. Researchers have developed hourglass-shaped thermoelectric materials that boost energy conversion by 360% compared to conventional rectangular designs. Using 3D printing, they optimized microstructures to reduce thermal conductivity and enhance power generation, achieving the highest thermoelectric performance index for 3D-printed materials. Meanwhile, new flexible thermoelectric films are emerging, capable of converting body heat into electricity. Made from bismuth telluride, these films are just one micron thick and maintain efficiency even after repeated bending. With potential uses in wearables, self-powered sensors, and electronics cooling, these innovations position TEGs as a key solution for sustainable energy harvesting in diverse industries.

SCENARIO YEAR 2029

RAINCHARGE: THE END OF DEAD PHONES

It started as a niche innovation—an experimental humidity generator capable of pulling electricity from the air. By 2029, this breakthrough has evolved beyond the lab, as a coalition of tech giants, energy companies, and materials science pioneers unveil RainCharge™—the world's first moisture-powered consumer charging system. Now, phones, laptops, and wearables seamlessly harvest electricity from ambient humidity, fog, and rain, eliminating the need for traditional charging in wet and tropical climates.

The breakthrough was made possible by cross-industry collaboration. Samsung and Apple integrated IH-MEG technology into their RainCharge™-ready smartphones, embedding microscopic moisture-electricity layers beneath their glass screens to allow for passive charging. Ford and Siemens developed RainGrid, a moisture-activated urban energy network that powers public transit shelters, outdoor advertising screens, and emergency response infrastructure without reliance on traditional electricity grids. Meanwhile, outdoor brands like Adidas and Patagonia pioneered RainWeave™, a hydrogel-embedded fabric that enables clothing to generate electricity from sweat and humidity, making it ideal for extreme sports, emergency workers, and disaster response.

Looking ahead, RainCharge technology is poised to move beyond Earth. By 2040, NASA and SpaceX will be testing moisture-electricity generators on Mars to harness trace humidity from the planet's thin atmosphere, while oceanic industries explore how RainCharge systems could provide backup power for offshore wind farms and cargo ships, reducing reliance on fuel-based generators. The once-radical idea that rain could be used as an energy source has now transformed global infrastructure, powering everything from personal devices to city-wide energy grids.

ENERGY STORAGE

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ENERGY STORAGE

Emerging Forms of Batteries

Innovations in battery technology are moving beyond conventional lithium-ion designs, introducing sustainable and long-lasting alternatives. Swiss researchers have developed a fungal biobattery, a microbial fuel cell that generates electricity from nutrients rather than chemical reactions. Fully biodegradable and 3D printed, this battery offers a low-impact solution for powering sensors in agriculture and environmental monitoring. Meanwhile, quantum batteries are showing promise, with nonreciprocal energy transfer increasing charging efficiency by a factor of four. These designs, leveraging time-reversal symmetry breaking, could revolutionize quantum computing and energy storage. Another breakthrough comes from nuclear-powered diamond batteries, which harness carbon-14 from nuclear waste to generate continuous energy for up to 5,700 years. These batteries could power pacemakers, satellites, and remote sensors without ever needing replacement. As researchers push the boundaries of energy storage, next-generation batteries promise to be more sustainable, efficient, and long-lasting, reshaping the future of power.

TPV Batteries

Thermophotovoltaic (TPV) batteries convert stored heat into electricity using high-efficiency photovoltaic cells, offering a promising alternative for grid-scale energy storage. US scientists have achieved a breakthrough in TPV efficiency by developing air-bridge thermophotovoltaic cells with 44% efficiency—a major improvement over previous designs. This innovation uses photon recycling via a nanophotonic air bridge, increasing energy capture and making TPV batteries more viable for high-temperature energy storage. Additionally, advancements in germanium-based TPV converters have reached 23.2% efficiency, improving cost-effectiveness for thermal battery applications. With scalable, low-cost, and sustainable designs, TPV batteries are emerging as a viable alternative to lithium-ion storage, particularly for renewable energy integration and industrial decarbonization.

Iron-Based Batteries

Iron-based batteries are emerging as a cost-effective, sustainable alternative to lithium-ion and vanadium-based storage systems. Researchers at Pacific Northwest National Laboratory have developed an iron flow battery using nitrogenous triphosphonate, achieving high cycling stability over 1,000 charge cycles while maintaining 98.7% capacity. Meanwhile, Worcester Polytechnic Institute scientists have enhanced alkaline iron batteries by adding silicate to suppress hydrogen gas generation in a move toward improving efficiency for grid storage. Iron cathodes are also being explored as a replacement for cobalt and nickel in lithium-ion batteries, potentially reducing costs and improving sustainability. Form Energy has secured $405 million to scale its 100-hour iron-air battery, designed for long-duration energy storage. Additionally, Australia's first iron flow battery factory is under construction with a goal of providing grid-scale storage by 2025. With advancements in chemistry and manufacturing, iron-based batteries are set to play a key role in decarbonizing energy storage.

Solid State Batteries

Solid-state batteries replace conventional liquid electrolytes with solid materials, improving safety, lifespan, and energy density for electric vehicles (EVs) and grid storage. A triple-layer lithium metal battery developed at DGIST enhances fire resistance and maintains 87.9% efficiency after 1,000 cycles, making it a safer alternative to traditional lithium-ion cells. Harvard researchers have designed a lithium metal battery that charges in 10 minutes and lasts for 6,000 cycles, solving dendrite formation issues with a micron-size silicon anode. Meanwhile, Toyota and Imec are leading commercialization efforts, with Toyota developing EV batteries capable of 621-mile ranges and 10-minute fast charging for release by 2027, while Imec's 1070 Wh/L lithium-metal battery surpasses current industry standards. Manufacturing innovations include polymerized ionic liquid electrolytes and compatibility with existing lithium-ion production lines, reducing costs.

ENERGY STORAGE

With faster charging, higher energy density, and improved safety, solid-state batteries are set to transform EVs and renewable energy storage.

Gravitational Energy Storage

Gravitational energy batteries store energy by raising heavy weights when surplus power is available and releasing them to generate electricity when needed. This emerging technology offers a long-lasting, low-maintenance alternative to conventional energy storage methods, particularly for integrating renewable energy into the grid. A Purdue University study assessed the feasibility of small-scale gravity batteries for residential use, but high costs and limited storage capacity proved prohibitive. In contrast, large-scale implementations are advancing globally. Skidmore, Owings & Merrill and Energy Vault are repurposing skyscrapers as vertical energy storage systems, using modular designs to integrate gravity-based storage into urban infrastructure. Meanwhile, Scottish startup Gravitricity is converting an abandoned Finnish mine into Europe's first underground gravity battery, demonstrating the potential for repurposing disused mining sites. In China, Energy Vault has deployed a 100 MWh gravity battery, capable of powering 3,500 homes, as part of the country's strategy to lead in renewable energy storage. These innovations highlight gravity batteries as a durable, scalable, and geography-independent energy storage solution, with potential applications in cities, remote areas, and repurposed industrial sites.

Flow Batteries

Flow batteries store energy in liquid electrolytes, offering scalable, long-duration energy storage solutions ideal for integrating renewable energy into the grid. Unlike conventional batteries, they separate energy storage and power generation, allowing for flexible capacity expansion. Harvard's Aziz Group has made breakthroughs in aqueous organic redox flow batteries, developing a self-repairing molecule called "zombie quinone" that reduces capacity fade by 40 times, significantly improving battery lifespan. Meanwhile, researchers at the Korea Institute of Energy Research have enhanced viologen redox flow batteries, achieving 99.4% efficiency and improved cycle life by adding functional groups that stabilize battery chemistry. At Pacific Northwest National Laboratory, scientists have boosted flow battery longevity by 60% using a starch-derived additive, β-cyclodextrin, which accelerates electrochemical reactions while maintaining stability. These advancements underscore the potential of low-cost, long-lasting flow batteries to revolutionize energy storage, reducing dependence on mined materials while enabling greater renewable energy adoption.

Capacitors

Capacitors are energy storage devices that rapidly charge and discharge electricity, playing a vital role in medical implants, electric vehicles, and consumer electronics. Recent breakthroughs are enhancing their efficiency, durability, and application range. Researchers at the University of Twente have developed a multilayer capacitor with more than 90% efficiency, capable of billions of charge cycles, significantly extending device lifespan. At the

ENERGY STORAGE

Indian Institute of Science, scientists have created a light-charged supercapacitor that achieves a 3,000% capacitance boost under UV light, with potential applications in self-powered sensors. Meanwhile, new heterostructures using barium titanate and molybdenum disulfide have demonstrated a record 191.7 J/cm^3 energy density, with minimized energy losses. These innovations are pushing capacitors beyond traditional roles, improving grid-scale storage, self-powered electronics, and sustainable energy solutions.

Compressed Air Energy Storage

Compressed air energy storage (CAES) systems store excess energy by compressing air and later releasing it to generate electricity. This method offers a scalable and cost-effective alternative to traditional batteries, supporting grid stability and renewable energy integration. Highview Power is constructing four cryogenic air storage facilities in the UK, each with 2.5 GWh capacity, utilizing liquid air energy storage to manage peak demand and store excess renewable energy. Meanwhile, researchers at the Chinese Academy of Sciences have enhanced adiabatic CAES (A-CAES) by injecting heated water under pressure, improving air storage density by 15% and achieving 71.7% efficiency. Additionally, a buoyancy-based CAES system developed at the University of Sharjah demonstrates a 60% round-trip efficiency, with a projected energy cost significantly lower than conventional batteries. As innovations in temperature regulation, underground storage, and system integration advance, CAES is emerging as a key player in large-scale energy storage, enabling a more resilient and sustainable energy grid.

SCENARIO YEAR 2032

COATINGS TO KEEP THE LIGHTS ON

As the humid air settles over Singapore's Marina Bay at dusk, the city quietly illuminates itself. Building facades glow thanks to Solvion's latest innovation, SolvLux—a coating that combines dye-sensitized solar cells, fungal bio-batteries, and graphene-based conductivity to create seamless, self-powered surfaces. Singapore first tested the new coating on its public transit hubs, creating a new generation of self-powered bus shelters. Now street lights, traffic signals, and building facades use the power-generating coating to reduce energy demand both during the day and at night without pulling a single watt from the electrical grid. SolvLux absorbs diffuse sunlight during the day, storing excess energy in moisture-activated fungal bio-batteries and ensuring uninterrupted operation through Singapore's frequent evening downpours and humid nights. The city no longer "turns on" its lights; the lights simply exist as they're seamlessly woven into the fabric of infrastructure.

Beyond Singapore's urban core, SolvLux is changing lives in rural Malaysia, Indonesia, and Vietnam, where it is leapfrogging traditional electrification efforts. Instead of waiting for government-funded grid expansions, off-grid villages have begun installing SolvLux on fences, pathways, and community hubs. Bio-energy technicians—workers trained to monitor and optimize fungal bio-batteries—have aided in these locations. Mushroom farmers and biotech specialists are being retrained to cultivate and maintain fungal battery colonies, ensuring consistent electron production and long-term system health. These workers operate fungal energy labs, periodically replenishing and optimizing urban biofilms, much like gardeners tending to a city-wide ecosystem.

ENERGY TRANSPORT & THE GRID

ENERGY TRANSPORT & THE GRID

UHV Power Lines

Ultra-high voltage (UHV) power lines transmit electricity over long distances with minimal energy loss, supporting large-scale renewable energy integration and improving grid efficiency. These transmission systems, which include ultra-high voltage alternating current (UHVAC) and ultra-high voltage direct current (UHVDC), are critical for enabling the clean energy transition. China is at the forefront of UHV technology with several large-scale projects. The Gansu-Zhejiang ±800 kV UHVDC transmission project will transport 36 billion kWh annually, with more than 50% from renewables, reducing 17 million tons of CO_2 emissions. The Zhangbei-Shengli 1,000-kV UHVAC project will transmit 70 billion kWh per year, supplying 19 million households and increasing wind energy integration. The Jinshang-Hubei ±800 kV UHVDC project, the highest-altitude UHV transmission system, spans 1,901 kilometers and will deliver 40 billion kWh annually to central China. With billions in infrastructure investment, UHV power lines are reshaping global energy grids, enabling the efficient transmission of renewable energy while reducing reliance on fossil fuels and meeting growing electricity demand.

Superconductors

Superconductors are materials that can conduct electricity without resistance when cooled below a critical temperature, enabling highly efficient power transmission, advanced computing, and next-generation energy storage. Recent breakthroughs in high-temperature superconductors (HTS) are expanding their real-world applications, from energy grids to medical imaging and quantum computing. MIT-backed startup VEIR is developing superconducting transmission lines that use a proprietary nitrogen-based cooling system, allowing for higher power capacity while minimizing grid expansion challenges. The technology could double US transmission capacity to meet 2035 decarbonization goals. Meanwhile, University at Buffalo researchers have created the highest-performing HTS wire using rare-earth barium copper oxide, achieving record current densities and improving efficiency in power grids, fusion energy, and MRI technology. Josephson junction research is also advancing, with helium-ion beam techniques enhancing superconducting circuits for faster, more efficient electronics. These innovations in superconductors are set to revolutionize energy infrastructure, improving transmission efficiency, reducing power loss, and supporting the integration of renewable energy worldwide.

ENERGY TRANSPORT & THE GRID

Dynamic Line Rating Systems

Dynamic line rating (DLR) systems use real-time data, such as temperature, wind speed, and line conditions, to assess the actual capacity of transmission lines rather than relying on conservative static ratings. By maximizing grid efficiency, DLR enables greater integration of renewable energy while minimizing costly infrastructure expansion. The Federal Energy Regulatory Commission is considering a new rulemaking to enhance DLR adoption across the US, aiming to improve grid reliability and operational flexibility. A large-scale DLR deployment by AES and LineVision has demonstrated how real-time monitoring can increase transmission efficiency and reduce environmental impact. Meanwhile, Georgia Tech and Smart Wires are integrating DLR with advanced power flow control technology, using machine learning and localized weather predictions to optimize energy flow. Research in Estonia highlights how confidence intervals in DLR models can improve transmission capacity by accounting for terrain-specific weather variations. These advancements position DLR as a key grid-enhancing technology that enables utilities to unlock additional capacity, integrate renewables more effectively, and modernize power infrastructure without extensive new transmission development.

Grid Management

Advanced AI models, blockchain technology, and grid-forming inverters (GFMs) are driving innovations in real-time grid management. A graph neural network model developed by the University of Virginia enhances power flow analysis, improving accuracy and efficiency while adapting to changing grid conditions. Powerledger and Energie Steiermark are using blockchain-based energy trading, allowing prosumers in Austria to buy and sell surplus electricity with greater transparency and flexibility. Digital twins and power hardware-in-the-loop testing methods are improving grid stability by modeling real-world power flow and restoration strategies. GFM inverters provide voltage, frequency, and inertia support, helping stabilize grids with high levels of wind and solar power. By leveraging AI, blockchain, and real-time modeling, these advancements enable a more resilient and decentralized power system, ensuring grids can efficiently handle fluctuations in demand and renewable energy supply.

Grid Instability

As grids transition to renewable energy sources, challenges such as reduced inertia, extreme weather events, and increasing demand spikes make stability solutions more critical than ever. Reactive Technologies is addressing grid stability concerns through real-time inertia measurement with its GridMetrix technology, which is already deployed in the UK and expanding into the US and global markets. Climate change–related risks, including flash floods, droughts, and extreme heat, are further straining grids, requiring massive investment in modernized infrastructure—an estimated $24.1 trillion by 2050. New technologies are emerging to enhance grid resilience. The Pacific Northwest National Laboratory has developed grid-forming inverters, which improve voltage and fre-

ENERGY TRANSPORT & THE GRID

quency stability when integrating wind and solar power. The University of Birmingham has designed smart control systems to prevent frequency dips and forced oscillations in wind farms. GE Vernova is deploying synchronous condensers in Chile to boost grid inertia and voltage regulation, reducing blackout risks. As renewable penetration increases, grid instability must be proactively managed using advanced analytics, real-time monitoring, and next-generation grid technologies to ensure a reliable and resilient energy future.

Virtual Power Plants

A virtual power plant (VPP) is a network of decentralized energy resources—such as solar panels, home batteries, electric vehicles (EVs), and smart appliances—that collectively act as a single power plant. VPPs enhance grid stability by intelligently managing energy supply and demand, reducing reliance on traditional fossil-fuel power plants and increasing renewable energy integration. Maryland became the first US state to pass legislation supporting vehicle-to-grid integration, allowing EVs to supply electricity back to the grid. The 1 GW AI-powered VPP in Texas, a partnership between NRG Energy and Renew Home, will use smart thermostats and AI-driven energy optimization to manage power for 200,000 homes. Renew Home also launched America's largest residential VPP, managing 3 GW of energy use and planning to expand to 50 GW by 2030, potentially covering 10%–20% of peak US electricity demand. In Europe, Enpal's AI-based VPP is connecting solar-equipped homes, EVs, and heat pumps to create a decentralized energy network, with plans to expand to 80,000 customers. By aggregating distributed energy resources, VPPs improve grid resilience, lower costs, and accelerate the transition to renewable energy.

CLIMATE TRENDS

ADDRESSING CARBON EMISSIONS

ADDRESSING CARBON EMISSIONS

Carbon Capture and Storage

Carbon capture and storage (CCS) is a technology that captures CO_2 emissions from industrial sources or directly from the air and stores them underground to prevent release into the atmosphere. Recent breakthroughs are making CCS more efficient and scalable. Tech companies like Google and Salesforce are investing in CCS at paper mills and wastewater plants, converting CO_2 into bicarbonate for long-term ocean storage or injecting captured emissions underground. AI-driven research at Argonne National Laboratory is accelerating material discovery for CCS, generating 120,000 new metal-organic frameworks in minutes. As climate goals drive CCS adoption, these innovations are making carbon removal cheaper, more effective, and widely deployable.

Natural CSS

Natural carbon capture and storage (natural CCS) refers to processes that use biological or oceanic systems to absorb and store CO_2, differing from conventional CCS, which relies on industrial technologies for direct air capture and underground storage. Researchers are enhancing these natural methods to boost efficiency and scalability. Scientists have genetically modified algae to absorb CO_2 more effectively, doubling biofuel production while aiding wastewater treatment. Meanwhile, Equatic is building North America's first ocean-based carbon removal plant, using electrochemistry to trap CO_2 while producing green hydrogen. Captura, another startup, is piloting an electrochemical process to remove CO_2 from seawater, increasing ocean alkalinity for long-term carbon storage. Additionally, a newly discovered cyanobacteria strain, Chonkus, thrives in CO_2-rich waters, rapidly sinking to store carbon naturally. These innovations are making nature-based CCS scalable and commercially viable, aligning with global decarbonization goals.

Direct Air Capture

Direct air capture (DAC) is a technology that removes CO_2 directly from the atmosphere and stores it underground or repurposes it for industrial use. Unlike natural carbon sequestration, DAC provides a faster, scalable solution for reducing greenhouse gases. In Iceland, Climeworks has launched Mammoth, a large-scale DAC facility using 72 industrial fans powered by geothermal energy to capture CO_2 efficiently. In Wyoming, Spiritus is developing Orchard One, a "Carbon Orchard" set to sequester two megatons of CO_2 annually, aiming to cut costs below $100 per ton through geological storage. University of California, Berkeley researchers developed covalent organic frameworks, lightweight materials designed to capture CO_2 from ambient air, with potential for large-scale deployment. At Rice University, a modular electrochemical reactor enhances direct air capture efficiency while enabling hydrogen co-production. These projects signal a shift toward industrial-scale DAC, increasing the feasibility of large-scale carbon removal as a key climate mitigation tool. As DAC infrastructure expands, technological advancements and cost reductions will be crucial for achieving global net-zero targets.

CO2 Storage

CO_2 storage is the process of securely trapping captured carbon dioxide in underground reservoirs, minerals, or ocean formations to prevent it from reentering the atmosphere. Unlike direct air capture, which removes CO_2 from ambient air, CO_2 storage focuses on long-term sequestration of emissions from industrial sources. In Texas, Oxy Low Carbon Ventures is leading a project to store 722,000 metric tons of CO_2 annually in underground wells, supporting Microsoft and Amazon's carbon removal goals. In Hungary, the Danube Removals Project marks the EU's first onshore CO_2 storage initiative, using biogenic CO_2 from biofuels. Meanwhile, researchers at the University of Texas at Austin have developed a sixfold faster CO_2 storage method using hydrates, offering a chemical-free, ocean-based solution. As carbon

ADDRESSING CARBON EMISSIONS

storage expands, scalability, stability, and regulatory support will determine its role in global decarbonization efforts.

Carbon Tracking

Carbon tracking technology is evolving as businesses face rising regulatory and investor pressure to disclose and reduce emissions. MSCI's Private Company Data Connect streamlines sustainability reporting for private markets, integrating with Persefoni's carbon accounting tools to standardize emissions data. Hyundai and Kia's IGIS platform leverages blockchain and lifecycle assessment methods to track emissions across supply chains, ensuring compliance with international regulations. Workiva's new carbon solutions platform, bolstered by its Sustain.Life acquisition, automates emissions reporting and aligns data with frameworks like SEC and California climate disclosure rules. Meanwhile, Coforge ENZO, developed with Salesforce, consolidates emissions data for real-time carbon footprint tracking. As governments mandate audit-ready climate disclosures, AI-driven platforms and blockchain-secured carbon tracking are becoming critical for corporate sustainability strategies.

Emission Reduction Solutions

AI-driven solutions and digital twin technology are reshaping emissions reduction strategies. IBM's Maximo Emissions Management integrates real-time monitoring with AI-powered incident tracking, optimizing sustainability in energy and transportation sectors. A Hexagon study found that digital twins reduce emissions by 15% and costs by 19%, yet only 16% of executives plan major investments, revealing an untapped opportunity. Meanwhile, AFEN, France's new carbon removal association, unites more than 30 members to advance negative emissions technologies, aligning with global carbon neutrality goals. The economic potential of carbon dioxide removal technologies exceeds a trillion dollars, driving interest in policy integration and private-sector collaboration. As AI enhances asset efficiency and digital twins provide predictive insights, companies face growing pressure to scale these innovations for both economic and environmental gains.

Reducing Digital Carbon Emissions

As data center energy demands surge, AI-driven optimization and liquid immersion cooling are cutting carbon footprints. AI models improve cooling efficiency, workload management, and dynamic resource allocation, reducing emissions from cloud computing. Refroid Technologies' liquid immersion cooling—India's first—lowers energy use by up to 40% and achieves a PUE as low as 1.05, aligning with India's growing 4 GW data center expansion. Meanwhile, structured pruning methods like MINI-LLM reduce GPU power consumption, making large AI models more energy-efficient. As hyperscale data centers expand, integrating AI, liquid cooling, and model efficiency techniques will be critical to reducing digital carbon emissions while supporting next-gen computing and sustainability mandates.

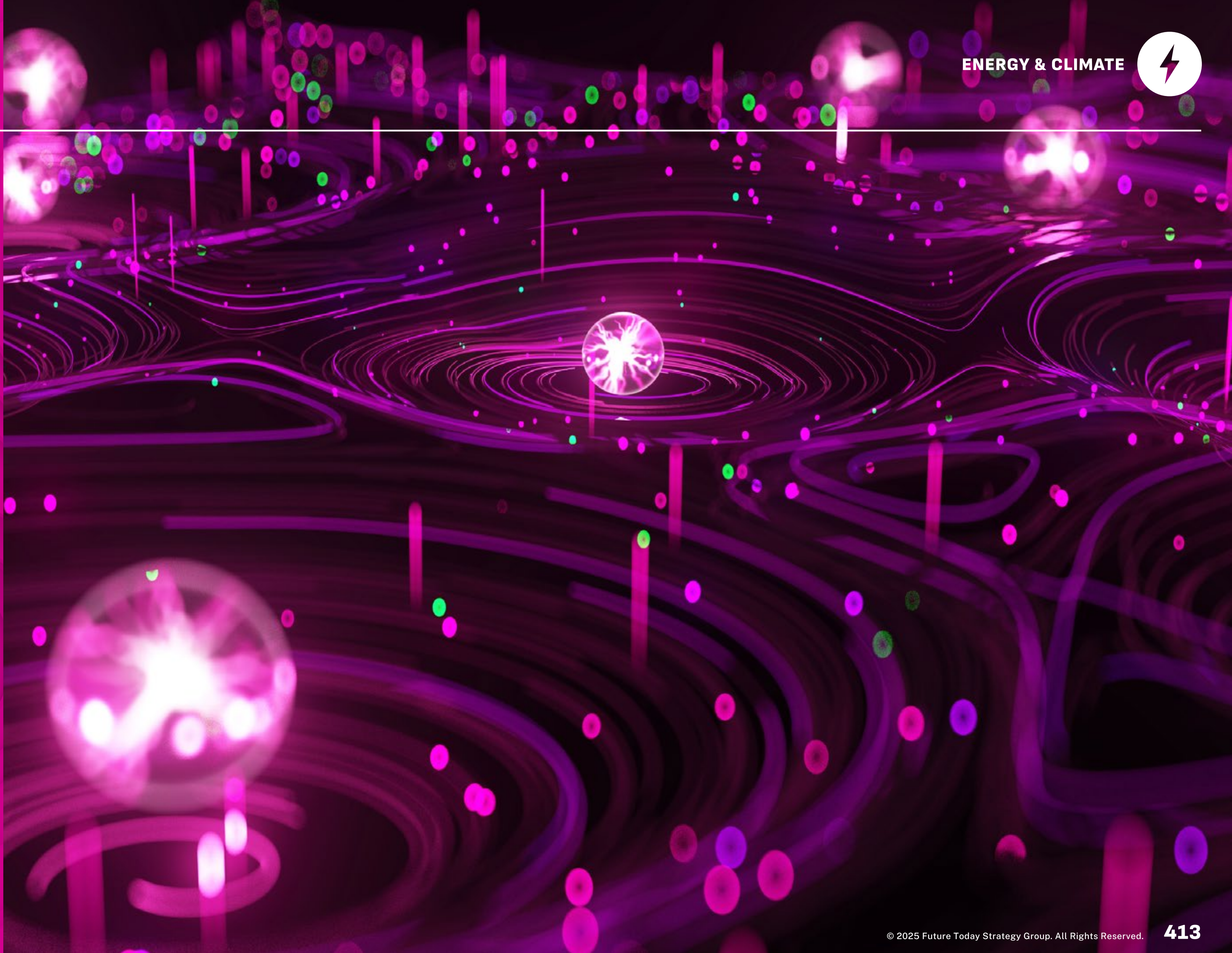
Carbon Credits

Carbon credits are tradable certificates that allow businesses to offset emissions by funding projects that remove or reduce CO2. Google's new deal secures 100,000 tons of biochar-based carbon credits from Indian farms, highlighting biochar's role as a low-cost, scalable carbon removal solution. Meanwhile, FG Capital Advisors' 2025 Carbon Token is targeting institutional investors with nature-based projects and battery metals investments, reinforcing carbon credits as a high-value asset class. In Europe, the EU's carbon removal legislation is establishing clear methodologies for biochar, direct air capture, and Bio-CCS, aiming to standardize global markets. With corporate demand rising and new financial mechanisms emerging, carbon credits are evolving from voluntary offsets to regulated, investment-grade assets, driving climate action through market-based incentives.

ADDRESSING CARBON EMISSIONS

Carbon Verification

Carbon verification ensures the accuracy and credibility of carbon credits, unlike carbon tracking, which focuses on measuring emissions. Net Zero Co. secured $5.5 million to develop blockchain-based carbon removal tokens, providing full traceability for sequestered CO2. Meanwhile, Gold Standard's pilot program for digital Measurement, Reporting, and Verification (dMRV) is testing automated emissions reporting to enhance efficiency and transparency in carbon credit certification. A study in IEEE Xplore highlights game-theoretic blockchain models that improve MRV accuracy, reducing fraud and increasing compliance. With corporations and governments prioritizing verified climate action, advancements in blockchain, AI, and automation are making carbon markets more transparent and trustworthy, strengthening their role in global decarbonization efforts.



RECYCLING

RECYCLING

Recycling Product Waste

New technologies are revolutionizing the recycling of e-waste, textiles, and EV batteries, making waste recovery more efficient and scalable. Recycleye has deployed the first commercial AI-powered sorting system for electronic waste in the UK, using machine learning to identify and separate valuable components like circuit boards, metals, and batteries. Researchers at Iowa State University have developed a rare-earth metal extraction method using proteins, reducing reliance on mining for critical materials. Meanwhile, South Korean scientists have introduced an eco-friendly lithium-ion battery recycling technique that restores cathodes to full capacity without high heat or toxic chemicals. In textiles, a University of Delaware team is using a microwave-based process to break down blended fabrics, enabling better recycling of polyester and cotton. As AI and advanced chemistry optimize material recovery, waste recycling is shifting from costly, inefficient processes to high-precision, sustainable solutions.

Recycling Material Waste

Breakthroughs in recycling are transforming plastic, textiles, and industrial waste into reusable materials. University of California, San Diego researchers have developed a biodegradable thermoplastic polyurethane embedded with bacterial spores, enabling 90% degradation within five months. A UC Berkeley team has created a vaporization process that converts polyethylene and polypropylene plastics into reusable gases with 90% efficiency, supporting a circular economy. Meanwhile, University of Southern California scientists have pioneered a fungal-based method to recycle carbon fiber composites, preserving 97% of their strength for reuse in aviation and automotive industries. AI-driven textile sorting is also advancing, with a new autonomous system integrating robotics and spectral imaging to improve fiber recovery. In construction, RMIT University has strengthened concrete by 40% using waste carpet fibers, reducing early-age cracking and repurposing textile waste. These innovations are reshaping material waste recycling, reducing landfill dependency, and creating new value chains across industries.

Recycling Hazardous Waste

New recycling technologies are redefining hazardous waste management. France is exploring a controversial plan to repurpose radioactive waste into consumer products like cutlery, pending public approval for a dedicated recycling facility. Meanwhile, AMG Critical Materials has launched New-MOX SAS to convert stored plutonium into mixed-oxide (MOX) fuel, addressing costly storage challenges while enhancing nuclear energy efficiency. MOX fuel recycling, already used in Europe and Japan, could recover 12%–22% more energy from uranium and reduce nuclear waste. These initiatives highlight a shift toward innovative waste reuse, but safety concerns and regulatory oversight remain critical to their success.

SCENARIO YEAR 2031

THE FINANCIALIZATION OF TRASH

In 2031, waste isn't just a sustainability concern—it's a trillion-dollar asset class, tracked, traded, and monetized in real-time digital waste markets. The old model of extraction and disposal has been replaced by AI-driven material circulation, where products are designed for reclamation from the start. Business leaders who once relied on raw material supply chains now invest in urban mining, smart biodegradables, and AI-powered waste arbitrage to secure competitive advantage.

Waste-backed assets (WBAs) have emerged as a dominant force in global markets, securitizing recyclable materials, carbon-negative plastics, and rare-earth metals recovered from urban mining. AI-driven waste audits, now mandated alongside financial audits, ensure that companies accurately report and offset their waste liabilities. Blockchain-secured waste verification systems prevent fraud, ensuring that every ton of traded material meets strict environmental and circular economy standards.

At the same time, AI-powered recycling infrastructure has reached unprecedented efficiency, with deep-learning models disassembling electronics at a component level to recover valuable materials with near-perfect precision. The rise of "virtual mines" has made landfills obsolete, turning e-waste into a key resource for the consumer tech industry. Meanwhile, biodegradable smart materials—embedded with bacterial spores, hydrolytic enzymes, and adaptive feedback systems—enable products to disassemble themselves when no longer needed. AI-driven carbon tracking platforms verify degradation rates in real time, ensuring compliance with increasingly strict circular economy laws.

CLIMATE CHANGE IMPACTS

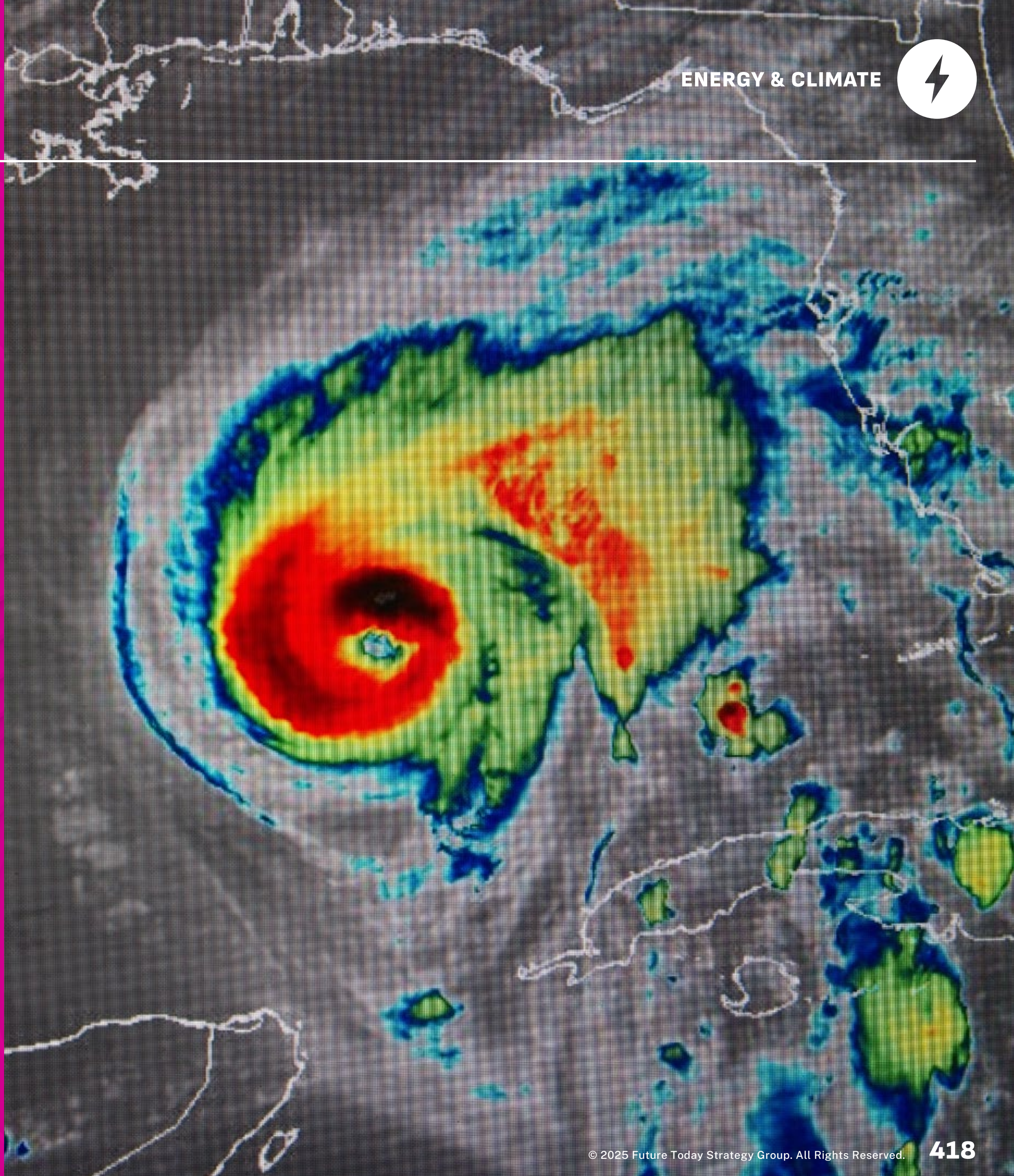
CLIMATE CHANGE IMPACTS

Intelligent Systems for Extreme Weather

Extreme weather events, driven by climate change, are intensifying in frequency and severity, prompting new technological solutions for disaster prediction and response. Nvidia's Earth-2 digital twin platform uses AI to simulate weather conditions, enhancing real-time forecasting for storms, flooding, and heat waves. Taiwan's Central Weather Administration is adopting Earth-2 to improve typhoon predictions, while the Weather Company integrates its APIs for global forecasting. The UN's new AI resilience initiative, led by the International Telecommunication Union and the UN Environment Programme, is developing global standards for AI-driven disaster response, addressing seismic and hydrometeorological risks. 3D wireless networks combining terrestrial, aerial, and satellite systems are being explored for early warning systems and emergency coordination, with AI optimizing their efficiency. In New York City, drones with thermal imaging are now used in hurricane simulations to locate victims and assist first responders. As climate threats escalate, AI, digital twins, and wireless networks are shaping the future of disaster resilience.

Improving Water Security

Rising global water shortages are driving technological breakthroughs in atmospheric water harvesting and sustainable farming. Aquaria Technologies' solar-powered atmospheric water generators extract moisture from the air, producing up to 264 gallons daily with near-zero operational costs. Researchers in Singapore have developed an advanced aerogel that absorbs water at 5.5 times its weight, enabling 12 harvesting cycles per day. King Abdullah University of Science and Technology's mass transport bridge system extracts 23 liters per square meter per day, even in arid regions. Meanwhile, AirFarm's inflatable aeroponic farms reduce water use by 99%, optimizing agriculture in water-scarce areas. Osaka Metropolitan University has also improved water adsorption technology, lowering energy needs by 55%. These innovations are transforming water access,



CLIMATE CHANGE IMPACTS

reducing reliance on depleting freshwater sources, and enabling sustainable water management in drought-prone regions.

Community Resilience Interventions

As climate change intensifies, communities are developing new strategies to address its emotional, social, and physical impacts. Climate cafes, grassroots gatherings modeled after death cafes, are emerging worldwide to help individuals process climate anxiety and grief, with more than 350 facilitators trained in North America alone. In wildfire-prone regions in British Columbia, Rogers Communications has deployed AI-powered cameras, successfully detecting wildfires 16 minutes faster than existing systems. At MIT, students are turning anxiety into action through hands-on engineering projects, from hydrogen-powered vehicles to autonomous ocean research drones. Meanwhile, refugee resettlement programs are integrating AI-driven dynamic allocation systems, improving employment outcomes by up to 50% while balancing resource distribution. These initiatives highlight how technology, innovation, and collective support networks are reshaping how communities prepare for and adapt to climate-related challenges.

Resource Scarcity Assistance

Climate change is intensifying resource shortages, prompting innovation in agriculture, water access, and emergency response. AI-driven tools like SOLACE-AI, funded by 4 million euros from Wellcome, aim to streamline decision-making in climate-related health emergencies, reducing evidence synthesis time from a year to near-instant. In agriculture, AI-powered weather forecasting is helping smallholder farmers in India cut debt and increase savings, while initiatives like AIM for Scale are expanding similar solutions across Asia, Africa, and Latin America. Meanwhile, Indian scientists are developing climate-resilient seeds to withstand rising temperatures, pests, and drought, with government support accelerating research. In Africa, the Nairobi Declaration seeks to triple fertilizer use and restore 30% of degraded farmland, though agroecology advocates push for bio-fertilizers over synthetic inputs. As climate pressures mount, AI, biotechnology, and regenerative farming are emerging as key solutions to global resource challenges.

ENVIRONMENTAL & ECOSYSTEM MANIPULATION

ENVIRONMENTAL & ECOSYSTEM MANIPULATION

Earth Engineering

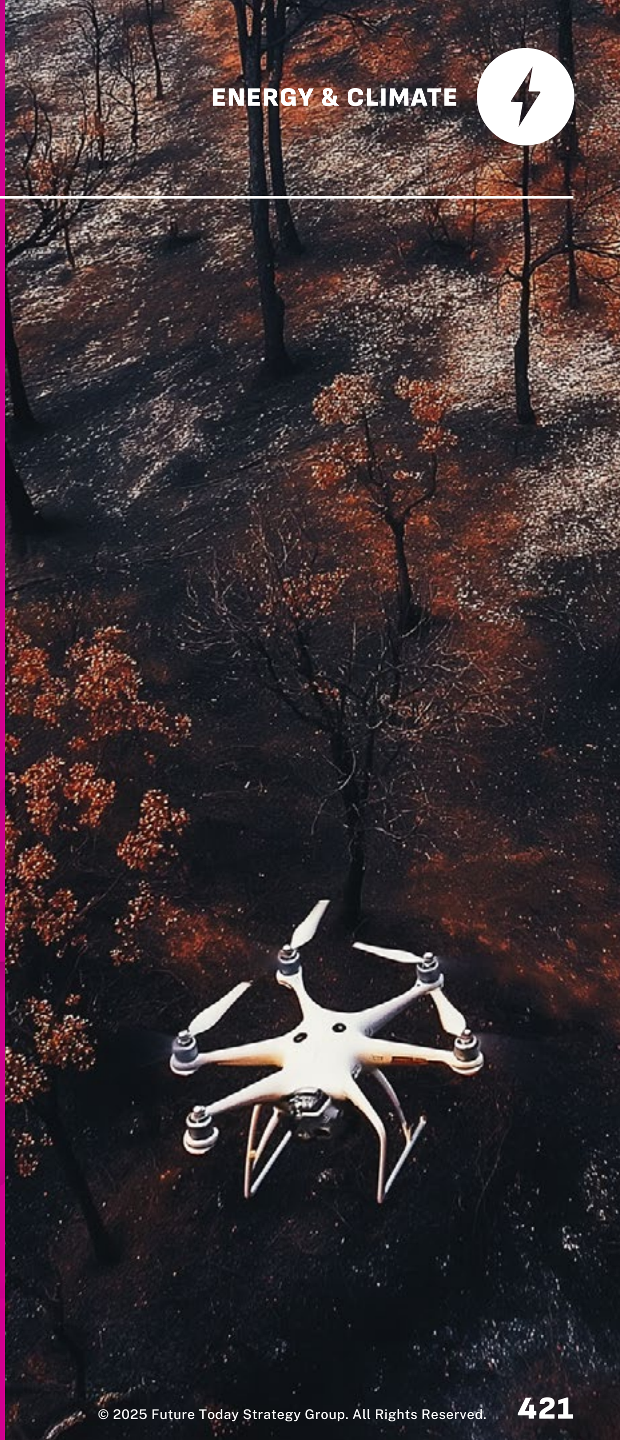
As climate change accelerates ecosystem degradation, advanced restoration technologies are emerging to rebuild forests, coastlines, and wetlands. Continental and Land Life have developed an autonomous tree-seeding robot capable of planting one tree per minute, addressing deforestation in inaccessible terrains. In Canada, Flash Forest is deploying UAVs (unmanned aerial vehicles) to rapidly distribute seed pods in wildfire-damaged areas, using microbial enhancements to boost germination rates. Coastal restoration efforts are also advancing, with an environmental group repurposing recycled oyster shells to stabilize sinking shorelines. Meanwhile, WWF's ManglarIA initiative is integrating AI, drones, and sensors to monitor and protect mangroves, crucial for carbon sequestration and storm protection. These innovations highlight a shift toward automated, AI-driven, and nature-based interventions to restore ecosystems at scale, mitigating climate impacts while enhancing biodiversity.

Atmospheric Climate Engineering

As climate risks escalate, engineered interventions in the atmosphere are being explored to cool the planet and mitigate extreme weather. Marine cloud brightening could reduce summer heat exposure in the Western US by 55%, but its effectiveness may decline due to ocean circulation shifts. Stratospheric aerosol injection strategies show varying cooling efficiencies based on injection latitude, with subtropical releases yielding the highest impact. A proposed method for intentional stratospheric dehydration could reduce water vapor in the upper atmosphere, enhancing radiative cooling. AI-driven simulations like Andrew Ng's Planet Parasol are enabling public exploration of solar geoengineering's risks and trade-offs. Meanwhile, autonomous solar-powered catamarans are being tested to spray seawater into the atmosphere, enhancing cloud reflectivity. As these geoengineering methods advance, researchers warn of unpredictable regional impacts, underscoring the need for robust modeling and global oversight.

Water Infrastructure Engineering

As climate change intensifies coastal threats and freshwater scarcity, new engineering solutions are transforming water management. In Boston Harbor, North America's first living seawalls mimic natural habitats, enhancing biodiversity while strengthening flood resilience. MIT's architected reefs dissipate 95% of incoming wave energy, protecting shorelines from erosion. Hybrid dunes in the Netherlands combine engineered dykes with natural sand formations to mitigate storm damage. Meanwhile, desalination technology is advancing, with a solar-powered hydrogel boosting seawater evaporation rates by 18.8%, offering a low-energy solution for freshwater production. AI-driven drought prediction models are also improving accuracy, aiding policymakers in proactive water resource management. These innovations mark a shift toward nature-integrated and AI-enhanced approaches, ensuring long-term resilience against rising sea levels and water scarcity.



SCENARIO YEAR 2045

THE OCEAN TERRAFORMING WARS

In 2045, climate collapse is no longer a distant threat—it's here. The solution? Terraforming the oceans. Some nations are turning the seas into massive carbon sinks with engineered algae blooms, electrochemical CO2 extraction, and deep-sea energy farms. Others call it a reckless gamble, fearing ecological disaster. The world is now divided, and the stakes couldn't be higher.

China and the EU lead the charge. China's genetically engineered coral reefs and deep-sea carbon vaults stretch across the South China Sea, while Europe's "Carbon Oceans"—floating CO2 capture platforms—dot the Atlantic. Germany and Norway have merged geoengineering with offshore wind and geothermal grids, making climate control a trillion-dollar industry.

But nature isn't cooperating. Massive algae blooms are warping food chains, oxygen-depleted "dead zones" are spreading, and once-thriving fisheries in West Africa and South America have collapsed. Climate refugees flood into nations that had no say in these experiments.

Meanwhile, the Pacific Rim refuses to play along. Japan, Australia, and Indonesia have outright banned ocean terraforming, calling it "climate imperialism." They warn that tampering with the seas could trigger hyper-hurricanes, acidification, or worse. The US, after years on the sidelines, is jumping in—but in true American fashion, corporations, not governments, are running the show. Amazon Blue and Exxon-Terraform dominate the market, selling carbon credits while reshaping entire ecosystems.

Now, the world teeters on the edge. Terraforming supporters say it's the only way to save the planet. Opponents warn we're engineering our own destruction. The question is no longer should we control the oceans—but can we?

ENVIRONMENTAL & ECOSYSTEM MANIPULATION

Engineered Plant Ecosystems

As climate change disrupts ecosystems, scientists are enhancing plant resilience, optimizing crop yields, and accelerating ecological restoration. University of California, Riverside researchers have implanted a marine algae gene into land plants, enabling them to absorb a broader light spectrum for increased productivity. AI-driven autonomous seaweed farms are optimizing carbon capture and biofuel potential. In Maine, hemp is being tested for phytoremediation, absorbing toxic PFAS chemicals from contaminated soil. At the Center for Advanced Bioenergy and Bioproducts Innovation, researchers have genetically modified bioenergy crops like sorghum and sugarcane to use 10%–20% less water without reducing yield. Drone-monitored silvopasture systems are integrating trees with grazing land for more sustainable agriculture. These advancements highlight a future where plant ecosystems are strategically engineered to support food security, environmental cleanup, and climate adaptation.

Engineered Animal Ecosystems

Scientists are leveraging genetics, robotics, and AI to enhance animal resilience and ecosystem stability in response to climate change. Assisted sexual propagation in corals has increased thermal tolerance, with lab-grown recruits showing significantly lower bleaching rates during the 2023 Caribbean heat wave. In agriculture, Canadian researchers are breeding low-methane cattle to cut emissions, integrating genetic selection with carbon credit incentives. AI-powered bee monitoring is optimizing pollinator conservation, using real-time object recognition to track colony health. Meanwhile, autonomous underwater robots are revolutionizing aquaculture by detecting biofouling and net damage, reducing labor costs and improving fish farm efficiency. These innovations highlight how engineered animal ecosystems are becoming critical tools for biodiversity conservation, sustainable food production, and climate adaptation.

URBAN INTERVENTIONS

URBAN INTERVENTIONS

Hybrid Urban Systems

Cities are integrating floating infrastructure, climate-adaptive transit, and resource-efficient developments to enhance resilience and sustainability. Seoul's Great Han River Project will introduce floating offices, hotels, and food zones by 2030, with marina expansions and river transit to support economic growth and leisure. In New York, the Climate Resilience Roadmap dedicates $6 billion to elevating transit infrastructure, installing flood defenses, and strengthening drainage systems to withstand extreme storms. Microsoft is launching zero-water AI data centers, eliminating more than 125 million liters of water use annually. In England, new town proposals emphasize walkability, green infrastructure, and car-free accessibility to lower emissions. These projects showcase a shift toward hybrid urban systems that merge climate adaptation with economic and environmental priorities.

Cooling & Green Infrastructure

Cities are deploying AI, ecological modeling, and green infrastructure to mitigate rising urban temperatures and enhance climate resilience. MIT, Google, and Purdue University's Tree-D Fusion technology uses AI-generated 3D tree models to optimize urban tree placement, predicting growth patterns and maximizing cooling effects. The system maps 600,000 urban trees, helping address environmental equity by guiding tree canopy distribution. Meanwhile, the Wayqecha Amazon Cloud Curtain Experiment explores how fog water supports ecosystems, providing insights into nature-based cooling strategies. By integrating AI-driven forestry management and climate-responsive ecological interventions, urban planners are creating smarter, greener cities that adapt to extreme heat while improving environmental sustainability.

Water Resilience & Flood Management

Cities are deploying AI, sensor networks, and nature-based solutions to manage stormwater and reduce flood risks in the face of climate change. Shanghai is expanding its sponge city initiative, aiming for 80% urban rainwater absorption by 2030 through green infrastructure, drainage upgrades, and digital monitoring. Meanwhile, AI-powered neural networks are improving flood prediction in sponge city systems, optimizing drainage performance and flood mitigation strategies. In India, researchers are developing an Arduino-based flood management system that uses real-time rainfall and soil moisture data to control reservoir gates and prevent downstream flooding. These innovations highlight a shift toward proactive, data-driven flood resilience strategies that blend smart infrastructure with ecological solutions.

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MOBILITY, ROBOTICS, & DRONES

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Nick Bartlett
Manufacturing Lead

Potential new bedrock of global trade needs to accelerate.

The next decade is a pivotal period for transforming how we move people and goods. The convergence of electric vehicles, autonomous systems, robotics, and drones is revolutionary, yet the pace of change threatens to outstrip our preparedness. Uncertain regulatory frameworks, infrastructure gaps, and safety concerns could stall their momentum at this critical juncture. The central question is whether governments, businesses, and society will adapt quickly enough to fully reap these innovations' benefits and mitigate their risks.

Take the transition to electric vehicles (EVs): Record sales signal a major shift, but supply chain disruptions, uneven charging infrastructure, and fluctuating incentives make the path to full electrification murky. Autonomous vehicles are still suspended between technological breakthroughs and the deployment realities of safety incidents and legal ambiguities. In robotics, the boundaries between industrial, collaborative, and humanoid robots are blurring, driven by AI that is making machines smarter and more adaptable than ever. And drones, once a novelty, are fast becoming ubiquitous tools in applications from retail delivery to emergency response.

These trends point to an urgent need for foresight, agility, and decisiveness. Businesses and governments that integrate these technologies will lead, while those that wait risk being left behind. And societies that proactively address the ethical implications of automation will build public trust and ensure the benefits of these technologies are broadly shared.

Heading into the 2030s, mobility, robotics, and drones could become the bedrock of the global economy. The choices we make today—to accelerate innovation, to adapt infrastructure and regulation, to prioritize safety and equity—will define the trajectory of that transformation. Industry leaders, policymakers, and communities need to embrace the future of mobility and actively pave the road ahead—one that leads to a safer, cleaner, and more connected world. The age of intelligent transportation is no longer on the horizon—it is upon us.

From smart cars to humanoid helpers: AI, autonomy, and connectivity are transforming how we move, work, and live in an increasingly intelligent world.

1

EVs become mobile power plants

Bidirectional charging turns electric vehicles into grid-supporting energy storage for homes and cities.

2

The software-defined car arrives

Over-the-air updates, AI copilots, and immersive infotainment are redefining the automotive user experience.

3

Soft robots gain finesse and power

AI-driven grippers and flexible actuators enhance robotic dexterity for logistics and health care applications.

4

Biohybrid bots blur boundaries

Scientists are merging biological materials and robotics to create muscle-powered actuators and self-healing systems.

5

Drone delivery goes mainstream

Retailers and logistics firms are scaling up aerial last-mile delivery as they overcome regulatory hurdles and pilot limitations.

Electrification, automation, and AI drive unprecedented shifts across the three industries.

Fast-moving technological advancements are reshaping the mobility, robotics, and drone industries. Electrification is transforming transportation globally, with heaps of investments continuing for battery production and charging networks. This shift extends to commercial fleets, maritime transport, and aviation. Closer to home, bidirectional charging is turning electric vehicles into mobile power sources, while innovations for improving EV production and use keep the focus on sustainability.

Vehicles of all kinds are evolving into high-performance computing hubs as automakers integrate AI, edge processing, and real-time connectivity. Software-defined vehicles enable over-the-air updates, autonomous capabilities, and immersive experiences—making them more customizable and the rides more enjoyable. As automakers shift toward these data-driven models, cybersecurity and interoperability will be critical.

Automation is redefining both mobility and work. Autonomous vehicles are moving from testing to deployment, and the robotaxi market is poised for growth. Humanoid robots and cobots are reshaping employment in various sectors.

On a broader scale, the convergence of mobility, robotics, and drones is blurring physical and digital boundaries. Mobility apps are consolidating transportation modes, while vehicle-to-everything (V2X) communication enhances safety. As these technologies advance, regulators will need to balance innovation and sustainability or risk cratering these industries.

The market has begun to see a regulatory push toward more autonomy and testing.

JANUARY 2024

Mercedes-Benz Rolls Out Level 3 Autonomous Driving

Sales of Drive Pilot-enabled cars in select US markets mark a step toward deploying higher levels of autonomous vehicles.

OCTOBER 2024

FAA Issues eVTOL Rules

New regs for powered lift operations affect air taxis and ambulances, treating them like helicopters in urban and rural areas.

DECEMBER 2024

Cruise's Robotaxis Suspended

GM stops funding Cruise's operations, cuts the staff in half, and folds the rest of the team into its engineering arm.

DECEMBER 2024

Baidu Wins Hong Kong License

The tech company gets to be the first to test autonomous vehicles in Hong Kong, with its Apollo Go robotaxi.

FEBRUARY 2025

UAE Maps Corridors for Air Taxis and Cargo Drones

The UAE sets a 20-month timeline to integrate advanced air mobility into its infrastructure, with newly defined routes and rules.

« PAST

Testing proceeds while new mandates help propel these industries forward.

FUTURE »

FALL 2025

Toyota's Woven City Opens

The $10 billion smart city/"living lab" tests advanced AI, robotics, and autonomous zero-emission transportation.

DECEMBER 2025

EU Mandates EV Charging Network

The Alternative Fuels Infrastructure Regulation requires fast-charging stations every 60 km along major transport routes.

JANUARY 2026

British Autonomy

The UK's Automated Vehicles Act will enable self-driving vehicles to potentially operate on British roads by next year.

AUGUST 2026

EU AI Robot Regulations

The EU will start enforcing stricter rules for AI-enabled robotics under the Artificial Intelligence Act.

2032

Queensland, Australia's Drone Taxis

The state plans to partner with Wisk Aero and Skyports Infrastructure to introduce drone taxis by the 2032 Brisbane Olympics.

Imparting autonomy to make vehicles, robots, and drones smarter will yield tangible efficiency gains.

Workforce Augmentation and Upskilling

The adoption of collaborative robots (cobots) and intelligent automation requires strategic upskilling initiatives and policy responses. Organizations that proactively invest in employee training and development will gain a competitive advantage in attracting and retaining top talent.

Sustainable Ecosystems

The shift toward EVs, renewable energy-powered drones, and smart city infrastructure will aid sustainability goals and climate efforts. Companies embracing eco-friendly mobility will benefit from lower operational costs, enhanced brand reputation, and alignment with evolving regulations or ESG targets.

Intelligent Logistics Transformation

The integration of autonomous vehicles, drones, and AI-driven systems will revolutionize supply chain management, enabling real-time optimization, predictive maintenance, and end-to-end visibility. Reduced costs, improved efficiency, and enhanced customer experiences will be felt across industries.

Innovative Revenue Streams

The rise of robotaxi services, drone deliveries, and AI mobility solutions opens new revenue opportunities. Businesses that embrace autonomous transportation can diversify into rapidly growing markets and create innovative services, expanding their customer base and enhancing profitability.

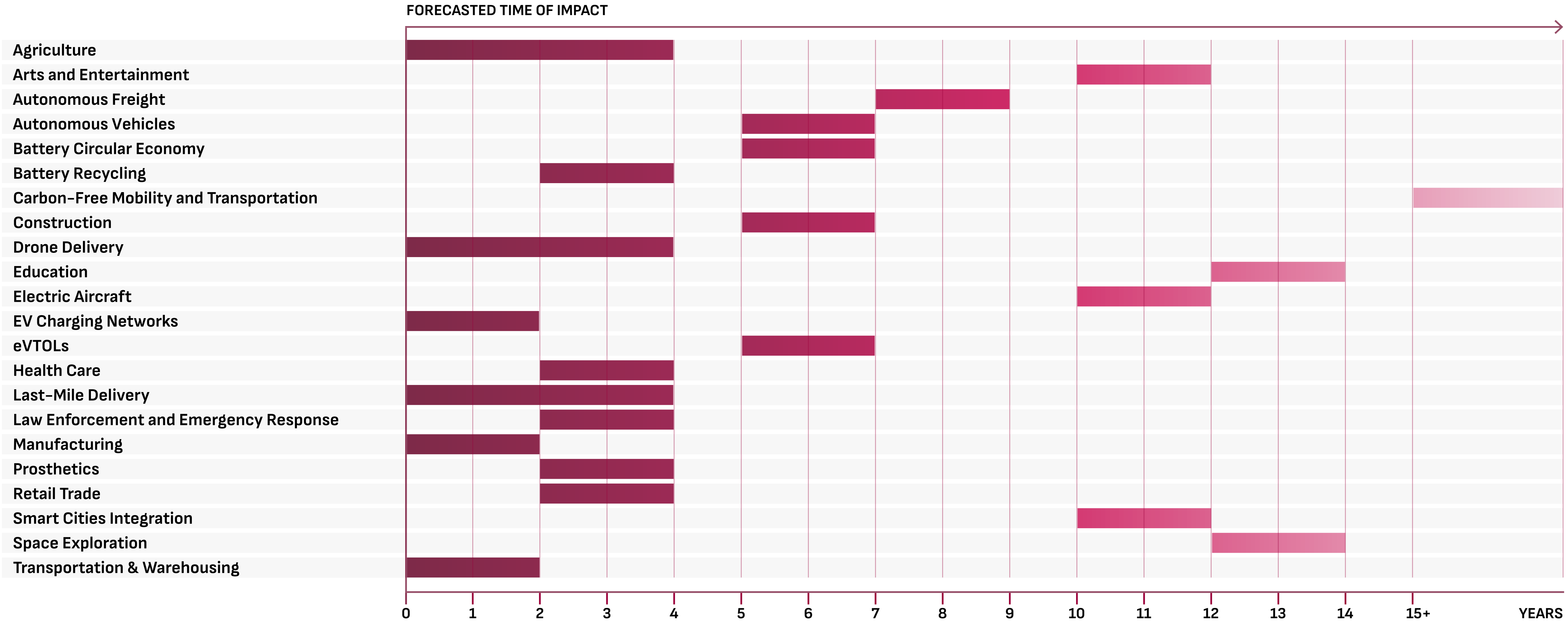
Resilient Infrastructure Networks

The integration of AI, robotics, and IoT in public and private infrastructure monitoring and maintenance will enhance resilience and safety. Predictive analytics, autonomous inspection drones, and self-healing systems will minimize disruptions, reduce costs, and extend the lifespan of critical assets.

Enhanced Operational Efficiency

With the adoption of AI-driven systems across transportation or combined with the use of drones and robots, businesses will see operational efficiency gains through reduced human error, lower long-term costs, and increased productivity.

Many industry operations are already being directly impacted.



The future of mobility, robotics, and drones hinges on scaling breakthroughs, regulatory agility, and public trust—businesses must shape, not just react to, the shift.

SCALING

Driven by AI and automation advances, technologies are scaling fast in logistics, manufacturing, agriculture, and surveillance. Companies must prioritize pilot programs, expand operational use, and leverage early-mover advantages in drone delivery, autonomous transport, and industrial robotics to secure long-term leadership.

COSTS

Falling sensor, battery, and AI processing costs will increase accessibility. Scale efficiencies in production will drive down unit costs, though supply chain volatility could create short-term price spikes. Early adopters will gain cost advantages through automation-driven labor savings and efficiency gains.

CONSTRAINTS ON ADOPTION

Infrastructure gaps, stringent airspace regulations, and high upfront costs slow adoption and are further complicated by limited charging networks, labor resistance, and cybersecurity concerns. In regulated industries like health care and finance, liability and safety concerns add complexity, delaying widespread deployment.

REGULATIONS

Policy uncertainty remains a key bottleneck. Privacy laws, cybersecurity requirements, and liability frameworks will evolve unpredictably. Governments will balance economic opportunity with national security concerns, creating a fragmented regulatory landscape.

MEDIA MENTIONS

Expect attention around major regulatory approvals (FAA drone corridors, autonomous vehicle legislation), high-profile commercial launches (Amazon, UPS drone fleets), and military applications. Public discourse will intensify over privacy, surveillance, and job displacement, shaping consumer and investor sentiment.

PUBLIC PERCEPTIONS

Public sentiment is polarized—enthusiasm for efficiency gains and safety improvements competes with fears of surveillance, job losses, and AI-driven inequality. Consumer acceptance will depend on transparency, ethical AI use, and demonstrated benefits. Companies must proactively address trust gaps to drive mainstream adoption.

R&D DEVELOPMENTS

Advancements in AI-powered navigation, lightweight materials, and swarm robotics will reshape industries. Breakthroughs in battery life, 5G/6G connectivity, and autonomous coordination will accelerate commercial viability. Defense investments will spill over into civilian applications, driving innovation but raising ethical concerns.

These individuals lead the way in transforming mobility, robotics, and drones.

- **Dr. Sai Shivareddy, co-founder and CEO of Nyobolt,** for pioneering high-performance batteries for EVs with ultra-fast charging and longevity.

- **Dr. Siyu Huang, founder and CEO of Factorial Energy,** for innovating solid-state batteries, offering greater energy density and safety for electric vehicles—and shaping the future of EV technology.

- **Dr. Mario El Kazzi, director at PSI,** for advancing scalable, sustainable next-gen battery tech, critical for the future of electric transportation.

- **Dmitri Dolgov, co-founder and co-CEO at Waymo,** for advancing autonomous vehicle tech and expanding robotaxi services.

- **Dr. Kevin Chen, head of MIT's Soft and Micro Robotics Laboratory,** for making significant progress in developing robotic insects for artificial pollination.

- **Dr. Soon-Jo Chung, Caltech's Bren professor of control and dynamical systems,** for developing decision-making control system algorithms that enable autonomous navigation for robots.

- **Dr. Axel Krieger, associate professor of mechanical engineering at Johns Hopkins,** for his team's work enabling imitation learning in medical robotics.

- **Dr. Anand Mishra, research associate at the Cornell University Organic Robotics Lab,** for innovative use of fungal mycelia to enable "sense" in a biohybrid robot.

- **Dr. Won Dong Shin, postdoctoral researcher at the Swiss Federal Institute of Technology in Lausanne,** for work developing a fast ground-to-air transition from an avian-inspired aerial robot.

- **Vadym Melnyk, founder and CEO of DroneHub,** for developing autonomous drone operation solutions enabling industrial automation.

- **Abe Bachrach, CTO at Skydio,** for advancing autonomous drone technology, with a focus on complex navigation and object avoidance in challenging environments.

- **Rema Matevosyan, CEO and co-founder of Near Space Labs,** for helping municipalities identify challenges with high-altitude, high-resolution imagery collected by autonomous balloon drones.

Autonomous tech will reshape the effectiveness of mobility and robotics...

...but supply chain disruptions and policy uncertainty may delay that future.

OPPORTUNITIES

Software-Defined Vehicles Unlock Recurring Revenue

Automakers shifting to software-defined vehicles will create new revenue streams via subscriptions, over-the-air updates, and custom vehicle configurations.

Autonomous Freight Reshapes Supply Chains

Self-driving electric trucks and AI-managed logistics hubs will improve shipping efficiency, cut costs, and reduce the carbon footprint of global supply chains.

Soft Robotics Unlocks New Industries

Robots made with soft grippers and flexible actuators are more efficient and less damage-prone as they can handle delicate tasks in food processing, medical procedures, and advanced manufacturing.

Drone Swarms Quicken Logistics and Emergency Response

AI-coordinated drone swarms will optimize package deliveries, monitor environmental changes, and enhance disaster relief efforts by providing real-time aerial data and autonomous resource deployment.

THREATS

Trade Tensions Disrupt Battery Supply Chains

Geopolitical conflicts and trade restrictions could limit access to critical minerals like lithium and cobalt, driving up battery costs and slowing EV production.

Regulatory and Policy Uncertainty

Evolving regulations on autonomous vehicles and drones pose a threat to market stability, potentially delaying or halting widespread adoption and technological deployment.

Public Safety and Liability Issues

The deployment of autonomous vehicles and drones, especially for deliveries, raises liability questions. Inadequate legal frameworks could cause delays and create uncertainty for manufacturers and insurers.

Manufacturing and Warehousing Could Shed Human Workforce

The rapid deployment of AI-powered robots in warehouses, manufacturing, and logistics could lead to mass layoffs, increasing economic inequality and requiring workforce reskilling.

Your organization can play a defining role in establishing the market's strategy.

Scale AI-powered predictive maintenance across vehicle fleets, aircraft, and industrial robots to reduce downtime, optimize repairs, and extend asset lifespans. Predictive analytics will become a core function in fleet management and urban infrastructure.

Build smart hubs to produce the next generation of manufacturing infrastructure. Investing in automated, AI-powered manufacturing ecosystems that produce next-gen batteries, EVs, and robotics will advantageously place organizations at the foundational level of manufacturing for years to come.

Shape policies for AI and robotics in labor. Companies must create policies and engage regulators to develop frameworks that balance automation-driven productivity gains with workforce protections, to ensure sustainable job creation amid rising robotic integration.

Proactively prepare for mass-scale EV and AV servicing as the shift to electrification and autonomy requires a new generation of service technicians trained in high-voltage battery systems, sensor calibration, and software diagnostics.

Build unmanned traffic management systems. As drones become more common in logistics, security, and infrastructure monitoring, these networks can prevent congestion, enhance airspace safety, and streamline drone integration for commercial and public services.

Explore developing public-private partnerships for smart cities. Cities must collaborate with businesses to deploy AI-powered transportation networks, urban drone logistics, and intelligent mobility systems. These partnerships will drive infrastructure modernization at scale.

Technology Deployment | Capital Expenditure | Talent Development | Regulatory Influence

Important terms to know before reading.

MOBILITY

ADAS (ADVANCED DRIVER ASSISTANCE SYSTEMS)

Technologies that assist drivers by performing functions such as adaptive cruise control, automated lane-keeping, pedestrian detection, emergency braking, and traffic sign recognition. Increasingly integrated with AI for predictive safety.

AMD (ASSISTIVE MOBILITY DEVICE)

A mobility aid such as a wheelchair, scooter, walker, or exoskeleton. Advances in AI and robotics are making AMDs increasingly autonomous.

BIDIRECTIONAL CHARGING

A system that enables an electric vehicle (EV) to transfer electricity back to the grid (V2G), power a home (V2H), or charge other EVs (V2V). Key for grid stabilization in an energy transition era.

EV CHARGING PORT

The connector that supplies power to an electric vehicle when plugged in. The North American Charging Standard (NACS) is becoming the dominant connector in the US, with major automakers adopting it.

ICE (INTERNAL COMBUSTION ENGINE)

An engine powered by fuel combustion, most commonly gasoline or diesel. As bans on ICE vehicles increase globally, hybrid and EV adoption is accelerating.

V2G (VEHICLE-TO-GRID)

Allows EVs to store and return energy to the grid, supporting grid resilience and renewable energy integration.

V2H (VEHICLE-TO-HOME)

A form of bidirectional charging that allows EVs to supply power to a home during outages or peak demand periods.

V2I (VEHICLE-TO-INFRASTRUCTURE COMMUNICATION)

Enables vehicles to communicate with smart city infrastructure, including traffic lights, RFID readers, cameras, and road sensors, for improved traffic flow and safety.

V2V (VEHICLE-TO-VEHICLE COMMUNICATION)

Allows vehicles to share real-time data on speed, location, and road conditions, enabling safer and more efficient driving, especially for autonomous fleets.

LEVELS OF AUTOMATION

The SAE International (formerly Society of Automotive Engineers) clearly defines six levels of driving automation:

Level 0
No Automation

A human driver manually performs all driving tasks.

Level 1
Driver Assistance

The driver remains in control, but the vehicle can provide assistance, such as adaptive cruise control.

Level 2
Partial Automation

The vehicle has combined automated functions like steering and acceleration but requires the driver to monitor the environment constantly.

Level 3
Conditional Automation

The vehicle can handle driving under certain conditions without driver supervision. However, the driver must be prepared to take control when needed.

Level 4
High Automation

The vehicle can perform all driving functions within predefined areas (geofenced). No driver intervention is required within these areas.

Level 5
Full Automation

The vehicle can operate independently in all conditions, eliminating the need for a driver. Fully autonomous ride-hailing fleets are emerging.

LEVELS OF EV CHARGING

Level 1
Slow Charging

Uses a standard 120V outlet, taking 60+ hours for a full charge. Typically used as an emergency or overnight charging option.

Level 2
Home and Public Charging

The most common charging method, using a 240V outlet. A full charge typically takes 6–12 hours.

Level 3
DC Fast Charging and Ultra-Fast Charging

Includes DC Fast Charging and Supercharging. Tesla, Electrify America, and other networks offer 250 kW+ chargers capable of charging an EV to 80% in under 20 minutes.

Megawatt Charging Standard or MCS

Emerging ultra-high-power charging technology designed for electric trucks and aircraft, delivering up to 3.75 MW of power for rapid recharging.

ROBOTICS

COBOT (COLLABORATIVE ROBOT)

A robot designed to work alongside human workers, assisting with tasks that require precision, repetition, or physical strength. AI-driven cobots are increasingly capable of learning from human interactions.

EXOSKELETON

A robotic assistive suit worn to enhance mobility, strength, or endurance. Used in industrial, medical, and military applications.

HUMANOID ROBOT

A robot designed with a human-like appearance and movement. AI-powered humanoids are increasingly used for customer service, elderly care, and general-purpose tasks.

MICROROBOTICS

The development of robots smaller than 1 mm, used in medical procedures, environmental monitoring, and surveillance.

NANOBOT

Robots at the nanoscale (billionths of a meter), primarily used in medicine for drug delivery and disease treatment.

NECROBOTICS

A field of robotics that repurposes biological materials (such as insect or animal cadavers) for robotic applications.

QUADRUPEDAL ROBOT

A four-legged robot designed for mobility in rough terrains. Used in search-and-rescue, military, and industrial applications.

SOFT ROBOTICS

A branch of robotics using flexible, deformable materials to create robots that mimic natural movement and adaptability. Used in medical applications and delicate manufacturing.

DRONES & UNMANNED SYSTEMS

AGV (AUTOMATED GUIDED VEHICLE)

A mobile robot that follows predefined paths or tracks, commonly used in warehouses and industrial settings.

AUV (AUTONOMOUS UNDERWATER VEHICLE)

A robotic submarine capable of performing underwater tasks without human control. Used for ocean research, infrastructure inspections, and defense.

BVLOS (BEYOND VISUAL LINE OF SIGHT)

Drone operations conducted beyond the direct visual range of the pilot. BVLOS regulations are evolving to allow for expanded commercial drone deliveries and autonomous operations.

DRONE (UNMANNED AERIAL VEHICLE OR UAV)

An uncrewed vehicle that can operate autonomously or remotely:

- **Fixed-Wing Drone:** Resembles an airplane; ideal for long-range missions.
- **Fixed-Wing Hybrid VTOL:** A combination of a fixed-wing aircraft with vertical takeoff and landing capabilities.
- **Single-Rotor Drone:** Resembles a helicopter, offers high endurance and heavy-lift capacity.
- **Multi-Rotor Drone:** The most common consumer drone type, typically a quadcopter.
- **Drone Swarm:** A networked fleet of drones operating in coordination. Used in surveillance, agriculture, and military applications.

EVTOL (ELECTRIC VERTICAL TAKE-OFF AND LANDING)

Electric-powered aircraft capable of vertical takeoff and landing. Increasingly used in urban air mobility (UAM) services, air taxis, and emergency response.

FEDERAL AVIATION ADMINISTRATION (FAA)

The FAA has expanded BVLOS permissions, UAM air corridors, and drone delivery regulations. Remote ID is now mandatory for all commercial UAVs unless operating in FAA-Recognized Identification Areas (FRIAs).

UAM (URBAN AIR MOBILITY)

Aerial transportation of passengers or cargo in urban environments, using eVTOL aircraft and autonomous drones. Major cities are testing vertiports to support commercial UAM services.

MOBILITY TRENDS

ELECTRIFICATION TRANSFORMS MOBILITY ECOSYSTEMS

ELECTRIFICATION TRANSFORMS MOBILITY ECOSYSTEMS

Decarbonizing Mobility

The push to decarbonize transportation is accelerating, with global policies, infrastructure investments, and technology advancements reshaping mobility. In the US, where transportation remains the largest source of greenhouse gas emissions, states like California are allocating more than $50 billion for climate-focused initiatives, including stricter freight pollution regulations and expanded zero emission vehicle (ZEV) deployment. Meanwhile, federal incentives have saved US consumers more than $2 billion in EV purchases, which may have contributed to the 10% increase in EV sales in Q4 2024. The Environmental Protection Agency's new emissions standards could further compel automakers to shift toward EVs, despite legal challenges from petroleum and biofuel industries.

Globally, the European Union is investing €422 million to enhance charging and hydrogen refueling infrastructure, and support its goal of cutting transport emissions 90% by 2050. New EU regulations require fast-charging stations every 60 kilometers on major highways by the end of 2025 to improve EV travel feasibility. Additionally, high-speed rail expansion is reducing reliance on short-haul flights, prioritizing new cross-border connections. In aviation and maritime environments, e-fuels, hydrogen, and electrification are emerging as decarbonization solutions, while Honda and Toyota are developing carbon-tracking systems to incentivize low-emission manufacturing. The next decade will be defined by how quickly automakers, energy providers, and policymakers adapt to this accelerating transition.

Automaker Restructuring

Global automakers are undergoing significant restructuring as they navigate the shift to electric vehicles (EVs), supply chain challenges, and changing market dynamics. In 2024 and early 2025, legacy automakers including Nissan, Volkswagen, General Motors, and Stellantis, announced major workforce reductions, factory closures, and strategic realignments. Nissan laid off 9,000 employees, while Volkswagen considered closing German factories for the first time. GM took a $5 billion write-down on its China business, reflecting increasing competition from China's BYD and a reassessment of GM's market position. Stellantis, facing declining US market share, replaced its CEO and reintroduced internal combustion engine models, signaling a strategic recalibration.

Automakers are also restructuring through partnerships. Volkswagen invested in Rivian to share EV technology, while Nissan deepened collaboration with Renault and licensed Mitsubishi's hybrid system. Ford decided to double down on hybrids, and saw payoffs with sales rising 27% in 2024. Meanwhile, emerging players like BYD continue to expand globally, challenging Western automakers with their lower-cost EVs. Trade tensions and potential tariffs add another layer of complexity that's influencing production and investment decisions. The evolving regulatory landscape, fluctuating consumer demand, and rapid advancements in automation and AI-driven manufacturing further underscore the industry's transformation.

Mass Market Goes Custom

Supply chain constraints are pushing mass-market manufacturers toward a build-to-order model. Initially triggered by the semiconductor shortage during the COVID-19 pandemic, this shift has continued due to ongoing geopolitical tensions, EV production transitions, and changing consumer expectations. Automakers like Ford and Acura are embracing direct-to-consumer sales that reduce the need for massive dealership inventories. Ford, for instance, is incentivizing preorders with discounts on models like the Mustang Mach-E. Meanwhile, software-defined vehicles are accelerating the trend by allowing for customizable features via over-the-air updates long after a car leaves the lot.

Digital retailing tools are also redefining how customers interact with vehicles. Virtual showrooms and augmented real-

ELECTRIFICATION TRANSFORMS MOBILITY ECOSYSTEMS

ity-based configurators enable buyers to personalize their cars without stepping into a dealership, further supporting the build-to-order model. Additionally, the rise of hybrid vehicles—which are expected to see substantive growth year-over-year in 2025—is expanding customization options. Advanced driver assistance systems (ADAS), transitioning to Level 2.5 and Level 3 autonomy, also contribute to this shift by allowing consumers to select automation and safety features tailored to their preferences. This industry-wide move to customization, once exclusive to luxury brands like Rolls-Royce and Bentley, is now becoming the standard for mainstream automakers, and it's reshaping dealerships, service networks, and profit structures.

Incentive-Driven Investments

The strategic deployment of financial incentives by automakers, governments, and policymakers is influencing the adoption and production of EVs. As of 2024, global EV investments are projected to eclipse $800 billion by 2030, with the US accounting for about a quarter of those investments.

Manufacturers are leveraging government subsidies, tax credits, and pricing strategies to stimulate demand amid fluctuating consumer interest. Ford, for instance, offered lease incentives of up to $10,500 for its F-150 Lightning EV to boost sales, while also offering an additional $1,500 rebate targeting Tesla owners. Governments are also working to lure manufacturers: Georgia, for example, has provided Rivian with $1.5 billion in tax incentives to establish a $5 billion factory that's projected to create 7,500 jobs. The US Inflation Reduction Act has fueled the rise of this country's so-called Battery Belt, a corridor spanning Michigan to Alabama, where manufacturers are capitalizing on tax breaks and lower energy costs. However, evolving political winds may challenge existing incentive structures. The Trump administration has signaled intentions to revise or eliminate the $7,500 federal EV tax credit, potentially reshaping the competitive landscape.

Global trends further illustrate the evolving nature of incentive-driven investments. Mexico has emerged as an EV production hub due to US policy incentives, while Italy is shifting its subsidies toward industrial EV development rather than direct consumer incentives. As automakers balance aggressive electrification goals with economic pressures, these investment strategies will continue to dictate the trajectory of the EV market.

Global Battery Belts

The race to establish dominant EV battery production hubs is heating up, with the US Battery Belt—spanning from the Midwest to the Southeast—emerging as a major competitor to Asia's long-standing dominance. Investments in US battery manufacturing neared $200 billion over the past decade, led by automakers like Hyundai, Toyota, and Stellantis, alongside battery suppliers such as LG Energy Solution and Novonix. These investments are fueled by lower electricity costs, workforce availability, and incentives from the Inflation Reduction Act, which has attracted hundreds of billions of dollars in private capital for clean energy manufacturing. While China still refines more than 90% of the world's manganese and holds the majority share of lithium, cobalt, graphite, and nickel processing, new US lithium reserves, such as the massive find on the Nevada-Oregon border, could help shift the balance over time. Meanwhile, Europe is attempting to extract Chinese battery expertise through industrial policies that require knowledge transfer in exchange for access to EU subsidies. With production hubs expanding in Canada and Mexico, the global EV battery supply chain is undergoing a seismic shift that will determine future market leaders.

Battery Recycling

The rapid adoption of EVs has intensified demand for critical minerals like lithium, cobalt, and nickel. At the same time, the projected surge of battery waste has turned a closed-loop recycling ecosystem into an environmental and economic imperative. By 2040, up to 40% of new EV battery materials could be sourced from recycled inputs, reducing reliance on mining

ELECTRIFICATION TRANSFORMS MOBILITY ECOSYSTEMS

and supply chain vulnerabilities, according to the World Economic Forum. The market for EV battery recycling is projected to grow from under $10 billion as of 2024 to nearing $100 billion into the mid-2030s. Investments are accelerating—startups and major players such as Redwood Materials, Ascend Elements, and Li-Cycle are scaling operations, leveraging innovative recycling technologies like direct recycling, bioleaching, and deep eutectic solvents. Regulatory momentum is also driving change, with the EU setting recycling efficiency targets of 75% for nickel-cadmium, 65% for lead-acid, and 50% for other chemistries, while California mandates battery labeling for transparency. Meanwhile, advances in solid-state battery recycling, such as polymer-layer separation, indicate that even next-generation battery chemistries can be sustainably repurposed. As governments and industries align, battery recycling is becoming a cornerstone of the EV revolution, positioning clean mobility as truly sustainable.

Better Batteries

Battery technology is rapidly evolving as manufacturers race to develop smaller, safer, and more efficient energy storage solutions for EVs. Solid-state batteries (SSBs) are at the forefront, with companies like QuantumScape and Factorial Energy making strides in commercialization. QuantumScape's QSE-5 battery, set for production in 2025, boasts an energy density of 844 Wh/L and can charge from 10%–80% in just 12.2 minutes. Toyota plans to integrate SSBs by the end of the decade, promising a 50% reduction in size, cost, and weight. Meanwhile, GM is leading the $60 million Series B financing round of Mitra Chem to develop iron-based cathodes, which could lower battery costs and reduce reliance on scarce minerals.

Alternative chemistries are also gaining traction. CATL's second-generation sodium-ion battery, expected to hit mass production by 2027, offers 200 Wh/kg energy density and improved cold-weather performance, reducing the need for lithium, cobalt, and nickel. Nyobolt's high-silicon anode battery recently demonstrated a 10%-80% charge in just four minutes and 37 seconds, signaling major advancements in ultra-fast charging. Additionally, researchers at Pacific Northwest National Laboratory are exploring sugar-based flow batteries for long-duration energy storage, which could reshape EV charging infrastructure.

These developments signal a transformative decade for EV batteries. While SSBs promise higher energy density and safety, sodium-ion and high-silicon technologies offer cost-effective and scalable alternatives. Automakers and battery firms must now overcome production challenges to bring these next-generation solutions to market.

Solar Vehicles

Solar-powered vehicles are emerging as a viable solution for reducing grid dependency and enhancing EV efficiency. In 2024, solar EVs demonstrated the ability to travel 5-15 miles per day solely on solar energy, reducing the need for frequent charging. This shift supports lower electricity consumption while making EV adoption more sustainable. Companies like Aptera Motors and Lightyear continue to refine solar EV designs, with Aptera's ultra-aerodynamic model offering up to 400 miles per charge, supplemented by solar panels.

Bifacial solar panels, which generate up to 30% more energy, are increasingly being incorporated into solar carports and public EV charging stations, accelerating solar infrastructure development. Despite challenges—such as Lightyear's financial struggles—continued investment in solar mobility suggests a long-term move toward self-sustaining transportation.

Shifts in the Servicing Model

The traditional vehicle servicing model is undergoing a major shift as mobile repair units, over-the-air updates, and AI-driven maintenance redefine the industry. Automakers and startups are investing heavily in mobile and remote servicing, and the reliance on dealerships is waning. Ford has

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been continuing to expand its mobile service fleet of nearly 1,000 Ford Escape SUVs offering software updates, light repairs, and recall resolutions on the go. Startups like Spiffy are scaling mobile servicing by partnering with dealerships and offering franchise opportunities, backed by a $30 million investment.

At the same time, AI-powered systems are enabling predictive maintenance and automated servicing. Ford's newly filed patent outlines a system for self-driving vehicles to autonomously navigate maintenance facilities, self-schedule repairs, and undergo automated checkups. Connected vehicle technology is also driving this shift, allowing mechanics to diagnose issues remotely and optimize repair logistics. Additionally, the Federal Trade Commission's lawsuit against John Deere for restricting independent repairs highlights the broader push for right-to-repair legislation, which could further disrupt traditional service networks. As automakers compete to offer more customer-centric and flexible servicing models, dealerships must adapt or risk obsolescence in an increasingly mobile-first landscape.

Electrification Expands Beyond Passenger Cars

Electrification is transforming transportation far beyond personal vehicles. Amazon and the USPS are leading fleet electrification, with Amazon planning to deploy 100,000 electric delivery vehicles by 2030 and the USPS acquiring 66,000 by 2028. In aviation, ZeroAvia's HyFlyer II project successfully tested a hydrogen-electric aircraft, and Heart Aerospace plans to test the 30-seat ES-30 electric plane in 2025. Meanwhile, China launched its first battery-electric container ship, the 700 TEU, showcasing the potential of electrification in maritime transport.

The trend extends to micromobility and recreational travel. Segway debuted its first e-bikes at CES 2025, featuring adaptive pedal assist and a range of up to 112 miles. Electric RVs, such as RollAway's rentable EV camper and the Pebble Flow trailer, are redefining off-grid travel with solar-powered, emissions-free mobility. Even the Vatican is embracing the shift—Pope Francis received an all-electric Mercedes-Benz Popemobile in December.

As infrastructure and battery technology improve, expect further electrification in rail, commercial trucking, and air travel. Tesla's launch of its all-electric Giga Train in Germany and Amazon's investment in electric freight trucks highlight the broader industry shift. The next phase will depend on cost reductions, expanded charging networks, and policy support to sustain adoption across all vehicle categories.

VEHICLE CHARGING SCALES

VEHICLE CHARGING SCALES

Charging Gets a Roadmap

The EV ecosystem is rapidly evolving, with global investments, regulatory mandates, and private sector innovation expanding the charging infrastructure. Though the US had allocated $5 billion through the National Electric Vehicle Infrastructure Formula Program, plus an additional $2.5 billion for community chargers, the Trump administration recently suspended the program. Across the pond, the EU is mandating fast charging stations every 60 kilometers along highways by 2026. Automakers are standardizing on Tesla's North American Charging Standard (NACS) connector, and brands like Walmart, Marriott, and IKEA are installing thousands of new chargers across their properties. Despite these efforts, range anxiety persists, exacerbated by inconsistent access, slow charging speeds, and regional disparities in station availability.

Private sector innovation is addressing these gaps. Tesla's V4 chargers promise 40% faster speeds, while ultra-fast chargers reaching 350 kW can now deliver 80% charge in 20 minutes. Automakers like Honda and Toyota are developing patents for wireless charging, smart scheduling, and bidirectional energy management. Honda's wireless charging patent envisions on-the-go power transfer, while Toyota's scheduling system prioritizes vehicles based on urgency. Meanwhile, the sharing economy is entering the charging space, with private station owners making chargers available to the public.

The industry is at an inflection point: Without rapid infrastructure expansion and efficiency improvements, consumer confidence could falter. However, with standardization, ultra-fast charging, and new business models, EV charging is set to become more accessible, accelerating adoption worldwide.

Charging Standardization

The global push for EV charging standardization has reached a critical turning point. In North America, the transition to the NACS is well underway, with nearly all major automakers—including Ford, GM, Honda, Nissan, Mercedes-Benz, and Volvo—either integrating NACS ports into their vehicles or providing adapters. SAE formally adopted Tesla's J3400 connector as the region's standard in 2024, reinforcing a move toward universal compatibility. Tesla's Supercharger network, which accounts for approximately one-third of all US fast chargers, is now accessible to non-Tesla EVs, signaling a major shift toward infrastructure unification.

As interoperability expands, competitive dynamics at charging stations are evolving. Companies are exploring new revenue models, including real-time pricing tied to solar energy availability and value-added services such as entertainment and retail integrations at charging sites. Rivian, for example, has opened its Adventure Network to other EVs, while GM and Honda-backed IONNA plans to deploy 30,000 chargers by 2030. At the same time, Europe's Alternative Fuels Infrastructure Regulation is pushing for cross-border interoperability, particularly for heavy-duty vehicles, with a mandate for 350 kW chargers at major transport hubs by the end of this year.

The rapid pace of standardization is reshaping the EV landscape, but challenges remain. Tesla's layoffs within its Supercharger team raise concerns about infrastructure expansion. Meanwhile, the development of Megawatt Charging Systems for heavy-duty EVs is still in pilot stages, awaiting further harmonization efforts between North America and Europe. Nevertheless, these advancements position 2025 as a pivotal year in achieving global EV charging compatibility.

Redefining the Roadside

The rise of EVs is leading to a fundamental shift in roadside infrastructure that will transform charging stops into retail, entertainment, and energy hubs. Unlike traditional gas stations, where refueling takes minutes, EV charge times present an opportunity for businesses to capture consumer attention. Major retailers like Walmart, Macy's, and IKEA are integrating

VEHICLE CHARGING SCALES

charging stations to turn wait times into shopping experiences. Tesla's upcoming Los Angeles drive-in diner merges EV charging with entertainment, featuring film clips on large screens while you eat. Autonomous retail, such as Juxta's self-contained convenience stores, is emerging at charging hubs, creating new commercial opportunities.

Beyond retail, innovations in charging technology are reshaping the experience. Startups like Ample are deploying battery-swapping stations that replace depleted batteries in minutes, reducing downtime. Mobile solutions, such as SparkCharge's on-demand charging and AAA's mobile EV rescue units, are addressing infrastructure gaps. Autonomous charging robots like Parky and EV Safe Charge's robotic systems are being tested to expand access where permanent infrastructure is lacking. Additionally, electrified roads, piloted in Sweden and planned for Detroit, could enable EVs to charge while driving, potentially reducing the need for large battery packs.

Sustainability and grid integration are also key trends. Solar-powered charging stations, particularly in rural areas, are extending access to off-grid locations. Meanwhile, bidirectional charging (V2G) allows EVs to act as mobile energy sources by contributing power back to the grid. These trends point toward increasingly interconnected and dynamic roadsides where charging is seamlessly integrated into everyday activities.

Electrifying Cities

Cities worldwide are accelerating their electrification strategies as climate resilience and EV adoption become urgent priorities, pushing urban centers to rapidly expand their charging infrastructure. Decentralized energy systems, like Vermont's Green Mountain Power initiative, are gaining traction by enhancing grid stability through home battery storage. Microgrids, such as North Carolina's Heron's Nest, showcase how communities can generate and manage their own power independently, increasing sustainability and resilience.

To meet rising EV demand, urban planners are integrating charging infrastructure into public spaces, businesses, and residential developments. Per the Department of Energy, US public EV charging ports grew by 4.8% in Q1 2024, with the Northeast leading at 6.9%. The state of New York committed $60 million in early 2025 to build 267 new fast-charging stalls, including a 60-stall hub in Maspeth, Queens—the largest in the Northeast. Tokyo mandated EV charger installations in new apartment buildings by 2025, aiming for 60,000 chargers by 2030. Meanwhile, Copenhagen's long-standing plan to provide public charging within 250 meters of all multistory buildings by 2025 underscores a growing trend in accessibility-driven policy.

Governments are also exploring innovations like wireless roadway charging, as seen in France's partnership with Electreon, while the US had previously announced $25 billion to boost community charging under the Biden administration. Meanwhile, China is incentivizing off-peak charging, targeting 60% of EV energy consumption outside peak hours by late 2025. The shift to electrified urban infrastructure signals a long-term transformation, where cities not only support EV adoption but also drive grid decentralization and sustainable energy solutions.

EVs at Home

The DoE has estimated that by the end of this year, nearly 90% of EV charging will take place at home. This makes residential infrastructure a critical factor in widespread EV adoption. This shift is driven by several forces: regulatory mandates, evolving real estate trends, and technological advancements in home charging systems. States like Illinois and California have enacted policies requiring new homes to be EV-ready, while Germany's home-charging grant program was fully subscribed in hours. Real estate developers are incorporating EV chargers as a standard feature, recognizing their value to prospective buyers. At the same time, utilities are offering special overnight charging rates, making

VEHICLE CHARGING SCALES

home charging more cost-effective than public stations.

However, this rapid adoption is exposing challenges. A study published by the American Council for an Energy-Efficient Economy found a significant number of US homes may lack the electrical capacity to safely support EV charging, increasing the risk of brownouts, surges, and even fires. Ford's patent filings aim to address these risks with bidirectional charging and modular upgradeable systems, so homeowners can efficiently charge their vehicles and even return energy to the grid. Meanwhile, innovations such as ultra-fast home chargers capable of 350 kW speeds and managed charging programs from utilities are helping to reduce strain on local power grids. These developments suggest that the home-charging ecosystem is evolving quickly, but infrastructure challenges could prompt regulatory intervention and community-based solutions such as shared solar arrays and neighborhood charging stations.

Bidirectional Charging

Bidirectional charging is shifting EVs from mere transportation tools to dynamic energy assets. As adoption accelerates, automakers, municipalities, and utilities are integrating EVs into the energy ecosystem, using them for vehicle-to-home (V2H), vehicle-to-grid (V2G), and vehicle-to-load (V2L) applications. General Motors has made V2H a standard feature in multiple 2024 models, while Volkswagen has enabled all ID models with 77-kWh batteries to supply power back to homes. Meanwhile, California is advancing legislation that could mandate bidirectional charging for new EVs.

The global energy landscape underscores the urgency of this transition. Climate-related grid disruptions, geopolitical energy crises, and aging infrastructure are pushing governments to explore decentralized power solutions. The DoE recognizes bidirectional charging as essential for grid resilience, and cities like Utrecht in the Netherlands are investing heavily in V2G networks. Additionally, Honda's patent for a renewable energy credit system could allow EV owners to monetize excess power, potentially lowering the cost of EV ownership. With many new EVs sold becoming equipped with bidirectional capabilities, the technology will evolve from a niche feature to a widespread energy solution.

SCENARIO YEAR 2041

LIVING BATTERIES

The revolution wasn't just electric—it was a genesis. BioEV technology has transformed vehicles into semi-organic entities through photosynthetic panels and carbon-capture fabrics. Your car breathes. The watershed moment came in 2036 when Stanford researchers merged synthetic biology with battery chemistry, creating the first living battery cells that self-heal, self-regulate, and grow stronger with use. Now, vehicles incorporate living components that adapt to driving patterns.

Cities have evolved in response. "Feeding stations" have replaced charging points—places where vehicles absorb nutrient solutions alongside electricity. The urban landscape is dotted with vertical algae farms that sequester carbon while producing BioEV feed. Streets themselves contain microbial colonies that interact with vehicles, absorbing pollution and providing real-time environmental data.

The most striking feature of modern transportation is color-shifting exteriors—vehicles literally blush when energy reserves are low, their surfaces transitioning from vibrant green to amber, signaling neighboring vehicles to share power through proximity fields. Rural communities have become energy exporters, with agricultural waste converted to vehicle fuel through regional fermentation cooperatives. Farmers no longer simply grow crops; they cultivate transportation energy.

This has transformed our psychological relationship with vehicles. Owners report emotional attachments to their "growing" vehicles, which develop distinct behaviors based on use patterns. Vehicle "health coaches" help maintain optimal biological battery systems, a profession that didn't exist a decade ago. As 2042 approaches, researchers are exploring neural interfaces between drivers and their living vehicles. Preliminary studies suggest vehicles can anticipate driver needs by detecting biochemical signals. What began as transportation has evolved into a symbiotic relationship—technology that lives with us rather than for us.

IMMERSIVE VEHICLES CONNECT TO OTHER ECOSYSTEMS

IMMERSIVE VEHICLES CONNECT TO OTHER ECOSYSTEMS

Livable Cabins

The concept of vehicle cabins is branching away from a passive place to sit to a fully integrated living space. As vehicles gain longer ranges, enhanced automation, and connected features, manufacturers are redesigning interiors to accommodate work, entertainment, relaxation, and even sleep. Hyundai's Mobis holographic windshield and BMW's Panoramic iDrive exemplify immersive digital interfaces that transform cabins into augmented environments. Honda's 0 Series takes a different approach, focusing on "Thin, Light, and Wise" design principles, emphasizing a spacious, tech-integrated cabin that serves as a functional living space. Meanwhile, Mazda's partnership with Unity aims to create a seamless, intuitive in-cabin experience by embedding real-time 3D technology into vehicle HMIs (human machine interfaces), enhancing interaction with digital tools.

The rise of livable vehicle cabins also intersects with broader lifestyle shifts, including remote work, digital nomadism, and off-grid travel. Alpine's Cross Cabin concept and Volkswagen's California Concept incorporate modular interiors optimized for both productivity and leisure. The RV industry is responding with smart, sustainable designs like the 2025 Honda Camper Motorhome and Living Vehicle's CyberTrailer, which feature adaptive sleeping arrangements and off-grid energy solutions. The growing integration of wellness-focused features, such as air purification systems, ergonomic seating, and biometric monitoring, suggests that vehicle cabins are evolving into personalized, mobile environments rather than simply modes of transport.

Simulated Driving Experience

Electric vehicles are redefining the driving experience, but their near-silent operation presents challenges for both drivers and pedestrians. EVs are 40% more likely to be involved in pedestrian accidents than traditional vehicles, and for visually impaired individuals, this risk jumps to 93%, per the National Highway Traffic Safety Administration. To address these concerns, automakers are integrating artificial soundscapes and haptic feedback into their vehicles. Toyota, Hyundai, and Dodge are developing simulated manual transmissions with artificial engine noise to make EVs feel more familiar and engaging. Rolls-Royce has taken a luxury approach, designing a subtle yet immersive synthetic tone for its Spectre EV, enhancing the driving atmosphere without compromising the brand's hallmark refinement.

Automakers are using these simulators for research and development, calibrating stability programs, and testing autonomous safety features. Virtual reality and AI-driven simulators are also gaining traction, providing immersive driver training and reducing the risks associated with real-world testing. As EVs become mainstream, simulated driving experiences—both in-vehicle and through advanced simulators—will be key to improving safety, driver engagement, and adoption rates.

IMMERSIVE VEHICLES CONNECT TO OTHER ECOSYSTEMS

In-Vehicle Connectivity

The automotive industry is entering an era when vehicles are no longer just transportation—they are becoming mobile data hubs, entertainment centers, and intelligent nodes in a broader connected ecosystem. High-speed, low-latency 5G and edge computing are driving this transformation, enabling enhanced safety, real-time navigation, over-the-air updates, and even in-vehicle gaming. AT&T and Verizon are advancing connectivity frameworks to support autonomous driving and smart city integration, while General Motors has already demonstrated connected gaming tournaments using in-car Wi-Fi. Meanwhile, partnerships like Unity and Mazda's collaboration aim to redefine in-car human-machine interfaces, creating immersive, AI-driven user experiences. As connectivity grows, subscription models for vehicle features—such as Verizon's Connected Car for BMW—are becoming more common, despite consumer resistance. Beyond infotainment, advanced V2X (vehicle-to-everything) communication is improving road safety by enabling cars to exchange real-time data with infrastructure, other vehicles, and pedestrians. Looking ahead, automakers and tech firms are exploring cloud-based vehicle ecosystems, biometric authentication, and AI-powered voice assistants to make vehicles more personalized and secure. With companies like Baidu envisioning autonomous vehicles as mobile data centers, the next wave of innovation will blur the lines between automotive, cloud computing, and AI-driven smart environments.

Mobile Computing and Entertainment Hubs

Automakers are rapidly transforming vehicles into mobile computing and entertainment hubs by leveraging AI, 5G, and cloud gaming to redefine time spent in the car. BMW's collaboration with Xperi to integrate TiVo's video platform and Polestar's addition of YouTube and Nvidia's GeForce NOW to its infotainment system signal a growing trend: Vehicles are no longer just for transportation but are becoming entertainment centers on wheels. With the rise of autonomous driving, this shift is accelerating. Honda's 0 Series EVs, launching in 2026, will integrate connected technologies to transform cars into personalized, immersive spaces. Meanwhile, Sony's Afeela 1 is pushing in-car entertainment further, enabling PlayStation Remote Play via DualSense controllers.

The competition to dominate this space is intensifying. At CES 2024, Forvia launched Appning, a connected car app store aiming to capture 20% market share this year while offering developers a scalable platform to build next-gen automotive apps. This mirrors Apple's expansion of CarPlay to support multiple screens and Google's deeper integration of AI-driven entertainment into Android Auto. Automakers are also experimenting with novel interfaces—BMW's Panoramic iDrive spans the windshield, and Lincoln's 48-inch dashboard display redefines infotainment control. Audi is even introducing virtual reality gaming synced to vehicle movement for an immersive experience.

As mobile entertainment becomes a key selling point, data security and regulatory concerns will follow. The UK has already approved TV viewing in self-driving cars, but safety will be an ongoing debate. Additionally, traditional AM/FM radio faces extinction as EV manufacturers prioritize streaming and AI-curated media experiences. In-car entertainment will become a battleground where automakers, tech giants, and media companies fight for consumer attention in an era of increasingly autonomous vehicles.

CarOS

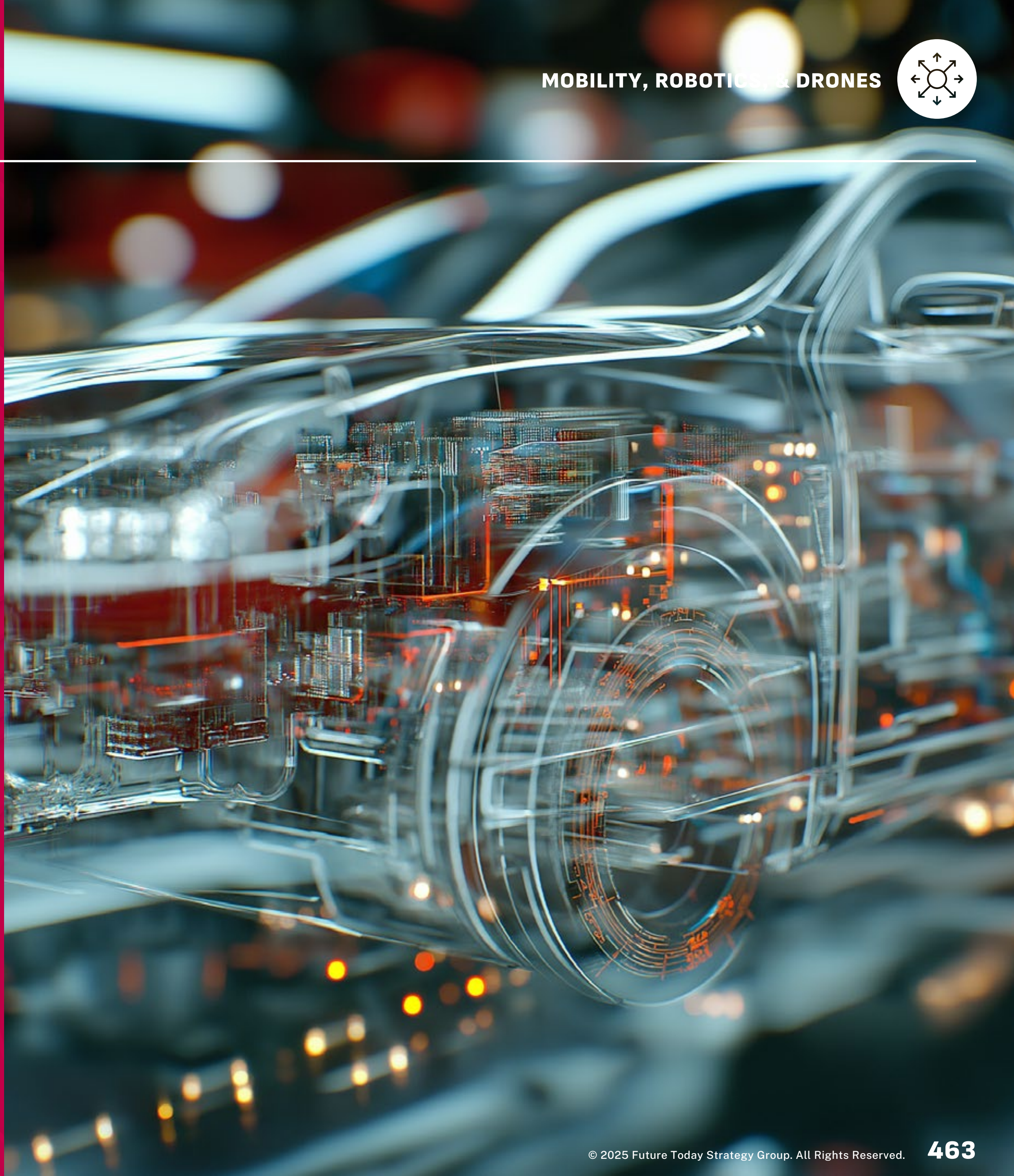
As CarOS (car operating systems) become central to the driving experience, automakers are reclaiming control of the tech behind them. Historically, tech giants like Google and Apple dominated the in-car software space through Android Auto and Apple CarPlay. General Motors is leading this new charge by eliminating CarPlay and investing heavily in its own Ultifi software, a bold move aimed at owning the user experience and unlocking new

IMMERSIVE VEHICLES CONNECT TO OTHER ECOSYSTEMS

revenue streams. Honda, too, is developing its proprietary Asimo OS, leveraging AI to enhance automation and driver assistance. Meanwhile, Volkswagen's VW.os and Tesla's proprietary software continue to evolve, reflecting a broader industry trend toward in-house solutions.

China is emerging as a CarOS powerhouse, with Polestar partnering with Xingji Meizu Group to tailor an OS for the Chinese market, while Xpeng Motors and Huawei collaborate on AI-driven systems with predictive maintenance and natural language processing. BMW, in contrast, is refining its Panoramic iDrive system by integrating augmented reality and smart home connectivity. The push for proprietary software is driven not only by differentiation but also by data ownership—automakers see CarOS as a gateway to monetization through subscriptions and over-the-air updates.

Cybersecurity is now a critical focus, as high-profile breaches in 2024 underscored the risks of increasingly connected vehicles. The formation of the Automotive Cybersecurity Alliance signals a coordinated industry response. Open-source solutions like Elektrobit's Linux-based safety OS are also gaining traction, providing automakers with an alternative to proprietary platforms while maintaining compliance with ISO 26262 safety standards. As CarOS matures, automakers must navigate the tension between innovation, security, and user expectations in this software-defined era.



DATA COLLECTION ENABLES SAFETY AND AUTONOMY

DATA COLLECTION ENABLES SAFETY AND AUTONOMY

AV Simulation

Simulation is redefining autonomous vehicle (AV) development, accelerating progress while reducing real-world risks. Tesla's Dojo supercomputer processes billions of virtual miles, refining its self-driving capabilities, while Mercedes leverages Nvidia's Omniverse AI to model intricate driving scenarios. Mcity's open-source digital twin, launched in 2025, further democratizes mobility simulation, enabling cities and developers to stress-test AVs in virtual replicas of real-world environments.

The global AV simulation market will continue growing, fueled by advances like Ansys' 2025 R1 AVxcelerate update, which integrates enhanced radar interfaces and ASAM OSI compliance for more accurate modeling. Fujitsu's "digital rehearsal" technology now incorporates behavioral modeling to simulate human interactions with mobility systems, while AI-driven segmentation optimizes smart transportation services. As mobility ecosystems expand, interoperability is also key—cities like Singapore and Mexico City use simulated testing to refine unified fare collection systems.

Automakers and tech companies alike are investing heavily in digital mobility environments. Baidu's patent for AVs as mobile data centers exemplifies how simulation extends beyond driving to infrastructure resilience. Meanwhile, Uber's strategic partnership with Wayve illustrates a shift from in-house AV development to collaborative simulation-driven ecosystems. As ADAS and Level 2 autonomy features expand, simulation will be a cornerstone of safety, efficiency, and scalability in next-gen transportation.

Self-Aware Vehicles

Vehicles are evolving from passive machines to intelligent systems capable of self-monitoring, decision-making, and adapting on their own. Advances in sensor technology, AI, and vehicle connectivity are driving the rise of self-aware vehicles, which can detect road hazards, monitor driver behavior, and even regulate their maintenance. Goodyear's SightLine and IntelliGrip tires now analyze real-time road conditions, while Tata Elxsi's RoadSense alerts vehicles to potholes, emergency vehicles, and dangerous curves. Honda and Sony's Afeela vehicles integrate biometric sensors to respond to driver emotions, and adjust in-cabin environments accordingly. Meanwhile, Ford's quietly patented self-reporting system allows cars to restrict usage, disable features, or autonomously return to an impound lot.

Beyond safety, self-aware vehicles are integrating cloud computing and AI-driven decision-making. Tesla's Quantum Drive dynamically switches between electric and hydrogen propulsion for stability and efficiency. Baidu's mobile data center patent envisions autonomous vehicles as roving cloud servers, bridging connectivity gaps in rural areas and disaster zones. Similarly, IBM's patents for autonomous rideshare systems would enable users to access onboard computing power, turning vehicles into mobile workstations. Meanwhile, 5G-enabled vehicle-to-vehicle (V2V) networks allow cars to share real-time traffic and weather updates that can enhance road safety.

As self-aware vehicles continue to integrate AI, biometrics, and cloud computing, regulatory and ethical challenges will emerge. Balancing privacy, cybersecurity, and AI decision-making in critical scenarios will be key as this technology reshapes urban mobility, fleet management, and personal transportation.

Pilot and Passenger Observation

AI-driven in-cabin monitoring is rapidly advancing as it integrates biometric identification, driver behavior tracking, and predictive safety interventions. Systems like Smart Eye's Driver Monitoring System and Magna's advanced driver assistance solutions can detect distraction, drowsiness, and even intoxication, and provide real-time alerts. The US government has explored mandating in-vehicle breathalyzers by 2026, while Ford's scene authentication patent could soon enable facial recognition for verifying drivers. These technologies

DATA COLLECTION ENABLES SAFETY AND AUTONOMY

enhance safety but introduce major privacy concerns. Automakers are already sharing detailed driving data with insurers, sometimes without explicit user consent, and it's impacting insurance rates. Simultaneously, AV providers like Lyft and Mobileye are deploying AI-driven monitoring to improve fleet performance and passenger security. As AI assumes greater control in vehicles, regulations that balance safety benefits with data privacy will be crucial.

Mobile Weather Stations

Mobile weather stations (MWS) are emerging as crucial tools in industries like agriculture for real-time environmental monitoring that will improve disaster response and urban planning efforts. Advances in AI, IoT, and sensor networks are enhancing their predictive capabilities, making them indispensable for data-driven decision-making. In 2024, New York City's FloodNet initiative leveraged MWS to keep track of water levels and predict flooding, while California deployed them to detect wildfire risks and ecological changes. Connecticut has used MWS to track air pollution and reinforce compliance with emissions thresholds. These efforts illustrate the growing reliance on mobile, sensor-equipped systems to manage climate-related challenges.

Autonomous vehicle manufacturers are also integrating MWS into their fleets. Waymo, for example, equips its AVs with LiDAR, radar, and cameras to assess microclimate changes, improving both vehicle navigation and weather forecasting. Meanwhile, AI-powered forecasting tools from companies like Munro Instruments are boosting the accuracy of mobile weather predictions, particularly in regions with rapid weather shifts. The expansion of wireless sensor networks, which eliminate the need for complex infrastructure, further enhances MWS deployment in remote or mountainous areas.

Agricultural technology leaders like John Deere have integrated MWS with farm management systems, to help optimize field operations based on hyperlocal conditions. Additionally, new sensor technologies, such as ultrasonic wind sensors and mobile lightning detection, are expanding the functionality of MWS in both urban and rural settings. As government initiatives and private sector investments accelerate, MWS are set to become essential for mitigating extreme weather impacts and optimizing infrastructure resilience.

Mobility Superapps

Mobility superapps are redefining urban transportation with their integration of ride-hailing, public transit, micromobility, and delivery services onto a single platform. Companies like Uber, Grab, and Bolt are leading this shift, leveraging vast datasets to improve their users' experience, and they're having an effect on urban planning. Uber's UK app now consolidates bikes, scooters, trains, and even flights, while Grab has built its own mapping system to improve hyperlocal navigation that's outperforming traditional providers like Google Maps. With extensive growth in highly populated areas of the world, the number of daily active users of multiple superapps has substantially grown, signaling a transformation in mobility habits.

Beyond consumer convenience, superapps are shaping sustainable urban mobility. The rise of 15-minute city concepts has spurred local superapp development that integrates transportation with broader urban services. Governments and city planners are beginning to utilize mobility superapp data to optimize their infrastructure, improve traffic management, and reduce carbon emissions. Superapps' growing global footprint is evident from Yandex Go's European expansion in 2024 and Bolt's diversified offerings—including micromobility and digital payments. These platforms' role in shaping intelligent, seamless, and sustainable mobility ecosystems will keep expanding.

Utilizing Mobility Data

Mobility data is increasingly viewed as a strategic asset for transforming transportation, urban planning, and business operations. The expansion of open-source map data from Amazon, Microsoft, and Meta—adding competition to Apple and Google—has sparked new innovations in

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mobility solutions. This year, more than 500 cities are expected to deploy digital twins, sophisticated simulations powered by real-time mobility data, to explore urban transportation improvements before putting them into place. AI-powered traffic management systems are also gaining traction for using predictive analytics that enhance traffic flow and reduce congestion. And micromobility data is reshaping city infrastructure by helping governments identify the best spots for e-scooters, bike docks, and EV charging stations.

However, as data collection becomes more pervasive, privacy concerns will escalate. Automakers, including GM, Kia, and Hyundai, have been found sharing driver behavior data with insurance companies, sometimes without clear consumer consent. LexisNexis and Verisk, major data brokers, aggregate this information to generate driver risk profiles, influencing insurance premiums. In response, regulators are investigating potential breaches of consumer rights, while researchers are developing privacy-preserving synthetic mobility datasets that allow for analysis without compromising personal data. The rise of 5G—expected to account for 34% of mobile traffic by the end of 2024, according to Ericsson—will make mobility insights even more precise, offering businesses new options for data-driven decision-making. As this landscape evolves, balancing innovation with ethical data practices will be crucial for maintaining consumer trust and regulatory compliance.

Relying on ADAS

Advanced driver assistance systems are transforming the driving experience, reducing human input in routine tasks such as lane keeping, adaptive cruise control, and emergency braking. However, as reliance on these systems grows, safety experts are raising concerns about driver disengagement and system limitations. The Insurance Institute for Highway Safety found that most partial automation systems do not adequately ensure driver attention, with only one out of 14 tested earning an "acceptable" rating. Regulatory bodies, including NHTSA, are also investigating issues like Tesla's "Actually Smart Summon" feature after multiple reported crashes. While ADAS has the potential to prevent a substantial number of deaths and accidents, failures in sensor accuracy, adverse weather performance, and driver overconfidence present new risks. Automakers must address these challenges through enhanced driver monitoring, stricter safety regulations, and improved sensor technology to ensure ADAS fulfills its promise of safer roads.

Pedestrian Safety

As autonomous vehicles and micromobility options proliferate, pedestrian safety concerns are mounting. High-profile incidents—such as a Cruise AV veering off-road in Austin, Texas, and robotaxis obstructing emergency vehicles in San Francisco—have fueled public unease. NHTSA is investigating Tesla's remote parking features after 16 alleged collisions. Meanwhile, the surge of pedestrian fatalities in New York City—an 18% increase in 2024—was partly blamed on the rise of new transportation methods. The Insurance Institute for Highway Safety projects 3.5 million AVs on US roads by 2025, amplifying safety concerns. Research from the University of Iowa found that children's road-crossing behavior is influenced by AV signaling, highlighting the need for standardized vehicle-pedestrian communication. Efforts to address these risks include California's Complete Streets Action Plan, which aims to enhance 623 pedestrian safety locations by December 2025, and the state's 2024 Daylighting Law, which improves crosswalk visibility. Advances in AV tech also play a role: Nvidia's latest patent seeks to enhance AI perception, potentially improving pedestrian detection. As cities integrate AVs, pedestrian safety will depend on regulatory measures, improved technology, and community engagement.

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AV Viability

Autonomous vehicles are steadily advancing but remain far from achieving full self-driving capability. While most new vehicles now include semiautonomous features—such as lane-keeping, automatic braking, and adaptive cruise control—higher-level autonomy is only beginning to emerge. In 2024, Mercedes-Benz launched Level 3 Drive Pilot in select US markets, with Audi and other manufacturers preparing similar rollouts following regulatory approvals in Europe, China, and Japan. Robotaxi companies like Waymo are expanding services to new cities, testing Level 4 autonomy. While investment in automotive-related AI and IoT is accelerating, the regulatory uncertainty in the US, cybersecurity risks, and ethical challenges remain significant barriers to full adoption.

The commercial sector is a proving ground for AVs, particularly in trucking and logistics. Companies like Aurora Innovation are testing autonomous long-haul trucking, with regulatory-friendly states such as Texas leading the way. These companies underscore the economic viability of autonomy in high-efficiency industries, though full Level 5 implementation remains elusive. The focus is shifting toward enhancing in-vehicle experiences, as seen in IBM's and Baidu's patents for using AVs as mobile data centers. Ford, Tesla, and Honda are also integrating advanced entertainment and workspace features to capitalize on passengers having more free time.

Local AV Regulations

As autonomous vehicle technology advances, local governments are asserting control over their streets while balancing innovation with public safety and economic considerations. In 2024, multiple states, including California, South Dakota, Kentucky, and Alabama, passed legislation allowing Level 3-5 AVs on public roads under specific conditions, such as safety driver requirements, insurance mandates, and law enforcement interaction plans. California's failed SB 915 would have given cities the authority to regulate AV services. So far Gov. Gavin Newsom has vetoed bills that sought stricter reporting and operational limits. In parallel, major urban centers like Phoenix and Los Angeles are expanding AV testing, with Waymo's January 2025 launch of freeway testing and multicity expansions underscoring the growing presence of AVs in complex traffic environments.

Despite this momentum, a fundamental challenge remains: regulatory fragmentation. Cities regulate their streets, states oversee broader transportation policies, and federal agencies control highways—yet seamless AV operation requires interoperability across all jurisdictions. The US could overcome this by following the European Union's lead for more standardized governance. The EU plans to develop a unified AV framework by 2026. Meanwhile, congestion pricing models, such as New York City's $9 entry fee, could impact AV deployment strategies, influencing fleet operations and route planning. As AV adoption grows, cities must align local policies with state and federal regulations to prevent a patchwork of inconsistent rules that could stall industry progress.

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Robotaxi Expansion

Robotaxis are entering a period of accelerated growth, driven by technological advancements, regulatory shifts, and shifting consumer sentiment. In 2024, Waymo doubled its weekly paid trips to 100,000 and expanded service to multiple new US cities, including Los Angeles, Austin, and Miami. Baidu's Apollo Go robotaxi division is on track to reach profitability in 2025, aided by its ability to cut vehicle costs to $28,000—far lower than US competitors like Waymo, whose vehicles cost upward of $150,000. Tesla is also entering the space, with plans to launch its own robotaxi service in Austin by mid-2025.

However, regulatory challenges remain a key factor. Cruise, GM's self-driving unit, was forced to shut down after a high-profile accident led to regulatory scrutiny and loss of operational permits in California and Texas. Waymo faces a new federal investigation into 22 incidents involving its vehicles, per NHTSA. Despite these setbacks, data suggests that robotaxis may already be safer than human-driven cars: A 2024 Swiss Re study found an 88% reduction in property damage claims and a 92% reduction in bodily injury claims for Waymo vehicles compared to human drivers.

Internationally, China is leading adoption, with Baidu expanding to Hong Kong and Singapore, and Wuhan aiming to become the first fully driverless city. Waymo announced plans to test its robotaxis in Tokyo in 2025, marking its first international expansion. With both technological and operational hurdles being addressed at an accelerated pace, robotaxis are approaching a pivotal tipping point in adoption.

SCENARIO YEAR 2036

THE AUTONOMOUS CITY SIGNATURE

By 2036, autonomous vehicles do more than navigate cities—they're reshaping them through unprecedented coordination. More than 60% of urban transport now operates at Level 4 autonomy, but the revolution isn't just technological—it's artistic.

The transformation began when Copenhagen replaced traditional traffic management with "aesthetic orchestrators"—AI systems that optimize for both efficiency and beauty of movement. Rather than vehicles simply maneuvering through intersections, they perform through them, adjusting their trajectories miles in advance to weave patterns visible from observation decks that have become tourist attractions.

The impact is both practical and profound. Commute times have decreased by 43% while commuter anxiety has fallen by 64%. Traffic accidents in these zones are now statistical anomalies, 98% less frequent than in manual areas. Former parking structures have been converted into viewing platforms where people gather to watch the daily commuter ballet. Signature "performances" occur during rush hours.

Cities have developed distinctive movement signatures. Paris vehicles flow in elegant arcs reminiscent of the Seine's currents, and Tokyo's rigid grid creates precise geometric patterns that transform throughout the day. Acoustic engineering ensures vehicle movements generate harmonious sound patterns at key intersections, as traffic flow serves as both visual and musical composition.

The autonomous ecosystem extends beyond passenger transport. Delivery robots operate in choreographed formations, fulfilling logistics while contributing to the urban performance. Neighborhoods program local vehicles to reflect community celebrations, with hundreds of synchronized vehicles creating living monuments during festivals.

"Manual enclaves" remain as cultural touchstones where traditional driving is preserved as artisanal practice. But even here, human drivers often attempt to mimic the graceful patterns of their autonomous counterparts.

As 2040 approaches, the next evolution is emotional response routing—journeys planned not just for efficiency but for psychological impact. What began as transportation optimization has evolved into an art form that transforms how humans experience movement through shared spaces.

ROBOTICS & DRONES TRENDS

COBOTS BECOME COWORKERS

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Accelerated Adoption

The rapid growth of collaborative robots (cobots) is reshaping labor dynamics across industries worldwide. Demographic shifts, labor shortages, and technological advancements are propelling businesses toward cobot integration. In Japan, cobots mitigate workforce shortages due to an aging population. For example, Fujita Works uses cobots in welding, reducing training time and enhancing productivity. Major corporations like Amazon are also expanding cobot usage; its Sequoia system in warehouses is designed to improve order fulfillment speed by 25% without reducing human labor.

Government policies are accelerating this trend. New York's Warehouse Worker Protection Act indirectly incentivizes automation by imposing strict worker safety and productivity quotas, making cobots a practical solution for compliance. Saudi Arabia's Vision 2030 aims to establish 32,000 smart factories that integrate robotics and AI, in addition to a robot factory funded by $150 million from SoftBank. This shift aligns with technological advancements like AI-powered digital twins that enable predictive maintenance and optimized operations.

The cobot landscape covers more than traditional manufacturing. In health care, ABB's YuMi assists in surgeries, and in construction, firms like Canvas use cobots for drywall finishing. In fast food, robots at restaurants like Kernel streamline operations, giving workers time to focus on customer service. Cobots are demonstrating their versatility and potential to enhance efficiency, safety, and profitability across diverse sectors.

General-Purpose Robots

General-purpose robots are evolving rapidly, fueled by AI breakthroughs, advanced sensory systems, and increased investment. Companies like Figure AI and Sanctuary AI are leading the charge with humanoid robots designed for diverse applications, from warehouse logistics to eldercare. Figure AI's Figure 02, tested at a BMW facility, demonstrates real-world adaptability, while Sanctuary AI's Phoenix, equipped with haptic sensors and AI control, learns new tasks through simulation and demonstration. Meanwhile, China's Agibot has claimed the mass production of nearly 1,000 humanoids, signaling a push toward large-scale deployment.

A major bottleneck in general-purpose robotics is training, but new AI-driven approaches are accelerating progress. MIT's Heterogeneous Pretrained Transformers, inspired by large language models, allows robots to learn from vast, diverse datasets, improving their adaptability to novel tasks. Similarly, RoboCat, a self-improving AI agent, can train robotic arms in as few as 100 demonstrations, significantly reducing the need for human oversight. These developments suggest that robots capable of performing multiple, complex tasks with minimal retraining are closer than ever.

As industry adoption grows, commercialization efforts are ramping up. Tesla's Optimus is slated for limited manufacturing in 2025, with broader deployment expected in 2026. Pudu Robotics and Wisson Robotics are also introducing new bipedal and soft-bodied robots with expanded capabilities. The International Federation of Robotics predicts that general-purpose robots will transform manufacturing, logistics, and service industries by mid-decade, making them essential workforce tools rather than futuristic concepts.

Domestic Robots

AI-driven domestic robots are expanding their responsibilities from handling simple automated tasks to acting as sophisticated, interactive companions. In 2024, the market for household robots noticeably grew with the debut of innovations like Samsung's Ballie, a mobile smart home hub that autonomously monitors pets and projects videos, and the SwitchBot K20+ Pro, a modular robot capable of vacuuming, air purifying, and even delivering objects. Robotic vacuum cleaners, now equipped with mechanical arms and AI-powered navigation, continue to dominate the space, while new categories—such as social companion

COBOTS BECOME COWORKERS

robots like ElliQ 3, which uses generative AI for conversation and cognitive engagement—are gaining traction. These robots not only perform household tasks but also provide emotional support, particularly for seniors. Meanwhile, advancements in mobile manipulators and cobots suggest a near future where robots can perform complex, hands-on domestic work with increasing autonomy. Apple's recent robotics research, including a mobile assistant and a robot lamp designed for expressive, human-like interactions, hints at a shift toward embedding personality into domestic automation. As AI and robotics continue to integrate seamlessly into everyday life, the home is transforming into a fully automated and emotionally aware ecosystem.

Robots Expand Creative Collaboration

Robots are rapidly integrating into creative fields, challenging the notion that artistic expression is solely human territory. In South Korea, the humanoid robot EveR 6 conducted a live orchestra, demonstrating the potential for robotics in music performance. Meanwhile, Alter 3, a humanoid robot, has advanced beyond conducting to collaborate on art projects with human artists while blending robotic precision with artistic interpretation. In visual arts, AI-powered robotic arms are assisting painters and sculptors by analyzing artistic styles and suggesting new techniques. Museums have begun employing humanoid robots, such as advanced versions of Ameca, as interactive guides capable of answering visitor questions in multiple languages and offering personalized experiences.

In education, storytelling robots like Kee-Ko and Tega are evolving, now using AI to adjust their narratives based on students' reactions. These robots are proving especially useful in language learning and creative writing classes. Even in entertainment, Tesla's Optimus robot, initially designed for industrial tasks, has demonstrated human-like movements with a potential for engaging with audiences. The emergence of AI-enhanced music composition is further proof of robotics' creative potential—robots now analyze complex musical structures, collaborate with human musicians, and even perform in live concerts.

As robots become increasingly intuitive and expressive, their role in creative industries will continue to expand. The fusion of robotics and art is not about replacing human creativity but enhancing it—pushing the boundaries of artistic collaboration and changing how we create and experience culture.

COBOTS BECOME COWORKERS

Space Exploration Robots and Drones

Space robots and drones are entering a new era of autonomy as they shape the future of extraterrestrial exploration, infrastructure development, and orbital maintenance. In 2024, NASA's Artemis program began testing robotic assistance systems to construct lunar structures, transport materials, and assist astronauts, marking a crucial step toward a sustainable human presence on the moon. Meanwhile, advancements in AI-driven autonomy are revolutionizing space drones, enabling them to execute complex missions with minimal human intervention. These developments are critical as communication delays remain a fundamental challenge for space robotics, especially for Mars and deep-space missions.

On the orbital front, space debris mitigation is gaining momentum. The ClearSpace-1 project is preparing for its first mission to capture and deorbit space junk, while advancements in Unmanned Aircraft System Traffic Management (UTM) systems are addressing congestion in Earth's lower orbit. Additionally, NASA's OSAM-1 robotic servicing mission, scheduled for launch in 2025, is set to demonstrate the ability to repair and refuel satellites in space, signaling a shift toward long-term orbital sustainability.

Lunar and Martian surface exploration is also evolving. Research from ETH Zurich is advancing robotic teamwork among quadruped robots for resource harvesting, while GITAI is developing robotic arms and rovers designed to autonomously construct off-world habitats. And events like RoboPalooza, a NASA-backed competition in the Mojave Desert, are accelerating the development of next-generation planetary rovers with enhanced autonomy and mobility. These innovations, combined with ongoing work on solar sail propulsion and AI-powered high-altitude observation drones, underscore a broader trend: Robotic autonomy will be the cornerstone of future space operations.

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ROBOT AND DRONE INFRASTRUCTURE

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AI-Powered Robotic Training

Virtual training and AI-driven decision-making are accelerating the capabilities of autonomous robots and drones. Nvidia's Isaac Sim and Isaac Gym use simulation and digital twins to train robots in parallel environments, slashing development timelines. Research collaborations, such as Nvidia's Eureka, leverage OpenAI's GPT-4 to refine robotic training goals, demonstrating how generative AI optimizes learning. Plus there's Toyota's AI robots, which have exhibited the ability to master complex tasks in mere hours, providing another example of how virtual training is redefining industrial automation.

AI-powered vision systems are enhancing robot adaptability, so they instantly can recognize new objects and environments. MIT's recent work in AI-driven packing optimization showcases robots efficiently organizing items into tight spaces—a task requiring spatial reasoning traditionally difficult for machines. Digital twins further improve path-planning by simulating diverse environmental conditions and ultimately preparing robots for real-world unpredictability. Beyond training, AI is also redefining robotic autonomy. DeepMind's latest patent aims to help enhance AI decision-making by simulating multiple environmental scenarios. This aims to ensure robots can respond to unexpected variables, reducing reliance on human intervention.

The integration of generative AI is creating robots capable of autonomous learning from diverse data sources, including human demonstrations and internet-scraped visuals. Researchers at University of California, Berkeley have applied reinforcement learning to robots, enabling them to assemble complex objects with human-like precision. Meanwhile, Google's work on long-term memory for robots allows machines to retain situational awareness, improving decision-making over time. As AI-driven training continues to evolve, these advancements signal a new era where robots seamlessly integrate into industries ranging from manufacturing to health care, reshaping the workforce and increasing operational efficiency.

Robot and Drone Swarms

Robot and drone swarms are poised to revolutionize industries by enabling large-scale, autonomous coordination in complex environments. Governments and private enterprises are accelerating research in this area, leveraging breakthroughs in artificial intelligence, connectivity, and decentralized control. The US Pentagon's Replicator program aims to deploy thousands of autonomous drones by August 2025, focusing on swarming tactics through its Autonomous Collaborative Teaming and Opportunistic Resilient Network Topology projects. Sweden's Saab-developed swarm program, set for testing in March 2025, will allow soldiers to control up to 100 drones simultaneously.

Beyond military applications, swarm robotics is transforming agriculture, disaster response, and smart manufacturing. In agriculture, autonomous swarms optimize irrigation, monitor crop health, and reduce pesticide use. Researchers at Imperial College London are exploring drone-based 3D printing, enabling autonomous construction in remote locations. Meanwhile, in places like the MIT AI Lab, federated learning and agentic AI systems are improving swarm coordination, allowing for more adaptive and resilient robotic networks.

As swarm intelligence advances, breakthroughs in soft-jointed robotics and stigmergy-based behaviors will unlock new capabilities, enabling robot swarms to operate in extreme and unpredictable conditions. However, challenges remain in real-time data processing and decentralized control. The integration of 5G and machine learning will be critical for unlocking the full potential of these autonomous networks, and set the stage for their widespread deployment.

Drone Fleets

Autonomous drone fleets are expanding across industries, reshaping logistics, security, and environmental monitoring. Companies like Amazon, Uber, and Alphabet's

ROBOT AND DRONE INFRASTRUCTURE

Wing are scaling drone delivery operations. Amazon continues to experiment with drone delivery of prescriptions and some retail products in very limited markets. Wing, in collaboration with Walmart, has initiated 6-mile drone deliveries in Dallas, illustrating a shift toward mainstream retail logistics. Multiple companies, including FedEx in conjunction with Elroy Air, and Ford, are also developing drone-based cargo transport and vehicle-integrated drone deployment systems, signaling future advances in autonomous mobility.

Regulatory progress is accelerating drone fleet adoption. Amazon's MK30 drone, approved by the FAA for beyond-visual-line-of-sight (BVLOS) operations, represents a significant shift in drone oversight. However, despite launching, operations paused in January 2025 due to software issue-related incidents.

Military applications are also growing, with the US Navy investing nearly $1 billion in unmanned surface vessels and establishing its second autonomous drone squadron, "Hell Hounds." The UK Royal Air Force is also expanding its Protector RG Mk1 drone fleet, signaling a broader shift toward unmanned defense systems.

Environmental and public safety applications are also increasing. The National Oceanic and Atmospheric Administration is deploying oceanic drones to monitor climate change, while law enforcement agencies, such as the Dallas Police Department, are integrating drone fleets for surveillance, with 139 drones deployed 8,000 times in 2024. As drone technology advances and regulations adapt, autonomous drone fleets are set to transform industries, as they enable faster deliveries, safer inspections, and more efficient resource management.

Unmanned Traffic Management

As drones proliferate in commercial and public services, airspace congestion has become a pressing challenge, prompting rapid advancements in Unmanned Aircraft System Traffic Management. The FAA, in collaboration with NASA and industry partners, has made strides toward real-time, scalable drone traffic systems, with localized UTM operations already active in Dallas, Tel Aviv, and North Sea ports as of late 2024. In parallel, the UK's Project Skyway operationalized a 265 km UAV corridor in 2024, and India plans to become a global drone hub by 2030, underscoring the urgency of global drone traffic solutions.

AI and machine learning are transforming UTM systems, allowing for predictive analytics and autonomous airspace decision-making. Innovations like MIT's real-time path-planning algorithm and the integration of 5G networks are enabling faster, more reliable communication between drones and control systems. Regulatory frameworks are also evolving—Avinor's nationwide UTM implementation in Norway, and FAA-approved drone delivery corridors in the US, signal a shift toward structured, scalable airspace solutions. As airspace digitization accelerates, governments and private firms must align on standards to ensure safety, scalability, and seamless drone integration.

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MOVING PEOPLE, PETS, AND OBJECTS

MOVING PEOPLE, PETS, AND OBJECTS

Last-Mile Delivery

The last-mile delivery sector is rapidly evolving as robots, drones, and autonomous vehicles become integral to logistics networks. Uber Eats has expanded deploying autonomous sidewalk robot partnerships with Serve Robotics in Miami and Avride in Jersey City, Austin, and Dallas. Avride plans to scale its fleet to more than 100 delivery bots in 2025, reflecting growing industry confidence in automation. Meanwhile, drone deliveries are gaining momentum, with Walmart leveraging Zipline, Wing, and Flytrex to establish drone hubs across seven states.

Autonomous deliveries are addressing long-standing inefficiencies in urban and suburban logistics. Starship Technologies' robots perform more than 100,000 daily road crossings, and Ottonomy's Ottobot Yeti has introduced doorstep package transfers, eliminating the need for human retrieval. These advancements enhance accessibility for individuals with disabilities and enable deliveries in areas where traditional couriers are less viable. Hybrid fleets combining drones, delivery robots, and electric vehicles are becoming the new standard as they reduce costs and emissions. AI-driven automation is further optimizing route planning and demand forecasting, aligning with growing consumer expectations for same-day and on-demand delivery. The shift toward robotic and drone-based delivery is accelerating, and shaping a future where human couriers are increasingly augmented—or replaced—by machines.

Expanded Payload Capacity

The expansion of payload capacities in drones and robots is reshaping industries, from logistics and infrastructure to defense and disaster response. Alphabet's Wing has doubled its drone payload capacity to 5 pounds while maintaining a 12-mile range, reflecting growing consumer demand for larger deliveries. Similarly the market also saw the introduction of the DJI FlyCart 30, which can transport up to 30 kg over a distance of 16 km, and the JOUAV CW-80E, which is capable of carrying 25 kg for up to 10 hours. Meanwhile, companies like Elroy Air are pioneering heavy-lift cargo drones capable of carrying up to 500 pounds more than 300 miles, potentially revolutionizing supply chains in remote areas. In construction and industrial applications, the Griff Aviation 300 can lift up to 500 pounds, offering new solutions for material transport.

Energy innovations are also pushing the boundaries of drone performance. Hydrogen fuel storage systems developed by Honeywell and the US Department of Energy could significantly extend flight durations, while solar-powered drones like Airbus' Zephyr 8 have already demonstrated 26-day endurance. The US Army is experimenting with Ultra LEAP and Global Hawk drones, which can stay airborne for at least two days, highlighting military advancements that may influence commercial applications. Regulatory frameworks are evolving in parallel, with the FAA looking to expand permissions for BVLOS operations, enabling drones to cover longer distances with heavier payloads.

The impact of these advancements extends beyond delivery and defense. High-altitude robotic balloons, weighing just 12 pounds, are now capable of capturing detailed aerial images across vast areas, aiding urban planning and disaster assessment. As AI enhances autonomous navigation, heavy-lift drones will become more reliable, increasing their adoption across industries. These innovations signal a future where drones and robots handle heavier tasks with greater efficiency, unlocking new possibilities for transportation, logistics, and beyond.

Flying Taxis (eVTOLs)

Electric vertical takeoff and landing aircraft—commonly known as flying taxis—are on the verge of commercialization, driven by advancements in technology, investment, and regulatory progress. Major players, including Joby Aviation, Archer, and Alef Aeronautics, are targeting 2025 for the first commercial flights, with locations such as Dubai, Paris, and select US cities leading the charge. The FAA finalized new

MOVING PEOPLE, PETS, AND OBJECTS

eVTOL regulations in late 2024, establishing pilot training and operational requirements, while vertiport infrastructure is rapidly expanding, with hundreds planned worldwide.

Investment in the industry continues to accelerate. Stellantis and Boeing are backing Archer, while Alef Aeronautics secured more than $850 million in preorders for its Model A flying car. Paris had plans to showcase the world's first flying taxi network during the 2024 Olympics, and Dubai's Advanced Air Mobility center is positioning the UAE as a global hub for eVTOL innovation.

Despite optimism, challenges remain. Battery limitations restrict current eVTOLs to ranges of about 100 miles, and regulatory approvals remain a hurdle, particularly in the US. Additionally, the high cost of early models, such as Alef's $300,000 flying car, limits consumer adoption. However, as technology scales and manufacturing costs drop, eVTOLs could transform urban mobility, cutting travel times while reducing congestion and emissions.

Ocean-Faring Drones

Ocean-faring drones, including unmanned surface vessels (USVs) and autonomous underwater vehicles (AUVs), are transforming maritime industries. The Yara Birkeland, Norway's fully autonomous cargo ship, is continuing its autonomy trials on select routes as of late 2024, signaling the rise of AI-driven shipping. Maersk has followed with a slightly different approach, integrating AI-powered situational awareness systems rather than pursuing fully autonomous ships. Regardless of the specific approach, these vessels reduce operational costs, lower emissions, and enhance safety by eliminating human-related errors. Meanwhile, defense applications are expanding—Ukraine has deployed USVs in naval conflicts. Singapore, too, launched AI-powered patrol USVs in January 2025 to bolster coastal security.

Scientific exploration is benefiting from ocean drones as well. The University of Bremen's TRIPLE project is leveraging AUVs for subglacial lake exploration. The Woods Hole Oceanographic Institution deployed a swarm of AUVs to map deep-sea ecosystems with unprecedented detail. Additionally, conservation efforts are accelerating through use of devices like the Searial Cleaners PixieDrone that are helping remove trash from marinas, resorts, docks, and public places. As AI, robotics, and sustainable propulsion advance, ocean-faring drones are poised to redefine security, commerce, and environmental stewardship across the world's waters.

SCENARIO YEAR 2033

AERIAL CORRIDORS

City skies now play host to a myriad of autonomous aerial vehicles moving through invisible corridors 100-400 feet above street level. What began as small-scale delivery experiments has evolved into a comprehensive transportation layer that transformed urban logistics.

The shift accelerated after the Global Supply Chain Crisis of 2027, when the pressures of trade wars came to a head while traditional ground transportation faltered in the US and Europe. The subsequent Emergency Drone Corridor Act established regulated flight paths and advanced unmanned traffic management systems. Today, these digital highways support more than 8 million daily drone flights across North America.

Multimodal heavy-lift drones, evolved from early eVTOL prototypes, form the backbone of this network. These hydrogen-powered craft, with 800-pound payload capacities, handle everything from emergency medical deliveries to modular home component transport. Amazon's ubiquitous Skycarrier-7 can transition from package delivery to passenger transport in under five minutes.

Cities have adapted with "Skyports" crowning most taller buildings, where ground robots receive packages from landing drones. Wealthier residents enjoy direct-to-balcony delivery, while apartment complexes feature community drone docks with secure retrieval lockers. The "Clear Skies Initiative" has pushed legislation requiring distinctive drone sounds and minimum altitudes over residential areas, while debates continue about equitable access between drone-serviced and traditional neighborhoods. For professionals, SkyCommute offers members access to passenger drones for trips under 30 miles through dynamic corridors monitored by AI systems that have nearly eliminated midair incidents.

Following Hurricane Isaac in 2030, drone swarms restored critical supply lines to isolated communities within hours, demonstrating their transformative impact on disaster response and helping cement their place in society into the mid-2030s.

BLURRING THE HUMAN-MACHINE LINE

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Natural Exoskeleton Movement

Exoskeletons are advancing beyond rehabilitation and industrial applications to enhance natural human movement, driven by AI, machine learning, and lightweight materials. In February 2025, German Bionic introduced the Apogee Ultra, a robotic exoskeleton capable of reducing strain during physically demanding tasks by providing dynamic lifting support of up to 80 pounds. Meanwhile, the FDA recently expanded clearance for Wandercraft's Atalante exoskeleton for rehabilitation, signaling increased regulatory acceptance. Innovations such as textile-integrated exoskeletons, developed by the Swiss Federal Institute of Technology, promise less bulky, more wearable solutions for mobility enhancement. Additionally, Stanford Biomechatronics Laboratory's self-adjusting battery-powered exoskeleton demonstrates how AI-driven adaptation can personalize support in real time. Looking forward, exoskeletons are being integrated with augmented reality and IoT to optimize movement and provide performance analytics for users and caregivers.

Exoskeletons Unlock Superhuman Potential

Advancements in exoskeleton technology are accelerating human augmentation and blurring the line between natural ability and machine-enhanced performance. In industrial settings, exoskeletons like German Bionic's Apogee reduce strain on workers by offsetting up to 80 pounds of weight, minimizing injury risks and increasing endurance. Meanwhile, Georgia Tech researchers have developed a task-agnostic robotic exoskeleton controller that enhances hip and knee joint power by 15%-20%, enabling more efficient movement across various applications. Beyond labor-intensive jobs, exoskeletons are now entering athletics—Chung-Ang University's wearable suit has demonstrated a 0.97-second speed boost for runners by optimizing acceleration and hip extension. The Hypershell X Series, introduced in 2025, takes this further with a 40% leg strength increase and 30% reduction in fatigue for outdoor enthusiasts. On the medical front, the CES 2025 award-winning XoMotion exoskeleton allows hands-free movement for rehabilitation patients, a big step in revolutionizing mobility solutions. With exoskeletons improving strength, endurance, and speed across industries, ethical concerns arise: Will these devices empower workers or push them beyond their limits? The rapid evolution of wearable robotics signals a future where human capabilities extend far beyond their biological constraints.

Redefining Personal Mobility

AI-driven robotics and assistive technologies are transforming personal mobility as they offer new levels of independence to individuals with impairments. Recent innovations highlight this shift. Control Bionics' DROVE integrates AI-powered navigation into wheelchairs, allowing users who have limited hand functionality or can't use standard joystick controls to move independently using a digital camera system and the NeuroNode interface. Labrador Systems' Retriever robot enables mobility-impaired individuals to transport items within their homes via voice or touchscreen commands. Meanwhile, Stanford's exoskeleton research has led to a device that enhances walking efficiency, reducing energy expenditure by 17% while increasing speed by 9%.

This year, WeWalk introduced the Smart Cane 2, an AI-enhanced navigation tool for visually impaired users. This next-gen cane offers real-time obstacle detection, a GPT-powered voice assistant, and integration with public transport systems, powered by Moovit. Its new lightweight design and tactile controls improve usability, while a barometric pressure sensor and ultrasonic time-of-flight technology enhance environmental awareness. In the wearables sector, NeuroVision Pro, set for release in late 2024, uses AI and neural interfaces to convert visual data into neural signals, offering real-time spatial awareness and text recognition.

Beyond assistive devices, autonomous vehicles and AI-driven mobility services are becoming integral to urban transit. Micromobility leader Lyft is restructuring its operations, filing patents for tandem

BLURRING THE HUMAN-MACHINE LINE

riding detection and smart scooter-camera systems to enhance safety and efficiency. With e-bike ridership growing rapidly—Lyft logged 56.7 million bike and scooter trips in 2023—AI-powered micromobility solutions are likely to play a critical role in future transportation ecosystems. These innovations signal a shift toward more inclusive, tech-driven mobility solutions.

Humanoid Robots

Humanoid robots are rapidly advancing from concept to deployment, driven by breakthroughs in AI, computer vision, and robotics hardware. Figure's $675 million funding round, backed by Microsoft, OpenAI, and Amazon, underscores growing investor confidence in AI-powered robotics. OpenAI's partnership with Figure aims to enhance robots' language understanding and make them better at interacting with humans and autonomously adapting to tasks. Tesla's Optimus Gen2, unveiled last year, features improved dexterity and balance, while Amazon is testing Agility Robotics' Digit for warehouse logistics.

Another example is Fourier Intelligence's GR-1, which addresses global aging trends by assisting eldercare residents.

Despite rapid innovation, commercialization hurdles persist. High production costs, safety concerns, and the need for reliable general-purpose applications could slow adoption. The debate over humanoid versus task-specific robotic designs continues, with critics questioning the necessity of a human-like form for industrial applications. However, the race to develop AI-integrated humanoids is intensifying, with industry leaders betting that robots will soon fill labor gaps and redefine automation.

Soft Robotics Get a Grip

Soft robotics is advancing rapidly, transforming industries from logistics to health care by enabling robots to grip objects with human-like dexterity. Historically, robots struggled with delicate handling, but innovations in materials, 3D printing, and AI-driven perception systems are closing the gap. MIT's Series Elastic End Effectors use soft bubble grippers and mapping cameras to grasp tools with adaptive force, while researchers at University of California, San Diego developed 3D-printed soft grippers powered solely by pressurized gas—eliminating complex actuation systems. These breakthroughs are reshaping warehouse automation, where soft robotic arms now outperform traditional rigid grippers in handling diverse products.

Beyond dexterity, soft robots are gaining strength. Korea Advanced Institute of Science and Technology unveiled a woven-structure robotic gripper capable of lifting more than 100 kilograms, demonstrating that softness no longer limits load-bearing capacity. Tesla's Optimus humanoid robot, recently showed off a demo of upgraded hands with 22 degrees of freedom, exemplifies the integration of precision grip and human-like dexterity, with potential applications in manufacturing and personal assistance. As AI-enhanced perception and novel materials advance, soft robotics will expand into new domains, from search-and-rescue operations to assistive exoskeletons.

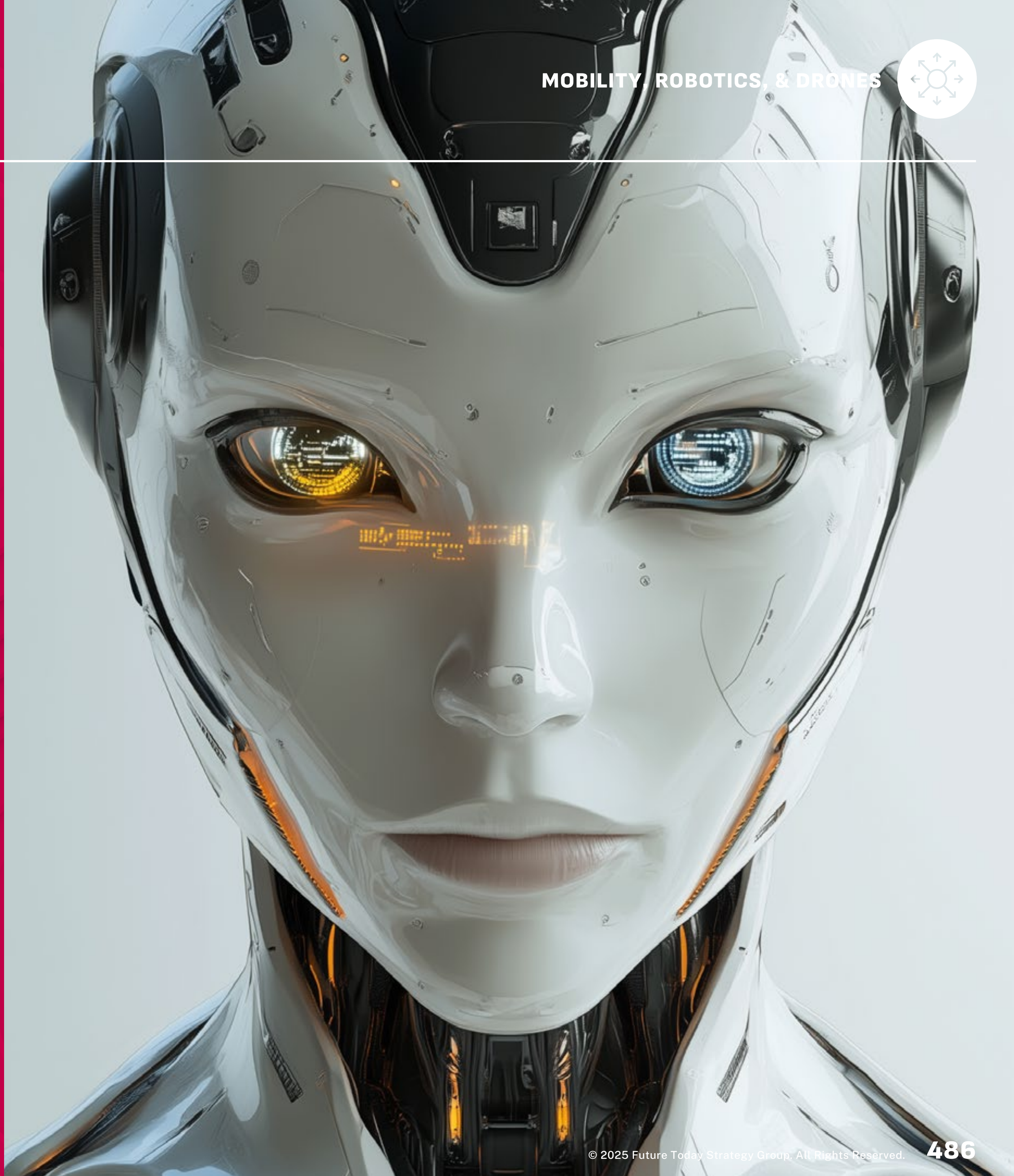
BLURRING THE HUMAN-MACHINE LINE

Robotic "Vision"

Robot vision is evolving beyond traditional cameras and lidar, integrating multi-sensor fusion, AI-driven perception, and novel imaging techniques to create more adaptable and capable machines. Sensor fusion—combining LiDAR, radar, 2D/3D cameras, accelerometers, and gyroscopes—allows robots to interpret their environment with greater accuracy. Emerging technologies like PanoRadar, which uses AI-processed radio waves for 3D imaging, are pushing perception beyond human limitations, enabling robots to "see" through smoke, glass, and walls. Meanwhile, Google and Nvidia are developing patents to improve robotic awareness and object recognition, making autonomous machines more efficient in industrial, transportation, and consumer applications.

New AI algorithms also enhance robotic vision. Researchers from the University of Edinburgh designed an ant-inspired navigation system that outperforms traditional computer vision in complex environments.

Nvidia's latest patent enables robots to detect objects at varying distances with greater precision by segmenting images for neural networks. Vision Transformers and self-supervised learning methods are advancing monocular depth estimation and multi-view reconstruction, allowing robots to perceive spatial relationships more effectively. As sensor fusion technology grows, robot "eyes" will continue to improve, enhancing automation, logistics, and human-robot collaboration.



TAKING CUES FROM NATURE

TAKING CUES FROM NATURE

Quadrupedal Robots

Quadrupedal robots are rapidly evolving as they gain agility, intelligence, and new applications across industries. Companies like Boston Dynamics, Unitree Robotics, and Deep Robotics are integrating GPT-based AI, advanced LiDAR, and reaction wheel actuator systems to improve mobility and adaptability. The Unitree B2-W can now perform a handstand, while Deep Robotics' Lynx model navigates extreme terrain with ease. Researchers at Carnegie Mellon have enabled quadrupeds to balance on narrow beams, and ETH Zurich is testing robots for lunar exploration. AI-powered virtual training, such as MIT's LucidSim, is making these robots more versatile by allowing them to learn complex tasks in simulated environments before real-world deployment, which may drive broader adoption in security, inspections, emergency response, and consumer applications.

Biohybrid Robotics

The field of biohybrid robotics—the integration of living and deceased organisms and biological materials with robotic systems—is in a state of rapid advancement. The point is to achieve capabilities beyond traditional artificial constructs. Researchers at Harvard and Caltech have developed a "medusoid" robot that mimics jellyfish movement using rat muscle tissue and silicone polymers. Scientists at Tohoku University are incorporating wood lice and chitons as effectors in robotic arms. And at Cornell, a research team has engineered robots powered by the mycelium of king oyster mushrooms, which function as biological controllers, to respond to environmental stimuli like light. This innovation suggests potential applications in agriculture, where fungi-controlled robots could monitor soil conditions and autonomously adjust fertilization.

Necrobotics, first demonstrated in 2022 by Rice University researchers using a deceased spider's natural hydraulic system to function as a robotic gripper, is being explored as a low-cost, sustainable alternative to conventional robotics.

The push for biohybrid systems extends beyond organic materials in mechanical structures. In 2025, researchers at Northwestern University and Georgia Tech developed synthetic neurons with response times comparable to human neurons, a breakthrough that could enable real-time tactile sensing and perception in robots. Similarly, Japanese scientists created a robot face covered in living, self-healing skin that can display facial expressions, further blurring the line between biological and synthetic entities. These advancements, while promising, raise ethical concerns, particularly regarding the release of biohybrid organisms into ecosystems and their long-term impact. As this field matures, regulatory frameworks will be necessary to balance innovation with ethical responsibility.

Bioinspired Robotics

As robotics evolve, engineers are increasingly turning to nature's most efficient designs to enhance agility, adaptability, and functionality. From insect-like micro-drones to AI-powered animal-inspired robots, the field of bioinspired robotics is rapidly advancing across industries. Researchers at ETH Zurich have demonstrated superior maneuverability in confined spaces with Magnecko, a gecko-and spider-inspired robot capable of scaling walls and ceilings using electro-permanent magnet modules. Similarly, Gecko Robotics' AI-enhanced wall-climbing bots are assisting the US Navy in digitizing vessels while reducing maintenance downtime.

The study of animal locomotion is also influencing soft robotics. North Carolina State University researchers have created a caterpillar-inspired robot that utilizes silver nanowires to move through controlled heating. Meanwhile, a manta ray-inspired soft robot has set a new speed record of 6.8 body lengths per second by leveraging fluid dynamics to improve propulsion. In aviation, the Raven drone at Swiss Federal Institute of Technology in Lausanne mimics bird takeoff strategies, using spring-like legs for more energy-efficient flight. Even

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mythical creatures are serving as inspiration—Tampere University has developed fairy-like robots using stimuli-responsive polymers for potential agricultural applications like pollination.

These breakthroughs are not just theoretical. MIT's SoftZoo platform is optimizing soft robot design by simulating various animal-inspired morphologies. NASA's Jet Propulsion Laboratory is exploring robotic insects, capable of enduring harsh planetary conditions. With AI integration enhancing these biologically inspired systems, the future of robotics will be defined by efficiency, adaptability, and unprecedented versatility.

Shape-Shifters

Fluid movement in robotics is advancing beyond rigid structures, enabling machines to navigate complex environments with greater adaptability. Researchers at Carnegie Mellon, Sun Yat-sen, and Zhejiang universities have developed shape-shifting robots that transition between solid and liquid states using magnetic fields. These robots can escape enclosures and perform intricate tasks such as targeted drug delivery and circuit assembly. Northwestern University has a soft quadruped robot, powered by soft rubber actuator like a human muscle, that can move safely and seamlessly, including in hazardous conditions.

Other innovations include a vine-like robot from the University of California, Santa Barbara, which moves toward light sources, making it a potential tool for search-and-rescue operations. Researchers at Lawrence Livermore National Laboratory are developing soft materials that change shape in response to light, enabling robots to crawl, swim, or fly in extreme environments. Additionally, liquid metal hydrogel composites, highlighted in a 2023 research paper, are opening new possibilities for surface-tension-driven artificial muscles and dynamic robotic structures.

With AI and machine learning enhancing real-time adaptation, robots are becoming more responsive and capable of seamless movement across diverse terrains. These breakthroughs signal a shift toward robotics that not only imitate biological motion but also surpass human limitations in extreme environments.

Multimodal Movement

Robots are no longer constrained to a single mode of movement. They are evolving to seamlessly transition between walking, flying, crawling, swimming, and even shape-shifting. This shift in multimodal mobility is unlocking new applications in search-and-rescue, industrial inspections, space exploration, and beyond. Caltech's Multi-Modal Mobility Morphobot, capable of rolling, crouching, climbing, and transforming into a flying quadcopter, exemplifies this trend.

Soft robotics and origami-inspired engineering are further expanding possibilities. The University of Washington's microfliers leverage origami-based folding techniques to change descent paths, while UCLA's OrigaMechs integrate data processing directly into flexible robotic structures, reducing reliance on traditional semiconductors. Advances in AI-driven control systems are also enabling robots to autonomously select the most effective locomotion mode. Carnegie Mellon's 2025 AI model, for example, dynamically adjusts robot movement based on terrain conditions, and NASA's latest planetary exploration robots utilize real-time sensor fusion to navigate extraterrestrial landscapes.

As these systems become more sophisticated, industries are finding new use cases. Mobile manipulators—robot arms combined with autonomous mobile robots—are transforming warehouses, while Google's RT-2 vision-language-action model enables robots to interact with environments in human-like ways. These advancements signal a future where robots will no longer be confined to single-use applications but will instead operate dynamically across multiple domains, reshaping industries and expanding automation's frontier.

SCENARIO YEAR 2046

MOBILITY PARTNERS

By 2046, humanoid robots have transformed urban transportation, creating a new mobility paradigm unimaginable two decades earlier. In cities worldwide, personal mobility companions—descendants of early Figure and Optimus models—serve as both assistants and transport enhancers.

Standing just under 5 feet, these carbon-composite “Mobility Partners” accompany elderly citizens and those with disabilities. Their revolutionary adaptive grip technology, evolved from 2020s soft robotics, allows them to convert into support exoskeletons within seconds, bearing 80% of a user’s weight while maintaining natural movement. For longer journeys, the humanoid transforms into a personalized vehicle, using its legs as a stabilizing platform while the user sits in its reconfigured torso. Urban infrastructure has adapted accordingly. Narrow “companion lanes” line boulevards, and buildings feature specialized docking stations for quick charging. This symbiotic relationship has reduced traditional vehicle traffic by 38% in urban cores and reclaimed vast former parking areas for community use.

The social landscape reflects this transformation. The “Natural Movement” political faction advocates for robot-free zones, while complex etiquette has developed around human-robot interaction. Dating apps now include filters for “companion-free encounters,” and restaurants maintain both humanoid valet services and storage facilities. Despite these tensions, health officials celebrate the benefits: Walking rates have increased 64% among seniors, and mobility-related injuries have plummeted as companions’ AI anticipates falls before they occur. As one city official noted, “We didn’t eliminate cars by building better public transit—we did it by reimagining personal mobility itself.”

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2025 TECH TRENDS REPORT • 18TH EDITION

COMPUTING

FTSG

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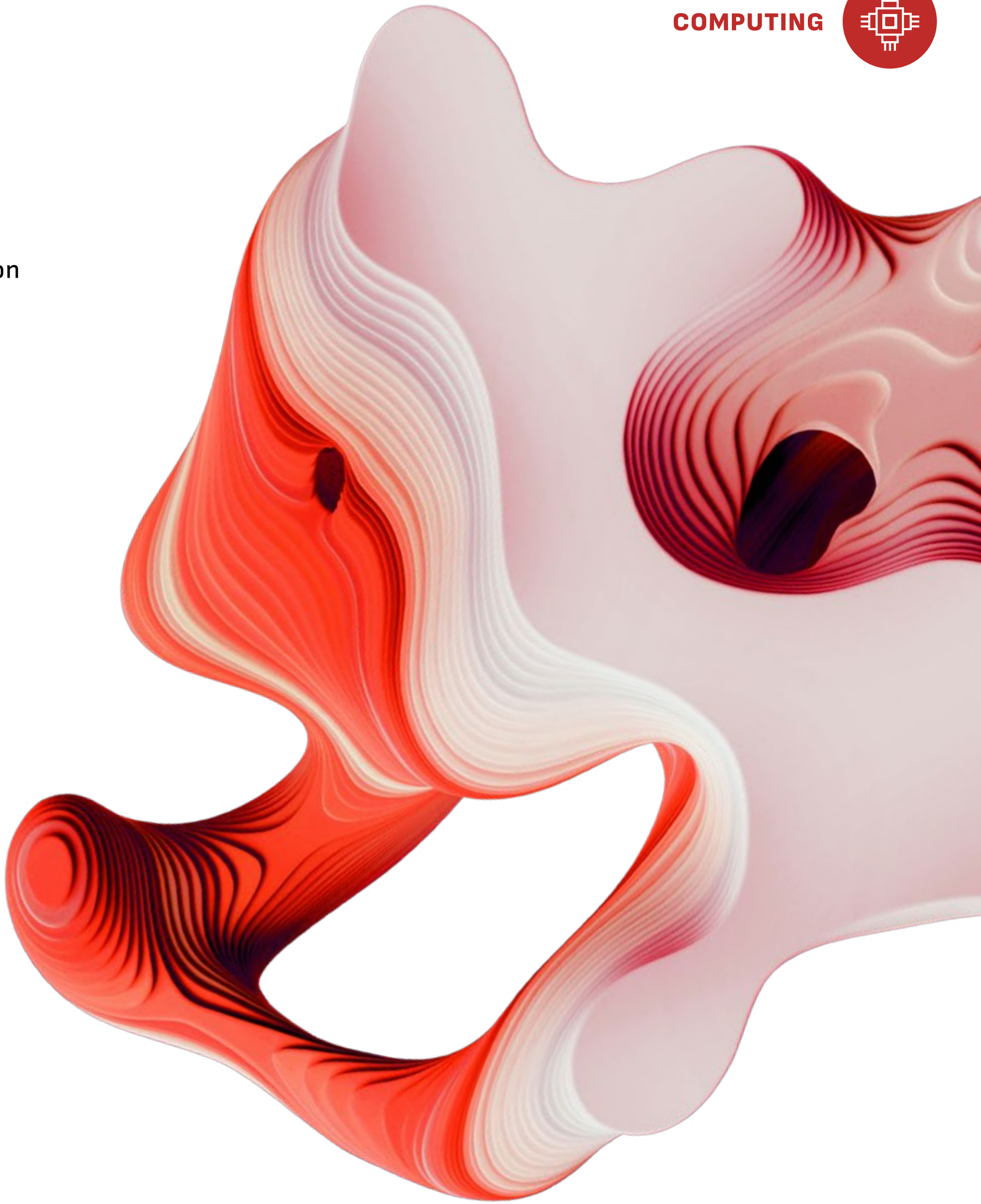


Sam Jordan
Technology & Computing Lead

The Next Currency of Power

The next decade will hinge on algorithms and atoms. Behind the headlines about AI model capabilities lies a fundamental challenge: our ability to build computing infrastructure at an unprecedented scale. We need semiconductors, cooling systems, fiber optic networks, power plants, grid infrastructure, and skilled workers. Building computing infrastructure to meet AI demand won't just come down to technology—the core components needed are enmeshed in bureaucracy and politics. Consider the energy required to power data centers. Many view electricity as a zero-sum game, where using more power for AI means less for essential services like hospitals, schools, and home cooling. While the law of conservation of energy holds true–energy cannot be created or destroyed–its form and distribution are not fixed. The real question is not how to split our current power supply, but how to expand it faster. It's about creating more efficient computing architectures and building flexible, resilient power systems. The country that masters these challenges will lead the AI race.

The stakes are higher than economic competition alone. National security depends on computational supremacy. When adversaries can deploy more powerful AI systems faster, they gain advantages in everything from intelligence to weaponry. Building robust computing infrastructure is just as much about maintaining strategic autonomy as it is technological leadership. And this is where quantum computing enters the chat. When Google's 2024 Willow quantum chip completed a problem in five minutes that would take today's supercomputers 10 septillion years to solve, it sparked equal parts excitement and bewilderment. The natural reaction was "Wait, what? Does this prove the multiverse exists? Does Willow's ability to perform calculations across multiple quantum states challenge our understanding of causality?" I'll let physicists tackle those questions. But to be clear, while Willow represents a genuine leap forward in error correction, it hasn't achieved true quantum advantage: the ability to solve practical problems faster and cheaper than classical computers. The first nation to achieve true quantum advantage won't just lead in AI — they'll crack unbreakable codes and solve problems once thought impossible. Every quantum breakthrough, each advance in AI capability, shapes the balance of power. And thus, the race for computing supremacy isn't just about technology or even economics—it's about the future of power itself.

The AI boom drives a global rush to construct massive computing infrastructure.

1

AI's growth fuels US chip manufacturing surge

In response to AI's skyrocketing demand, more than 90 new US chip fab projects were announced by August 2024. Tech giants are investing nearly $450 billion across 28 states to meet AI's power and data demands.

2

US-China chip war escalates with tightened export controls

The two-year feud heats up as the US partners with allies to tighten export controls on advanced semiconductor tech, citing security concerns. This sparks Chinese countermeasures and investment in domestic chip production.

3

Tech giants invest in small modular reactors for AI power needs

OpenAI, Oracle, and SoftBank announce Stargate, a $500 billion project to build AI infrastructure, including data centers and power facilities, across the US. Microsoft, Amazon, and Google are partnering with small modular reactor developers, investing billions in nuclear energy to power their data centers.

4

Google unveils "Willow" quantum chip

Willow marks a major breakthrough in quantum error correction. By exponentially reducing errors as more qubits are added, Willow paves the way for scalable quantum systems.

5

Embedded intelligence: personal devices get smarter

Intel, Microsoft, Nvidia and others are embedding AI directly into personal devices, boosting power and privacy. On-device AI enables faster, personalized responses without cloud reliance, making PCs and smartphones smarter and more self-sufficient for users.

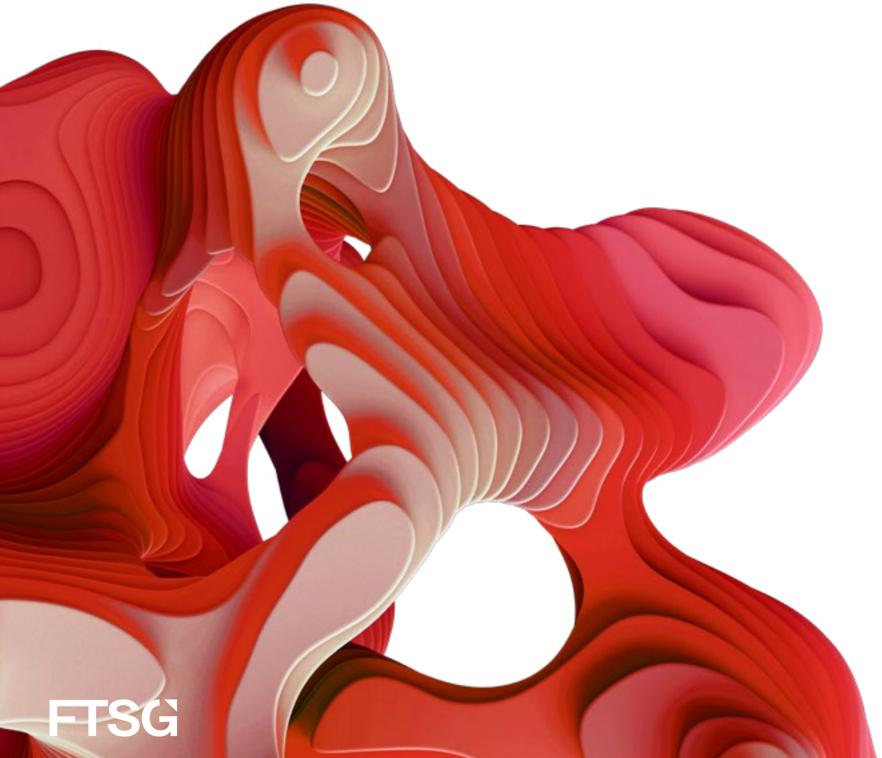
As AI's compute demands soar, nations vie for supremacy through energy expansion and innovative architectures, reshaping global power dynamics.

Over the past decade, ever-increasing computing power drove AI advances, with top models doubling their training compute every six months. Yet this relentless scaling is now hitting practical and physical limits: global infrastructure and energy capacity are struggling to keep pace. The Institute for Progress estimates that by 2030, global AI power demand could rise by as much as 130 GW, while U.S. electricity generation is projected to grow by just 30 GW in the same period. Meanwhile, China continues to outpace the U.S. in energy expansion, adding an average of 50 GW per year since 2010.

Bolstered by strong manufacturing and construction, China is also establishing new chip fabrication plants, while Saudi and Emirati sovereign wealth funds funnel resources into massive data centers. Should the most advanced models take shape overseas, the U.S. risks losing oversight of how these technologies are developed and deployed—particularly for dual-use applications that could fall into the wrong hands.

Against this backdrop, DeepSeek's r1 model has sparked fresh worries about American AI supremacy, leading to concerns that the U.S. might be losing its edge. DeepSeek's release highlights two parallel truths about AI progress: bigger models trained with more computing power do deliver performance gains, but major breakthroughs can also stem from more efficient, smarter algorithms. This challenges the assumption that ever-larger hardware investments are the only avenue to AI progress. Still, it would be a mistake to conclude we can abandon compute infrastructure altogether; the future will demand both efficiency improvements and robust hardware.

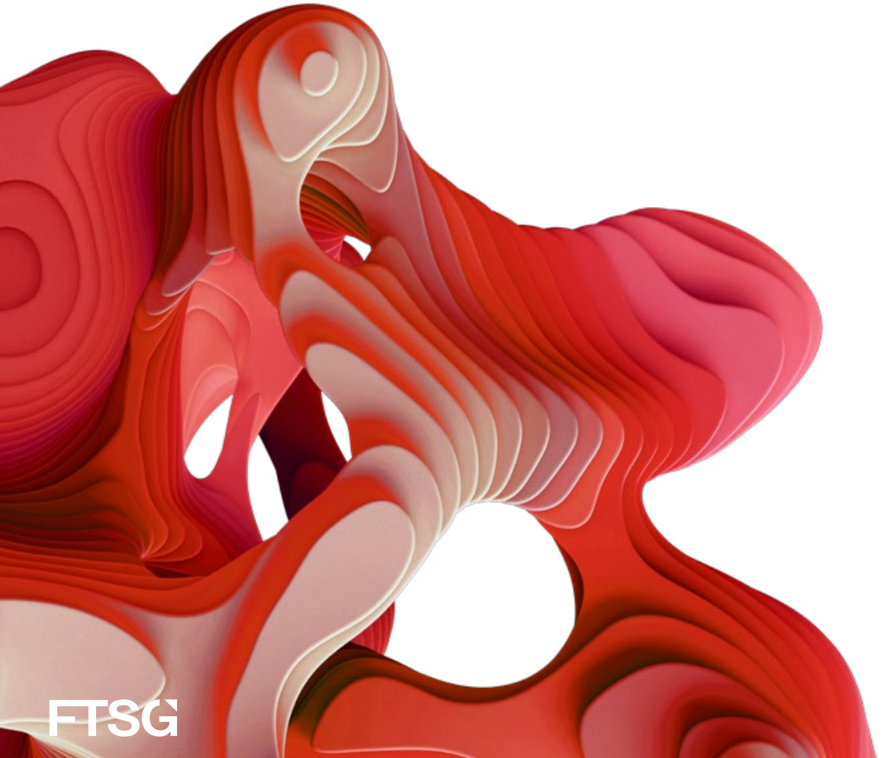
In response, the U.S. and its allies must consider not only expanding energy production but also rethinking compute architectures. One promising frontier is neuromorphic computing, inspired by the human brain's efficiency in processing information. Another emerging concept, organoid intelligence, relies on clusters of human brain cells to perform computational tasks. These novel approaches mark a shift away from traditional silicon-based architectures toward technologies specifically engineered to handle AI workloads more sustainably.



The potential for quantum computing to enhance AI efficiency is also substantial. Quantum computers leverage quantum mechanical phenomena like superposition and entanglement to perform calculations exponentially faster than classical computers for certain types of problems. This immense processing power could allow AI algorithms to tackle complex tasks that are currently infeasible or too time-consuming with classical computers.

Behind the scenes, quantum computing is making slow and steady progress in reducing noise and improving error correction, but quantum advantage has not yet been demonstrated. Even if it were, there's the question of whether the business models are viable enough for companies to invest in quantum computing, given its extremely capital-intensive nature. Nevertheless, due to geopolitical considerations, we must persist. The first country to achieve quantum advantage would gain significant strategic benefits, such as the ability to break current encryption methods, solve complex optimization problems, accelerate drug discovery, and revolutionize materials science—which could all lead to substantial economic and security advantages.

Computing today is not merely a technical pursuit; it drives global influence and sets up economic and cultural landscapes. The ability to scale computational infrastructure and advance energy-efficient architectures will impact everything from entertainment to human-computer interaction, transforming how we work, create, and live. This convergence of technological capability with geopolitics underscores a defining aspect of our time—where computing power both drives innovation and shapes the contours of our social, economic, and cultural narratives.



AI's surging demands pushed computing to its limits, driving advancements in infrastructure, energy strategies, and new architectural frontiers.

JANUARY 2024

China Announces Chip Fab Expansion

China aggressively expands chip fabs, announcing 18 new semiconductor manufacturing facilities.

MAY 2024

Microsoft and OpenAI Plan 100 MW Data Center

The $3.3 billion Wisconsin facility will feature 100,000 AI accelerators and support advanced AI operations.

OCTOBER 2024

AI Workloads Drive Nuclear Investments

Tech companies announce investments in nuclear plants to meet rising energy demands of large-scale AI.

DECEMBER 2024

Google Announces Willow

The chip completed a benchmark in under five minutes, a task that would take supercomputers 10 septillion years — far exceeding the universe's age.

JANUARY 2025

Deepseek Disrupts Nvidia

Deepseek's open-source LLM outperformed expectations at a fraction of the cost, tanking Nvidia stocks just after it unveiled the Blackwell GeForce RTX 50 Series, the world's most powerful GPU.

« PAST

The future of computing hinges on overcoming energy constraints and navigating geopolitical tensions, as AI's growth outpaces current infrastructure and resources.

FUTURE »

MID-2020s

Protocols for AI Data Centers

Hardware screening, cluster encryption, and real-time monitoring protect IP and secure AI infrastructure.

MID TO LATE 2020s

US Enhances Export Controls

The US and its partners expand chip controls to curb China's AI growth, impacting global markets.

LATE 2020S TO EARLY 2030s

"Invisible Interfaces" in Personal Devices

Devices move toward letting users interact seamlessly through eye tracking, voice, and even on-skin gestures.

EARLY 2030s

Power Bottleneck for Data Centers

As AI training clusters scale, they demand gigawatt-level power, and new energy benchmarks for data centers.

MID-2030s

Nuclear-Powered Data Centers Come Online

As proof that AI can run on reliable, clean energy, more companies adopt nuclear power in tech infrastructure.

Access to energy and compute power could define which organizations lead and which will be left behind.

Cheaper Energy, More Compute, Faster Innovation

The cheaper the energy, the cheaper the compute, making high-demand AI applications more affordable and experimentation more attractive. This shift not only accelerates innovation across industries but also allows companies with cheaper compute to gain a competitive edge in AI-driven markets, expanding the scope of what's possible in fields like health care, autonomous systems, and scientific research.

Compute Scarcity Will Reshape the Market

With rising AI adoption, demand for scalable, specialized compute infrastructure is surging, fueling competition and creating revenue opportunities in AI cloud services and hardware leasing. But as VC funding slows, a scarcity of compute resources could redefine market dynamics, with premium access favoring companies that can afford the cost, intensifying competition in AI infrastructure.

Data Center Security

As companies invest in creating differentiated, advanced AI models, robust data center security becomes essential for protecting valuable IP and maintaining a competitive edge. With the rising threat of cyber espionage, companies must prioritize end-to-end security, including their supply chains, to prevent costly breaches and IP theft. This also strengthens client trust, crucial as data protection becomes a top priority in AI.

Seamless Ecosystems Boost Brand Loyalty

As users increasingly rely on wearables and interconnected devices, one of two outcomes may emerge: They could become locked into single-brand ecosystems that offer seamless integration, enhancing customer lifetime value. Alternatively, users might demand interoperability across brands, expecting devices to work fluidly in any ecosystem. This push could drive new standards for compatibility, challenging brands to adapt.

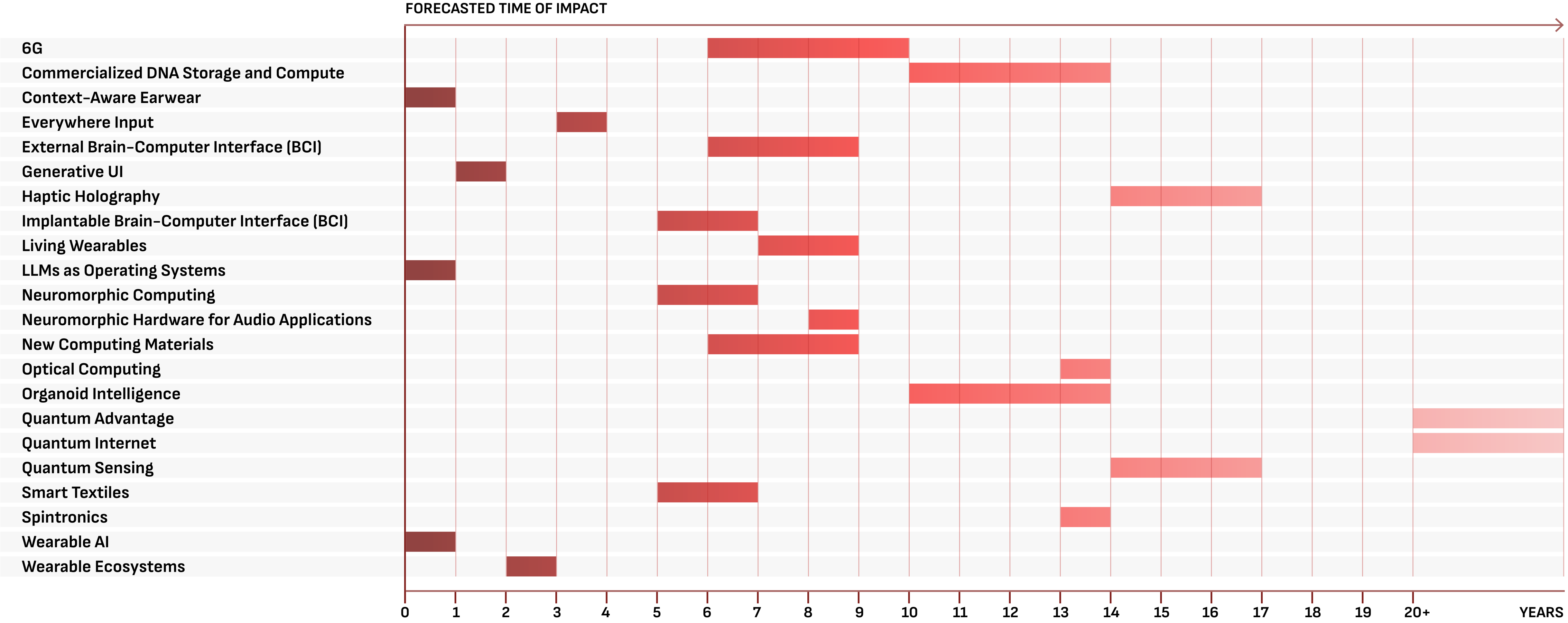
Cutting Costs with Distributed and Edge Computing

AI-enabled PCs and wearable ecosystems use edge computing to process data locally, reducing cloud dependency and transmission costs while enabling faster, real-time responses. This shift lowers cloud expenses and enhances the user experience, especially in sectors like gaming, health care, and retail, where low latency is essential.

Cross-Disciplinary Talent for Novel Architectures

As computing merges with biology, neurology, and physics, companies will need cross-disciplinary talent; recruitment and training will favor hybrid skills and interdisciplinary collaboration. Finding employees with computational and biological sciences experience may drive partnerships with academic institutions and require new recruitment strategies and in-house training to build teams adept at meeting complex needs.

AI-driven interfaces and wearables transform operations short-term, while advanced computing and quantum technologies redefine the long-term tech landscape.



The battle for AI computing shapes two paths to power: nations race for strategic control, while individuals compete through AI access and literacy.

BIOLOGICAL COMPUTING
Bio compute may start in research but could expand as AI demands strain traditional architectures, though entry costs will remain high. Ethical and regulatory issues will likely arise, especially in regions where biology is politicized.

COMPUTE INFRASTRUCTURE BUILD-OUT
Countries are rapidly expanding AI infrastructure, creating opportunities for companies that provide fiber optic cables, concrete, and energy. However, regulatory hurdles could slow progress, while China's centralized approach may give it a speed advantage.

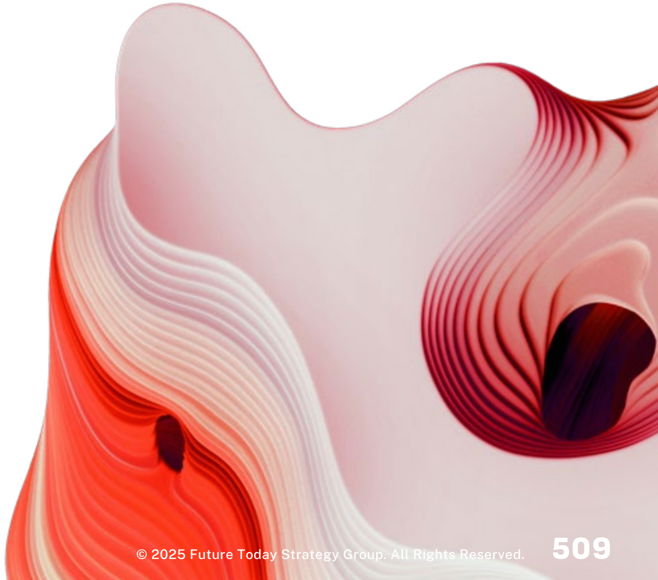
INFRASTRUCTURE POLITICIZATION
Expect political debates to intensify as computing infrastructure strains resources, sparking environmental concerns. But because this same infrastructure enables AI-driven climate solutions, stakeholders will have to weigh immediate costs versus future benefits.

QUANTUM ADVANTAGE
Quantum computing hasn't shown an advantage over traditional compute yet, and even if it does, high costs may slow business adoption. But quantum advantage could disrupt geopolitics by breaking encryption, sparking an arms race for quantum security.

AUDIO-CENTRIC FORM FACTORS
Multimodal AI can process text, images, and audio to enable more intuitive interactions. With audio-centric applications rising, form factors may evolve, embedding compute power in diverse spaces while reshaping security for voice-driven devices.

EDGE AI
Edge AI processes data where it's generated, reducing latency while enhancing privacy. Expect edge devices to become more powerful and efficient, supporting real-time applications in areas like health care and augmented reality.

WEARABLE AI ECOSYSTEM
Wearable AI ecosystems could distribute processing across devices, enhancing efficiency. Expect smartwatches, earbuds, and fitness bands to share compute and combine sensor data, providing richer insights into health and activity.



These individuals are rewriting how we'll work, think, and create with computers.

- **Dr. Taner Esat, researcher at Forschungszentrum Jülich in Germany,** for his significant contributions to the field of quantum sensing.
- **Dr. Yoel Fink, researcher and professor at the Massachusetts Institute of Technology,** for his work on multifunctional fibers and fiber assemblies, including developing rechargeable lithium-ion batteries in fiber form and multifunctional fibers for in vivo photopharmacology.
- **Dr. Ali Heydari, director of data center cooling and infrastructure at Nvidia,** for his work on advanced liquid-cooling systems.
- **Dr. Tom Harty, co-founder and chief technical officer at Oxford Ionics,** for his work on developing a quantum chip.
- **Dr. Seung-Woo Lee, researcher at the Quantum Technology Research Center at the Korea Institute of Science and Technology,** for his quantum error correction technology.
- **Michael Intrator, CEO and co-founder of CoreWeave,** a specialized cloud computing company focused on GPU-accelerated workloads, for his leadership in building out the computing infrastructure needed to fuel the AI boom.
- **Emre Ozer, senior director of processor development at Pragmatic,** a flexible chip manufacturer in Cambridge, England, for developing the first-ever flexible programmable chip not made of silicon.
- **Dr. Paolo Pintus, assistant professor at the University of Cagliari, Italy** for his significant contributions to the development of integrated photonic devices, especially in silicon photonics.
- **Brian Potter, senior infrastructure fellow at the Institute for Progress,** for his analysis on the technology and economics of the compute infrastructure build-out.
- **Dr. Shreyas Sen, Elmore Associate Professor at Purdue University,** for his work on designing AI chips inspired by the human nervous system to improve efficiency.
- **Jordan Schneider, founder of the "ChinaTalk" podcast,** for his writings and analysis on the geopolitics and national security of compute infrastructure.
- **Mike Davies, head of Intel's Neuromorphic Computing Lab,** for his leadership in developing neuromorphic computing technology.

The build out of AI computing infrastructure offers opportunities and global influence to its developers....

...but the race to build it exposes critical vulnerabilities in energy, security, and privacy.

OPPORTUNITIES

New Export Players Emerge

Countries focused on developing a robust and scalable computing infrastructure could lead in exporting high-quality AI technologies, services, and intellectual property to emerging markets, strengthening economic influence.

Wearables Get Lighter and More Powerful

By offloading processing to interconnected ecosystems, companies can create lightweight wearables that don't sacrifice performance. These more comfortable devices could reshape industries like entertainment and health.

Cutting Edge Computing Improves Efficiency

Novel computing architectures like neuromorphic computing can reduce data center operational costs by cutting energy and cooling needs, offering a way to handle computationally intensive applications while meeting sustainability goals.

Personalized Health Gets Real

Biometric and body-interface technology allows companies to offer new, secure health monitoring products. Personalized health-tracking devices could combine fitness monitoring with secure logins, creating products that serve dual purposes.

THREATS

Cyber Breaches Threaten AI Clusters

High-value AI clusters are prime targets for sophisticated cyberthreats, making cybersecurity investment essential. The stakes are especially high as thieves could use compromised AI clusters to steal proprietary models, impacting industries globally.

Energy Infrastructure Needs A Boost

US energy infrastructure lags in AI demands due to long build times, permitting, and supply chain issues. Meanwhile, China's centralized approach avoids regulatory hurdles and relies on nonrenewable energy, giving it a competitive edge.

US Supply Chain Faces Vulnerabilities

The US tech supply chain is particularly vulnerable in advanced semiconductor access, and disruptions in this supply chain could heavily impact American tech companies dependent on these critical components.

Data Privacy Risks Rise

As context-aware devices integrate sensors (cameras, microphones, biometrics), they're always monitoring environments. Such technologies can inadvertently capture sensitive data, leading to potential misuse by unauthorized entities.

The computing build-out creates opportunities but demands strategic planning.

Participate in the computing infrastructure expansion—it's not just for AI-focused hardware companies. This build-out needs advanced networking, security systems, supply chain tracking, and sustainable energy to connect and support data centers. Opportunities abound across industries as each component is vital for scaling AI, mitigating bottlenecks, and ensuring a secure, efficient infrastructure ecosystem.

Prepare employees to understand which products justify intensive compute use. As compute costs rise, companies will need to prioritize profitable applications over open experimentation, and all employees will need to be trained to embrace a strategic approach that maximizes resource value while balancing innovation and cost-efficiency.

Diversify component sourcing to reduce dependency and risks tied to a single country or region. Establish relationships with multiple suppliers and partners to distribute production and adapt smoothly to shifting geopolitical conditions.

Leverage AI at the edge to optimize data flow and reduce cloud storage and bandwidth costs. Edge devices can preprocess and filter data, sending only essential insights to the cloud. This reduces bandwidth, lowers storage needs, and keeps critical functions close to the source, creating a cost-effective and responsive data ecosystem through seamless cloud-edge integration.

While biological computing may seem niche, it has the potential to disrupt various industries, from health care to data storage. Companies unprepared for this shift may face competitive disadvantages. With energy-efficient advantages over traditional electronics, biological computing offers a sustainable alternative for companies focused on reducing energy use and environmental impact.

For young people, this can feel like a daunting time with many jobs at risk of disappearing in the future. To those reading this: Focus on building adaptable skills. The computing infrastructure build-out could be an ideal opportunity to gain practical experience and develop highly transferable skills.

Technology Deployment
Capital Expenditure
Talent Development
Regulatory Influence

Important terms to know before reading.

AI HYPERSCALERS
Major cloud providers with extensive infrastructure and resources that allow users to run AI applications at massive scale. These hyperscalers can support highly intensive AI workloads, offering the scalable computing power, storage, and specialized tools needed to deploy and manage large AI applications.

AI TRAINING CLUSTERS
High-performance computing setups that aggregate computational resources specifically to handle the intensive demands of AI model training. These clusters typically consist of multiple GPUs or specialized hardware optimized for handling large-scale data and complex algorithms in AI training.

BIOCOMPUTER
A computer that uses biological molecules like DNA and cells to store and process information.

BRAIN-COMPUTER INTERFACE (BCI)
A direct interface between the brain and computer that can enable control and communication by thought alone, with potential to help people with disabilities as well as elucidate cognition.

CENTRAL PROCESSING UNIT (CPU)
The key computer component that performs the computations, makes decisions on data, and tells the other components what to do. You can think of it as the computer's mission control center.

CLASSICAL COMPUTER
The standard binary digital computer that manipulates zeros and ones to store data and perform computations sequentially using hardware chips and switches.

EXASCALE COMPUTERS
Supercomputers capable of performing over 1 exaFLOPS, which is a quintillion calculations per second.

FAULT TOLERANCE
The ability of a quantum system to operate reliably despite errors and noise.

FORM FACTOR
The overall physical attributes and dimensions of a device according to standard specifications or for particular use cases. It impacts the usability and compatibility of hardware.

GRAPHICS PROCESSING UNIT (GPU)
A specialized circuit designed to rapidly process and manipulate computer graphics and image data.

HYBRID CLASSICAL-QUANTUM
A computational architecture that combines both classical computers and quantum computers to exploit the complementary strengths of each.

NEUROMORPHIC COMPUTING
Computer architectures that are inspired by the biological brain's structure and function.

OPEN SOURCE
Computer software or other products with source code that anyone can inspect, modify, and enhance.

ORGANOID INTELLIGENCE
A new scientific field of study that aims to actualize biological computing by utilizing 3D cultures of human brain cells and brain-machine interfaces.

PERVASIVE (UBIQUITOUS) COMPUTING
Aims to seamlessly integrate computer hardware and software into all objects and activities, creating an always-available, helpful computing environment.

Q-DAY
The hypothetical point in the future when a fully operational quantum computer capable of running practical quantum algorithms finally becomes available.

QUANTUM ADVANTAGE
Also known as quantum supremacy, refers to the potential capability of quantum computers to solve certain problems that are intractable for classical computers in practical time frames.

QUANTUM-AS-A-SERVICE
The provision of quantum computing resources on demand as a cloud service.

QUANTUM COMPUTER
A type of computer that utilizes quantum mechanical phenomena like superposition and entanglement to perform computations. Unlike classical computers, which operate on binary bits (0 or 1), these computers run on quantum bits, or qubits, representing a 0, 1, or a quantum superposition of both states at the same time. Since they consider multiple possibilities simultaneously, they can potentially be much faster at some types of problems than classical computers.

QUANTUM ENTANGLEMENT
A phenomenon in which two or more quantum particles are intrinsically linked to each other in such a way that the state of one particle cannot be described independently of the others, even when separated by a large distance.

QUANTUM INTERNET
A hypothetical global quantum communication network that connects quantum processors using quantum entanglement and teleportation.

QUANTUM SUPERPOSITION
Allowing a quantum system to exist in multiple possible states at the same time until it is measured. The quantum parallel processing enabled by superposition is fundamental to achieving speedups and novel applications using quantum computers.

QUANTUM SUPREMACY
This refers to a quantum computer performing a task that no classical computer can match, regardless of its practical usefulness.

QUBIT
The basic unit of information in quantum computing. Unlike classical bits, qubits can be in a superposition of 0 and 1 simultaneously. The superposition, entanglement, and interference properties of qubits are what allow quantum algorithms to efficiently solve certain problems that are believed to be intractable on classical computers.

RISC-V
An open-source instruction set architecture based on established reduced instruction set computer (RISC) principles.

COMPUTING TRENDS

CHIPS

What are the different types of AI chips?

GPUs (Graphics Processing Units)

Originally designed for rendering graphics for gaming applications, GPUs have become indispensable in AI workloads due to their ability to handle parallel processing efficiently. GPUs are highly versatile and well-suited for the high computational demands of training AI models. Their ability to perform thousands of parallel operations simultaneously makes them particularly effective for matrix-heavy tasks like deep learning. In the AI field, GPUs are widely used in both training and inference, though they are more commonly associated with training large-scale neural networks. For example, Nvidia GPUs, such as the A100 and V100, are a standard in AI research and commercial applications due to their performance. Other notable manufacturers include AMD and Intel.

TPUs (Tensor Processing Units)

Developed by Google, TPUs are designed specifically to accelerate machine learning workloads, especially those involving deep learning models that use TensorFlow. TPUs are highly optimized for matrix operations and are tailored for deep learning tasks, making them efficient for both training and inference. TPUs excel at executing operations like matrix multiplications, which are central to neural networks. These processors are often used for training large models and handling inference tasks in Google Cloud's AI services. TPUs have powered significant projects like AlphaGo and large-scale models such as GPT. Google remains the sole manufacturer of TPUs, with the TPU v4 being the most recent version available for use.

FPGAs (Field Programmable Gate Arrays)

FPGAs are reconfigurable chips that can be programmed after manufacturing, allowing a unique blend of flexibility and performance. These chips are highly customizable, enabling developers to adapt the hardware for specific AI models and tasks. FPGAs are especially valuable in low-latency applications, where custom processing pipelines can significantly accelerate inference. They are primarily used in inference tasks, particularly in edge computing or environments that demand high power efficiency and fast execution times. Microsoft, for instance, utilizes FPGAs in its Azure AI infrastructure to handle inference workloads. Leading manufacturers in the FPGA space include Xilinx, now part of AMD, and Intel, with its Arria and Stratix series.

ASICs (Application-Specific Integrated Circuits)

ASICs are custom-built chips designed for a specific application, offering unparalleled performance and energy efficiency for that particular task. Since they are built for a single purpose, ASICs are extremely efficient, making them ideal for inference tasks where speed and power consumption are critical. These chips are primarily used in large-scale inference deployments, such as in data centers or in specialized hardware products like smartphones. For example, Apple's Neural Engine handles on-device AI tasks like facial recognition, while Google's Edge TPU powers inference in low-power environments. Tesla's Dojo D1 is another ASIC designed for high-performance computing in self-driving applications. These manufacturers create chips finely tuned for specific AI tasks, offering performance that general-purpose processors can't match.

NPUs (Neural Processing Units)

NPUs are specialized chips designed to handle AI tasks, with a focus on deep learning and neural network operations. Their architecture is optimized to efficiently process the specific types of calculations AI models require, such as matrix multiplications in convolutional layers. NPUs excel in performing these operations quickly and efficiently, making them highly suitable for both inference and, to a lesser extent, training. They are most commonly used for inference in mobile devices, edge computing hardware, and other low-power environments where energy efficiency is crucial. NPUs are increasingly found in smartphones, IoT devices, and automotive applications. Examples of NPU-based systems include Huawei's Kirin NPU, Qualcomm's Hexagon DSP with AI Engine, and Apple's Neural Engine.

RISC-V AI Chips

RISC-V is an open-source CPU architecture that has gained attention for AI workloads due to its flexibility and scalability. Unlike proprietary chip architectures, RISC-V allows developers to modify and optimize the architecture for specific AI tasks, which can be particularly advantageous for companies or applications that require custom hardware solutions. This flexibility has made RISC-V chips appealing for both training and inference tasks, although they are more commonly found in experimental AI systems or edge devices where adaptability is key. SiFive is one of the leading companies developing RISC-V-based AI chips, with other companies exploring custom designs for specialized AI tasks based on this architecture.

What is the difference between training vs. inference chips?

Training
Training a machine learning model involves feeding massive amounts of data into the model and adjusting its parameters over time. This process is compute-intensive, often requiring high parallelism and flexibility, which is why GPUs are commonly used for training. TPUs are also used for training, particularly in Google's ecosystem.

Inference
This is the phase when the trained model makes predictions. Inference workloads tend to focus on low-latency and power efficiency, particularly in edge or real-time applications. FPGAs and ASICs excel here because they can be optimized for fast and efficient inference tasks, while GPUs and TPUs can also be used for inference but are less power-efficient.

Why different chips for different applications?

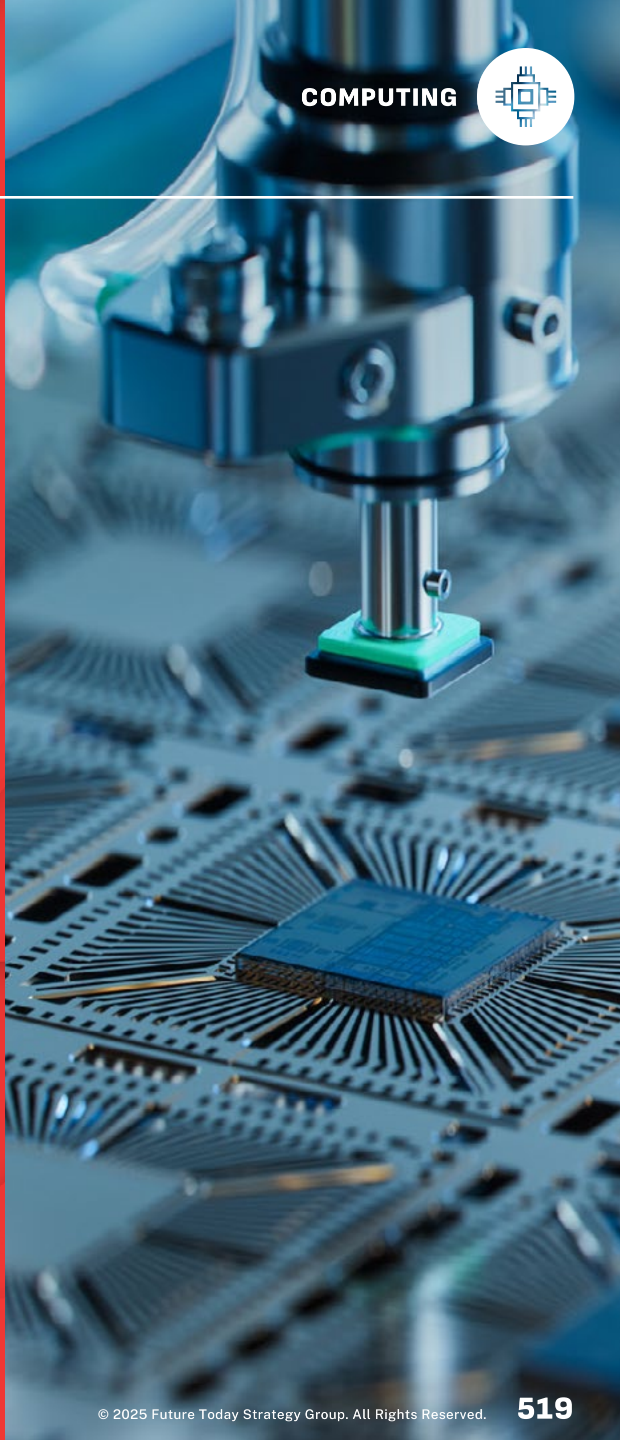
Training and inference have different computational demands, and applications can range from cloud-based AI model training to real-time inference on mobile devices. This variability leads to the following considerations:

1. **Flexibility vs. specialization**
GPUs offer flexibility, making them suitable for a wide range of tasks, while ASICs provide performance for specific, repetitive tasks.

2. **Cost and efficiency**
ASICs and FPGAs are cost-efficient for large-scale, repetitive tasks like inference, whereas the general-purpose nature of GPUs can lead to higher operational costs.

3. **Scalability**
TPUs are designed to scale well in cloud environments, where massive amounts of data can be processed. FPGAs are more suited for small-scale, specialized environments where low-latency and power efficiency are essential.

The choice of AI chip depends heavily on the specific needs of the application, including whether you're training a model or using it for inference, the power and latency requirements, and the environment in which the chip will operate (cloud vs. edge).



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The US-China Chip War

The ongoing US-China chip war has intensified, with the US Department of Commerce citing national security and foreign policy concerns to justify multiple rounds of export controls to limit China's development in advanced semiconductor technology. To strengthen its position, the US has been building a coalition with allies, notably striking a multilateral trade agreement with the Netherlands and Japan in January 2023 to restrict sales of advanced lithography equipment to China. The Netherlands, home to leading chipmaking equipment manufacturer ASML, is a crucial player. Despite these sanctions, older deep ultraviolet scanners have allowed China to produce 7-nanometer chips via its leading chip manufacturer, Semiconductor Manufacturing International Corp. (SMIC), although it remains behind global leaders such as Taiwan's TSMC.

The consequences of these controls have been felt both in China and the US. US-based chip giant Nvidia's sales in China and Hong Kong fell by 20% as of February 2023. China has responded to these restrictions with countermeasures, including banning the use of US-made Micron Technology chips in critical infrastructure projects, restricting exports of rare earth elements vital for chip manufacturing, and heavily investing in domestic semiconductor production capabilities. Beijing has poured more than $150 billion into its chip industry, including a $47 billion investment fund announced in May 2023. SMIC has become China's de facto national semiconductor champion, though it still lags behind global rivals in producing the most advanced chips.

Chips Onshoring

The US has ramped up efforts to onshore semiconductor manufacturing, spurred by global supply chain disruptions and national security concerns. The 2022 CHIPS and Science Act was a significant turning point: It earmarked $52 billion in grants and research funding for US-based semiconductor manufacturing, as well as an investment tax credit for chip manufacturers that establish or expand US operations. This has sparked a wave of private sector investments: More than $395 billion has been announced since its passage, and the US is on track to produce nearly 30% of the world's leading-edge chips by 2032, exceeding initial projections. TSMC announced that its first Arizona fab, which was previously delayed, has achieved early production yields that surpass comparable fabs in Taiwan—signaling early onshoring success.

The US isn't alone in these efforts. China was an early mover in trying to reduce dependence on foreign-made chips; the country launched the China Integrated Circuit Industry Investment Fund, commonly known as the "Big Fund," in 2014 to foster domestic chip production and achieve technological self-sufficiency. The European Union has rolled out the European Chips Act, which aims to attract 43 billion euros in public and private investment to boost semiconductor research, development, and manufacturing, including mega

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fabs. And several countries in Southeast Asia and India are also working to expand their semiconductor capabilities. Malaysia is actively expanding into semiconductor manufacturing and design, building on its strengths in packaging and testing. Singapore has the most complete semiconductor supply chain in Southeast Asia and is the only country in the region with foundry manufacturing. While already major players, Japan and South Korea are also increasing investments.

AI Chips

Nvidia currently holds a commanding presence in the AI chip market, capturing between 70% and 95% of the market share. Its flagship AI accelerators, such as the H100, and proprietary CUDA software have enabled the company to triple its year-over-year sales for three consecutive quarters, driven by unprecedented demand for AI processors. The company's aggressive strategy, which includes releasing a new AI chip architecture annually, aims to deepen its dominance, making it difficult for competitors to catch up. However, despite its market lead, the company faces growing competition and risks.

The potential for disruption looms as tech giants like Google, Microsoft, Meta, Intel, and Amazon develop their own AI chip solutions. Google's Tensor Processing Units (TPUs), in use since 2015, have evolved into powerful chips, such as the newly released Trillium, which powers its Gemini and Imagen models. Similarly, Microsoft has begun incorporating AI chips from AMD, whose Instinct MI300X is seen as a potential rival to Nvidia's GPUs. The MI325X, expected to debut by year's end, features more than 150 billion transistors and 288 gigabytes of high-bandwidth memory, but its performance in real-world applications is yet to be determined. Intel, too, is attempting to carve out space in the AI market: The company recently launched its third-generation AI accelerator, Gaudi 3, which it claims is more cost-effective and efficient than Nvidia's H100 in running inference tasks. Another AI chip, Lunar Lake, launched last fall. Intel's AI efforts highlight the intensifying competition in AI chips, with price and efficiency becoming key factors. Startups like Cerebras Systems are also entering the fray, marketing its CS-3 system as a viable competitor to Nvidia. The field of AI chips is rapidly evolving, and while Nvidia currently leads, the market is far from static.

Chips for Inference

Once AI models are trained, they require significant compute power to deploy or "infer" answers for users, a process called inference. While model training builds the foundation, 99% of the compute in a model's lifecycle is dedicated to inference, running the model repeatedly to respond to real-time queries. This means efficiency gains during inference are crucial to manage compute costs effectively. For instance, increasing training compute can reduce inference demands, potentially lowering costs by up to 80%. But inference workloads in data centers differ greatly from training tasks: Since inference doesn't require as much raw processing power, data centers can use older chips effectively, focusing instead on memory bandwidth—the ability of chips to access and manage data quickly, which is the primary performance constraint in inference. Unlike training, which can run on large clusters of accelerators, inference is often managed in smaller batches and can operate efficiently with only tens of accelerators instead of thousands. This compact setup also enables data centers to allocate resources flexibly, using space for various hardware types and workloads.

Another key difference is the proximity requirement for inference: While training can be done remotely, inference needs low-latency connections close to end users, often necessitating data centers near backbone fiber networks for fast responses. In response, companies like Nvidia and AMD are expanding their GPU offerings, including the Nvidia-dominant A100 and H100 GPUs and AMD's Instinct MI300 series, optimized for both training and inference. Meanwhile,

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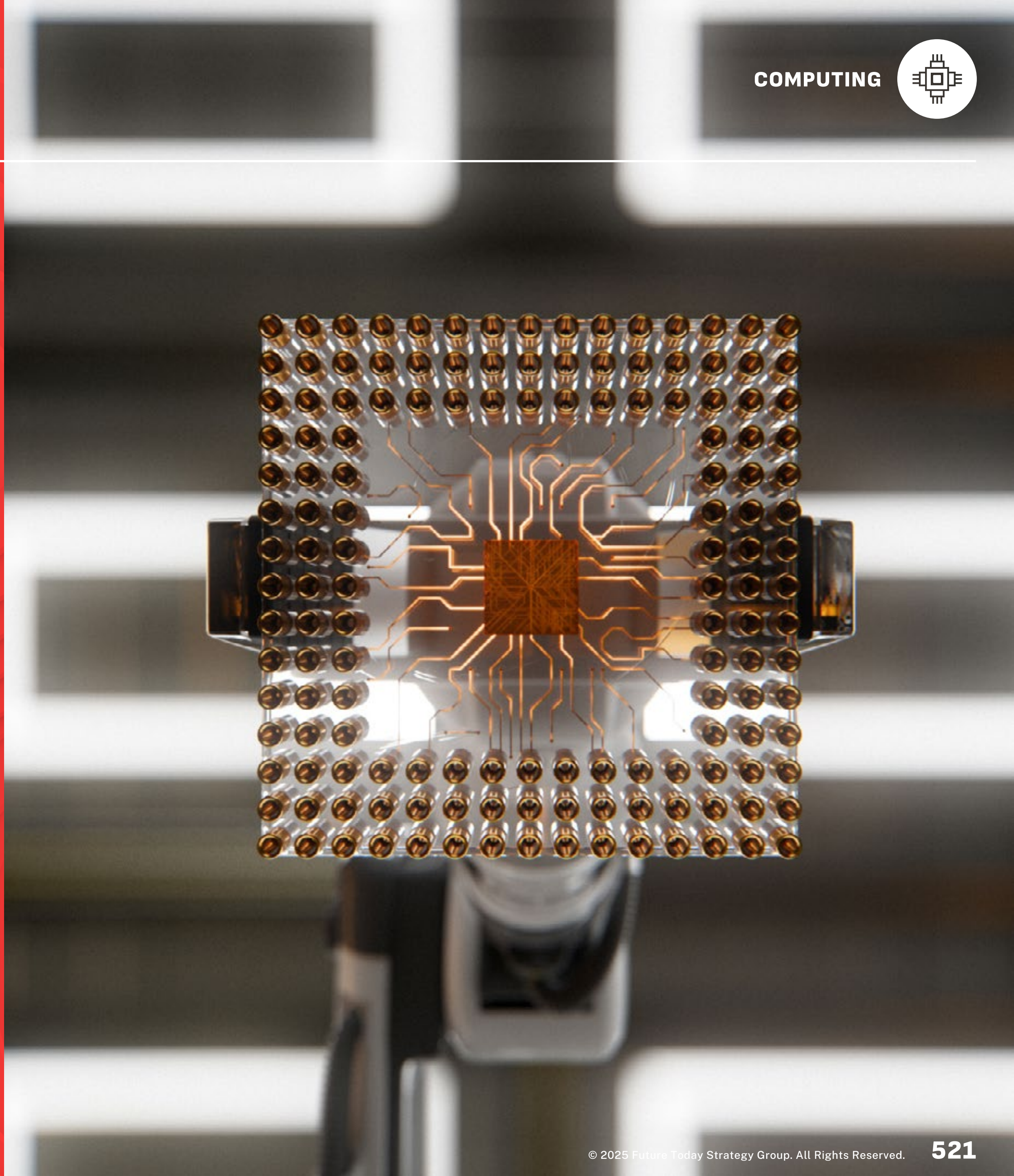
Qualcomm, AWS, Meta, and specialized AI chip startups like Groq and Untether AI are developing inference-specific chips, recognizing that efficient, lightweight inference is essential for scalable AI deployment across industries.

AI-Assisted Chip Design

AI is playing an increasingly vital role in chip design, with major tech companies like Nvidia leveraging it to enhance the process. Chip design requires the precise placement of billions of transistors, which significantly affects cost, performance, and power efficiency. Traditionally, designing these chips has been a highly complex and labor-intensive task. Now, AI techniques like reinforcement learning are being used to optimize chips for power, performance, and area, creating more efficient designs than those made by humans alone. Companies such as Nvidia, Intel, AMD, IBM, Google, and Apple are integrating AI into various stages of the chip design process, from conceptual design and transistor modeling to simulation, verification, and testing. AI has been particularly effective in simplifying processes like clock tree synthesis, a critical step in distributing signals across a chip. Intel, for instance, employed AI to help design its Meteor Lake processors, which consist of innovative chiplets stacked into a single package. These processors feature a dedicated neural processing unit (NPU) alongside the CPU and GPU, optimizing them for AI tasks such as image recognition, video processing, and natural language processing.

AI's impact on chip design extends throughout the entire product lifecycle. The collaboration between chip designers, electronic design automation (EDA) tool providers, and foundries is key to advancing AI-driven chip design. A notable example is the partnership between Synopsys and TSMC, which are working together to develop AI-assisted EDA solutions for advanced chip process nodes. These efforts underscore AI's transformative potential, enabling more powerful and efficient chips that can better handle the growing demands of modern AI applications.



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Counterfeit Chip Detection

Counterfeit chips are a growing problem, costing US semiconductor companies more than $7.5 billion annually and posing serious risks to both industry and consumer safety. The shortage of new semiconductor chips has led to an increase in counterfeit chips, which can result in malfunctions or even security vulnerabilities. There are estimates that as many as 15% of all spare and replacement semiconductors purchased by the Pentagon are counterfeit. To combat this, researchers are developing advanced technologies to verify the authenticity of semiconductor components. One such breakthrough is RAPTOR (residual attention-based processing of tampered optical responses), an AI-powered detection method developed by Purdue University researchers that uses deep learning to analyze light patterns from gold nanoparticles embedded in semiconductor chips or their packaging. These nanoparticles scatter light in unique ways, creating specific patterns that can be recorded and stored for later authentication. The RAPTOR technique involves taking microscopic images of the nanoparticle scattering patterns, allowing for high-contrast imaging even though the materials are mostly transparent to light. The AI model then distinguishes between natural degradation of the chip over time and intentional tampering by analyzing these patterns. The model is trained to detect adversarial attempts to replace nanoparticles, which could potentially hide tampering efforts. This technology can detect tampering with 97.6% accuracy, outperforming traditional detection methods by up to 40%.

Flexible, Programmable Chips

A flexible, programmable chip is a type of microprocessor that combines the processing capabilities of traditional chips with a bendable or foldable structure, enabling it to operate on flexible surfaces. Unlike conventional rigid silicon-based chips, these flexible chips are made from bendable and ultrathin alternative materials. Because of this design, the chip can conform to non-flat surfaces and endure physical stress without breaking or losing functionality. Programmability is key to these chips, as it allows developers to write and execute specific instructions so the chip can perform complex tasks like data processing and machine learning operations.

The Flex-RV microprocessor exemplifies this advancement in flexible computing. Developed by Pragmatic Semiconductor, this 32-bit processor runs on an open-source RISC-V architecture and is built with non-silicon materials, using indium gallium zinc oxide transistors on a polyimide substrate. Designed to operate while bent, Flex-RV offers a durable, energy-efficient solution capable of executing machine learning tasks while consuming less than 6 MW at 60 kHz. Robustness tests show that Flex-RV maintains consistent performance, even under bending, with only minor performance variation. The Flex-RV microprocessor is groundbreaking because it brings computing power to flexible, affordable applications that rigid silicon chips cannot support, such as wearable health monitors, smart packaging sensors to track produce freshness, and adaptable components for soft robotics.

Advancing Data Processing with Photonics

Silicon-photonic (SiPh) chips are circuits that combine traditional silicon electronics with optical (light-based) components, allowing them to process data using light rather than electricity. This approach enables much faster data speeds and lower energy use, making SiPh chips ideal for tasks that require processing large volumes of data efficiently. In February 2024, researchers at the University of Pennsylvania announced development of one of these types of chips to perform mathematical computations (vector-matrix multiplication) for training AI. Beyond faster speeds and lower energy use, this chip offers enhanced privacy: By performing many computations simultaneously, it eliminates the need to store sensitive data in a computer's working memory. This design makes a computer powered by this technology nearly impossible to hack. Chinese

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researchers have developed a photonic chip called the OPCA chip, which operates entirely with light and processes 100 billion pixels in just 6 nanoseconds. This speed is ideal for edge AI applications like autonomous driving and robotics, enabling rapid, energy-efficient image processing directly on the device.

RISC-V

RISC-V, first released in 2010 by UC Berkeley's Parallel Computing Lab, is an open-source, modular instruction set architecture that allows for flexible and cost-effective chip design. This openness enables companies to innovate without the licensing fees associated with proprietary architectures like x86 and Arm. However, RISC-V faces notable trade-offs, particularly in performance. As of 2024, RISC-V processors still lag behind top-tier Arm and x86 CPUs in raw speed, with benchmarks consistently placing even the fastest RISC-V chips well behind their competitors. To address these challenges, several initiatives are underway. The Berkeley SonicBOOM project is advancing experimental cores with features like out-of-order execution to enhance efficiency. Companies like Tenstorrent, led by renowned chip designer Jim Keller, are also investing in high-performance RISC-V solutions to close the gap.

Adoption of RISC-V is steadily growing, particularly in data centers. Startups such as Ventana Micro Systems and Tenstorrent are leveraging its flexibility to create innovative server solutions. Major industry players have also shown strong commitment to RISC-V. Samsung has established a Silicon Valley R&D lab dedicated to RISC-V development, while Alibaba's C910 server chip, based on RISC-V, is already powering cloud servers for Scaleway in France. Alibaba plans to release an even more advanced server chip soon, signaling confidence in RISC-V's future. Nvidia has embraced the architecture on a massive scale, with projections indicating that around 1 billion RISC-V cores will be shipped in its 2024 product lineup alone. This adoption highlights RISC-V's versatility and its growing influence across the technology landscape.

Vertical Integration

Companies are increasingly adopting vertical integration strategies, aiming to control the entire development ecosystem—from hardware to large language models (LLMs). Nvidia, in particular, stands out for its aggressive pursuit of vertical integration, which has positioned the company as a dominant player in the AI and high-performance computing markets. The company has created a comprehensive, vertically integrated ecosystem that includes its proprietary CUDA software stack, which has become the de facto standard for AI development. By controlling the entire stack—ranging from chips to software frameworks and services—Nvidia sets a high barrier for competitors. Its dominance in both hardware and software has created significant lock-in effects, as developers and enterprises become reliant on CUDA for seamless AI deployment. For companies to compete with Nvidia, they need to not only match its advanced hardware capabilities but also offer an equivalent software ecosystem, a daunting challenge in a rapidly evolving field.

While vertical integration is currently in the spotlight due to AI, it's not a novel concept. MBA programs have long taught this strategy, and tech giants like IBM have employed it for decades. IBM's history of vertical integration in computing predates the current AI boom—for decades, the company has developed, manufactured, and controlled multiple layers of the computing stack, from hardware to software. This long-standing approach has allowed IBM to remain a key player in the tech industry, illustrating how vertical integration can provide a sustained competitive advantage across generations.

New Materials to Power Advanced Computing

Recent advances in semiconductor materials are driving breakthroughs in computing, electronics, and bioengineering. Moving beyond traditional silicon, researchers

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are exploring topological semimetals and other quantum materials that offer higher power output with lower energy use. Topological semimetals, for example, exhibit unique electron behavior that supports spintronics—a technology that utilizes electron spin rather than charge for data storage and processing, enabling faster and more efficient devices. Two recent examples: University of Minnesota researchers created a thin-film topological semimetal, and a team in Korea created a new p-type semiconductor alloy of selenium and tellurium (Se-Te). The latter material, which can be deposited at room temperature, shows improved mobility and a higher on/off current ratio, outperforming existing transistors. Such advancements are expected to benefit next-generation displays, including high-refresh-rate OLED TVs and extended reality devices.

In chip manufacturing, where creating smaller, faster processors is always a goal, Applied Materials introduced two new materials for use in ultra-tiny 2nm (nanometer) chips. For perspective, a nanometer is about 50,000 times thinner than a human hair. These materials include a ruthenium-cobalt metal coating that reduces thickness, allowing electric current to pass through with less resistance, making chips faster and more efficient.

Meanwhile, scientists at the University of Chicago's Pritzker School of Molecular Engineering developed a hydrogel semiconductor, which combines the electrical properties of semiconductors with the flexibility of hydrogels, which are soft stretchy materials. This soft semiconductor could be used in flexible medical devices implanted in the body, providing better comfort and adaptability to biological tissues.

Optical Computing

Optical computing processes data with light (photons) rather than electricity, which could lead to faster, more energy-efficient computing systems. An international team, including scientists from the University of Pittsburgh, has developed a photonic memory platform using a magneto-optical material called cerium-substituted yttrium iron garnet (Ce) on silicon—a setup that stores and processes data in light rather than electronics. By applying a magnetic field, the researchers can adjust light speed within micro-ring resonators, giving them control over the light's direction and speed. This technology achieves both high switching speed and energy efficiency, with durability reaching 2.4 billion cycles, making it suitable for demanding photonic memory applications.

At Purdue University, scientists achieved a quantum photonic breakthrough by trapping cesium atoms on photonic circuits to act like transistors for light, controlling the flow of photons. By using lasers to freeze cesium atoms near absolute zero, the atoms can interact precisely with circulating light in a microring resonator and the atoms can control photon movement. This atomic-level control over light flow brings optical computing closer by enabling logic and data storage in photonic circuits. In another advancement, researchers at the Swiss Federal Institute of Technology in Lausanne developed a cost-effective, efficient photonic integrated circuit (PIC) based on lithium tantalate. Unlike silicon, which struggles with high-speed data, lithium tantalate performs well in optical systems and is easier to produce at scale. The team's new PICs achieve minimal optical loss, supporting high-speed operations at telecom frequencies. This breakthrough promises scalable, affordable photonic systems for optical computing, communication, and lidar, making high-speed, low-energy optical technologies more accessible. As a whole, these advancements move optical computing from theoretical to practical, scalable applications.

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Scaling AI Clusters

The computing requirements for training leading-edge AI models have surged, with computational demand increasing fivefold annually from 2010 to 2024. This escalation calls for highly advanced AI training clusters—specialized networks of interconnected systems designed to support the immense processing loads required by modern machine learning models. These clusters primarily consist of numerous GPUs or TPUs working in tandem to meet the rigorous needs of AI training, and their sizes are expanding rapidly to keep pace with these demands.

For the US to remain competitive in AI development, projections indicate that by 2030, the most advanced AI clusters may require around 5 GW of power and incorporate up to 1 million accelerators. Currently, the largest clusters contain approximately 100,000 GPUs and demand tens of megawatts. By comparison, OpenAI's GPT-4 reportedly needed 25,000 GPUs, drawing 30MW of power, enough to power 25,000 US homes. Future expansions by companies like Microsoft and OpenAI aim to build clusters with even greater capabilities, with plans underway for facilities requiring up to 5 GW, or 150 times today's typical power usage.

The infrastructure push includes investments by key AI computing companies. The Stargate Project is an initiative to build a network of AI-dedicated data centers. OpenAI and its partners have announced plans to invest $100 billion to build a supercluster in Texas as part of a larger $500 billion computing infrastructure expansion project. CoreWeave recently secured $7.5 billion in financing to expand its data center operations, aiming to double its capacity by the end of 2024. Similarly, Microsoft and OpenAI's planned cluster in Wisconsin, set to launch in 2026, will feature around 100,000 of Nvidia's latest accelerators, consuming more than 100MW. The next stage, expected by 2028, envisions a supercomputer requiring close to 5 GW, indicating the scale of infrastructure needed to sustain AI training growth. Building this infrastructure at an unprecedented scale will be essential to meet AI's increasing computational demands and to support continued advancement in AI capabilities globally.

Nuclear-Powered Data Centers

The resurgence of nuclear power is gaining momentum as tech giants like Microsoft and Amazon turn to nuclear energy to power their vast data centers. Microsoft has signed a 20-year power purchase agreement with Constellation Energy to buy all the electricity generated by the Three Mile Island nuclear plant's Unit 1, which is set to reopen as the Crane Clean Energy Center by 2028. This marks a remarkable revival of a site known for the 1979 Unit 2 partial meltdown, the worst commercial nuclear accident in US history. AWS recently acquired a data center next to the Susquehanna Steam Electric Station in Pennsylvania. The proximity to nuclear power allows AWS to directly tap into the 2.5 GW of energy produced by the plant, cutting out reliance on the grid and ensuring a steady, clean energy supply. This method of colocating data centers next to nuclear plants is gaining popularity as a way to secure reliable power while avoiding grid-related fees. Proposals for similar setups are surfacing in New Jersey, Texas, Ohio, and other regions. Looking further ahead, ventures like Helion Energy aim to make nuclear fusion a reality. Supported by investors like OpenAI CEO Sam Altman, Helion plans to launch the world's first fusion power plant by 2028. If successful, this breakthrough could provide Microsoft with fusion-generated energy, offering an even more advanced clean power source for the company's future data centers.

Fortifying the Data Center

Securing AI data centers is emerging as a major trend among tech companies as cyberthreats grow more sophisticated and targeted. With AI systems increasingly deployed for critical applications, companies like OpenAI, Microsoft, and Google are focusing intensively on protecting their in-

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frastructure. Recent high-profile breaches highlight the risks: In early 2023, a hacker accessed OpenAI's internal messaging systems to steal sensitive design information, and more recently, the Chinese espionage group Diplomatic Specter launched a spear-phishing campaign against OpenAI employees in an attempt to exfiltrate proprietary data. This incident underscores the escalating vulnerability of AI facilities, pushing companies to prioritize robust security practices to safeguard their valuable intellectual property.

This shift toward stronger data center security involves securing the entire ecosystem, from the supply chain to internal networks. Companies now face a new imperative: ensuring that all hardware entering their facilities—from chips to network devices—is screened to detect tampering. Enhanced protocols for network and storage security have also become critical. This includes encryption of all data transfers within the cluster, strict identity verification for every device connected to sensitive networks, and real-time monitoring of network links, especially fiber connections between data centers, to detect any unauthorized access.

Fortifying data center security is not just about protecting corporate assets but also about retaining a competitive edge. By investing in security, companies can mitigate the risk of adversaries stealing AI models that would otherwise require massive investments to develop. As competition grows and AI infrastructure becomes even more critical, data center security will be key to advancing these technologies safely and securely.

Automated Data Centers

In 2024, Nvidia filed a patent for "intelligent components of a data center," detailing a system where autonomous robots manage server racks and components. The patent describes robotic systems that handle server rack manipulation and maintenance, controlled by a central monitoring system. This automation addresses the growing challenges of manually managing expanding data centers, by enabling dynamic rack reconfiguration and real-time cooling adjustments based on computational demands and environmental conditions.

Industry experts see this as strategic positioning for Nvidia. "This reinforces Nvidia's leadership in data center innovation," notes Trevor Morgan, OpenDrives' senior vice president of operations. While Nvidia may not build data centers directly, the patent could generate substantial licensing revenue. Gartner analysts project that advanced robotics could enhance data center operational efficiency by 30% through continuous monitoring and precise adjustments.

The industry is already embracing robotics. Novva Data Centers deploys modified Boston Dynamics Spot robots (dubbed WIRE—Wes' Industrious Robot Employee) for autonomous facility patrols, temperature monitoring, and security verification. Similarly, DE-CIX's "Patchy McPatchbot" handles automated fiber optic connections in distribution frames, demonstrating robotics' diverse applications in modern data centers.

Specialized AI Cloud

A specialized AI cloud is a cloud infrastructure designed specifically to meet the demands of AI and machine learning workloads. Unlike general-purpose cloud platforms, specialized AI clouds are built to handle the complex computational needs and large datasets associated with AI applications. These clouds utilize high-performance GPUs like Nvidia's A100 or H100, and sometimes TPUs, which are great for tasks like neural network training. These platforms often come with pre-built environments that include popular machine learning frameworks like TensorFlow, PyTorch, and JAX, reducing setup time for developers. Specialized AI clouds like Google's Vertex AI, AWS SageMaker, and Azure AI also offer managed services, which provide end-to-end support for building, training, deploying, and monitoring AI models without requiring deep expertise in cloud infrastructure. These

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platforms typically feature tools to streamline machine learning operations, including automated model versioning, testing, and retraining, ensuring smooth transitions from development to production.

AI on the Mainframe

Mainframes, IBM's legacy systems, quietly underpin much of the financial world, processing 70% of all credit card transactions. Known for their unmatched ability to handle high transaction volumes with top-tier security, mainframes remain vital in industries that demand reliability and speed. Despite attempts over the past decade to migrate workloads from mainframes to the cloud, many companies have struggled. Not all workloads are suited for the cloud—some run more efficiently and cost-effectively on mainframes, while certain applications are simply too difficult to move. But AI may be the key to revitalizing the mainframe. Modern mainframes are now being equipped with AI-specific hardware and software to handle various AI workloads. IBM's current z16 mainframe already integrates AI for running machine learning models, and the upcoming Z mainframe, set for release in 2025, will feature the Telum II processor and Spyre AI Accelerator Card, designed to support large language models (LLMs) and advanced machine learning. These advancements will power applications like fraud detection, real-time transaction analysis, and AIOps for system monitoring and anomaly detection.

One of the reasons companies considered moving off mainframes was the shrinking pool of COBOL programmers as they near retirement age. However, AI's evolution in programming—allowing developers to code in natural language without needing deep expertise—could shift this trend. Instead of training new cohorts in COBOL, companies may find it more practical to have them utilize AI to translate their work and continue using the platform. Additionally, running machine learning models and LLMs on a mainframe offers a security advantage. Since data doesn't need to be distributed across disparate systems for AI processing, enterprises can maintain stricter control over data governance and security, reducing the risk of breaches.

Data Center Cities

Data centers play a key role in the development and training of AI language models, as they provide the massive amounts of electricity, storage, and cloud computing power needed to support their operations. Data centers are the backbone of the AI boom and, as such, cities around the world are positioning themselves as hubs for this critical digital infrastructure. These cities are tapping into the upside potential by expanding their data center capacity, attracting substantial investments and driving economic growth, from Europe to Latin America and Southeast Asia.

Ireland, with more than 80 data centers, sees these facilities as essential to its tech hub vision, though the rapid growth of AI workloads is straining the national grid with unprecedented energy demand. Porto Alegre, Brazil, launched Scala AI City in September 2024, starting with a $500 million investment that could expand to $90 billion, making it Latin America's largest AI-focused data center. Johor Bahru, Malaysia, is the fastest-growing data center market in Southeast Asia, boasting 1.6GW of capacity. In the UK, Northumberland will host one of Europe's largest AI data centers, backed by a $13.3 billion Blackstone investment. In the US, northern Virginia remains the "data center capital of the world," housing key facilities for AWS, Google Cloud, and Microsoft Azure. Other US cities seeing expansion include San Antonio, with a $482.6 million Microsoft investment; Racine, Wisconsin, where Microsoft is building a new AI data center; central Ohio, where AWS is adding $7.8 billion to the $10.3 billion it has invested since 2015; and Memphis, Tennessee, where xAI has made its home.

Hyperscale Water Usage

Hyperscale data centers, which power cloud computing and internet services, use vast amounts of water to cool their servers. These centers can consume 3 million to

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5 million gallons of water per day—about as much as a city with 30,000 to 40,000 people would use. AI demands even more power and water, and as more hyperscale data centers shift their workloads to AI, their resource consumption continues to rise. This growing water demand has raised concerns, especially in areas like Virginia, where data center water usage jumped from 1.13 billion gallons in 2019 to 1.85 billion gallons in 2023. As a result, major companies such as Amazon, Google, and Microsoft have started to report their water usage after years of keeping it private, and industries have implemented a new standard, Water Usage Effectiveness (WUE), to measure how efficiently these centers use water.

In Memphis, xAI's data center plans to draw more than 1 million gallons of water daily from the Memphis Aquifer to cool its servers. Similarly, Google's data center in The Dalles, Oregon, has nearly tripled its water use over the past five years and now consumes more than a quarter of the city's total water supply. According to Google's 2023 Environmental Sustainability Report, the company's data centers and offices used 5.6 billion gallons of water in 2022, a 20% increase from 2021. Though these numbers are significant, it's worth contextualizing that they still make up a comparatively small amount of the world's total daily water consumption, which is largely dominated by agricultural use. However, as the demand for cloud services fed by thirsty AI grows, so will the pressure on data centers to balance their operations with sustainable water practices.

Advanced Cooling Technologies

As hyperscale data centers continue to consume large amounts of water and AI workloads grow more intensive, traditional air-based cooling methods will likely become insufficient. In response, the industry is shifting toward advanced cooling technologies: Methods like direct-to-chip cooling and submersion cooling—where servers are immersed in nonconductive fluids—are becoming more efficient options.

The challenge is in using water efficiently. One solution comes from the US Department of Energy, which launched the COOLERCHIPS program in 2022, allocating $82 million to develop energy-efficient cooling technologies. The goal is to reduce cooling energy use to below 5% of a data center's total IT load, regardless of system density or location.

The COOLERCHIPS program has spurred collaboration between leading companies and research institutions, including HP, IBM, Nvidia, the US National Renewable Energy Laboratory, UC Davis, University of Florida, and University of Illinois. Some projects aim to dissipate up to 40 watts of heat per square centimeter, a significant challenge for modern data centers. Companies are bringing new liquid-cooling technologies to market. CoolIT, a leader in liquid-cooling for AI and high-performance computing, recently announced a new line of products tailored to support Nvidia's Blackwell AI platform. These include direct liquid-cooled servers and coolant distribution units designed to meet Blackwell's performance demands. In October 2024, Hewlett Packard Enterprise announced the industry's first 100% fanless direct liquid-cooling system for large-scale AI deployments. This system reduces the power needed for cooling each server blade by 37%, cutting down on utility costs, carbon emissions, and noise in data centers.

SCENARIO YEAR 2030

TWO FUTURES: THE COMPUTE CHALLENGE

The US stands at a pivotal moment in AI development: scaling compute infrastructure. With AI's vast appetite for processing power, the future of innovation, economic strength, and global influence hinges on our ability to expand the compute capacity needed to drive these advancements. Success means an era of abundant, affordable compute, fueling scientific breakthroughs, democratizing creativity, and accelerating medical progress. But if we hit a bottleneck, compute power will become scarce and fiercely contested, reserved for only the highest-paying applications, stifling innovation and widening the global gap in AI advancement.

1 THE AGE OF ABUNDANT COMPUTE

Noah sits in his home studio, directing his seventh feature film this year. No cameras, no crew, no million-dollar budget—just his imagination and an AI system running on cheap, abundant compute. He speaks into his microphone: "Adjust the lighting in scene four, make it more noir," and then he watches as the AI instantly reprocesses the entire sequence, transforming his sci-fi thriller's atmosphere in real time.

Across town, Dr. Williams runs a protein-folding simulation for the thousandth time today. Five years ago, such computational intensity would have cost millions of dollars. Now, thanks to breakthrough computing architectures that made AI processing as cheap as electricity, her small biotech startup simulates millions of molecular interactions daily. Last week, they discovered a promising treatment for Alzheimer's. Three other labs confirmed it within days—the kind of rapid verification that only becomes possible when compute constraints disappear.

The great compute scaling of the mid to late 2020s changed everything. Abundant nuclear and geothermal energy supply and AI-optimized chips pushed capacity well beyond the critical 130 GW growth threshold. But it wasn't just about adding power—new architectures made AI computation exponentially more efficient, creating a surplus of computational capability.

Now, high school students run complex climate models for science projects. Independent artists generate feature-length animations overnight. Small research labs simulate decades of climate change scenarios. The democratization of compute power has unleashed a creative and scientific renaissance. Every day, somewhere in the world, someone with a good idea can test it, simulate it, and bring it to life without worrying about computational costs.

2 HITTING THE COMPUTE BOTTLENECK

Noah sits dejectedly in his empty home studio. "Insufficient compute resources available in your tier." He speaks to his computer, "Just adjust the lighting in scene four." Nothing happens. Five years ago, he could have processed this in seconds. Now, independent creators like him can barely afford the most basic AI operations.

The world has hit a hard cap on compute scaling. Regulatory pressures and bureaucracy have strangled AI infrastructure expansion, turning computational power into a luxury commodity. Large companies devote their limited resources only to profitable applications, abandoning experimentation. Even text-based AI models strain budgets, while multimodal processing—combining images, video, and text—has become prohibitively expensive. Basic research has ground to a halt, with tasks like protein simulations now requiring funding on par with particle accelerator experiments. Innovation across medicine, entertainment, and science has slowed to a crawl.

The effects ripple through society. High schools have abandoned their AI curriculum—the computational costs of running even basic training exercises exceed most educational budgets. Medical researchers share limited computing time on aging infrastructure, often waiting months to test new hypotheses. What was once a revolutionary tool for scientific discovery has become another scarce resource, carefully rationed and jealously guarded.

Most concerning is the shift in AI alignment. With China dominating the compute landscape, one country's values and priorities increasingly shape AI development. US companies, struggling with limited resources, can't compete with the scale and scope of Chinese AI models. The dream of democratized AI has given way to a harsh reality: In the compute-constrained world of 2030, innovation follows the path of least computational resistance, and that path increasingly leads east.

PERSONAL COMPUTING

PERSONAL COMPUTING

Us as Input

We are increasingly merging with the technology we interact with, transforming into "invisible" accessories that seamlessly integrate with our devices. Traditional input methods like keyboards and mice are being replaced by more natural and intuitive modes of interaction, such as facial recognition, body movements, and eye tracking. Biometric data, including facial recognition and fingerprint scanning, is now commonly used for security, simplifying how we log in and authenticate our identities. Technologies that were once considered niche or assistive, like eye tracking, are now part of mainstream devices, allowing users to navigate screens with just their eyes. Voice input is also becoming a dominant method for communication with our devices, slowly replacing the keyboard for tasks like typing. Even skin input is on the horizon: Researchers at Cornell University have developed on-skin devices that enable direct interaction with technology. One such device, SkinPaper, uses silicone-treated washi paper that conforms to the body, allowing for simple on-skin interactions. This technology has broad potential applications, ranging from health monitoring to assistive technologies for individuals with disabilities. In a separate development, a team from Seoul National University and Stanford University has created a spray-on smart skin. Made from nanowires embedded in a polyurethane coating, this mesh adapts to the natural contours and wrinkles of the skin. It uses AI to recognize hand gestures and typing without the need for external devices like cameras or gloves, offering a more seamless way to control and communicate with devices. These advancements signify a shift in the way we interface with technology. By incorporating our bodies into the interface, these technologies open new possibilities for personal safety, health monitoring, and accessibility, all while making our interactions more intuitive and fluid.

AI embedded PCs

AI-powered PCs are emerging as the next evolution in personal computing, with companies like Intel, Microsoft, Qualcomm, Nvidia, and AMD at the forefront of integrating neural processing units (NPUs) directly into devices. This signifies a shift toward standalone in-device AI capabilities, allowing users to interact with advanced AI features without needing constant internet or cloud connectivity. The inclusion of NPUs in PCs will enable real-time processing of AI tasks, such as natural language understanding, computer vision, and machine learning, all within the device itself. These AI PCs are designed to enhance the user experience, not just by improving processing speed but by making interactions more intuitive and personalized. With an AI-powered PC, you could speak commands like, "Open last week's report," and the device would process and execute the request instantly without needing internet access. These PCs could also adapt to user habits, such as adjusting settings for comfort during long work hours, making interactions smoother and more responsive in real time.

In January 2025, NVIDIA announced Project DIGITS, a desktop-sized personal AI supercomputer, aimed at AI researchers, data scientists and students. There are also rumors of an upcoming NVIDIA AI PC processor called N1, which has not been confirmed at the time of this writing. Microsoft's newly redesigned Copilot+ offers another example of how these AI-driven systems can integrate voice and vision capabilities. With Copilot Voice and Vision, users can interact with their PC in more natural ways, such as speaking commands or having the system recognize and respond to what's displayed on the screen. Intel has plans to produce 40 million AI-enabled CPUs in 2024, increasing to 60 million in 2025. Meanwhile, Qualcomm and AMD are also developing AI PCs with NPUs focused on energy-efficient AI processing, essential for real-time interactions on portable devices. At Computex 2024, Nvidia hinted at new RTX AI PCs, potentially previewing upcoming Copilot+ systems from Asus and MSI. These systems are expected to feature Nvidia's graphics cards alongside AMD's latest Strix CPUs.

PERSONAL COMPUTING

Wearable Ecosystems

One of the biggest challenges with AR glasses is that integrating powerful computing directly into the glasses often results in a bulky, unattractive, and heavy design. This compromises both their aesthetic appeal and comfort, making widespread consumer adoption less likely. A potential solution lies in distributing the computing tasks across a network of interconnected devices. Instead of relying solely on the glasses to handle all functions, a system of complementary devices—a wearable ecosystem—could work together to share processing and sensory tasks.

By distributing the processing load and combining data from various sensors across multiple devices, users can enjoy a more sophisticated and efficient experience. The devices can share information on environmental factors or the user's activities, resulting in richer insights that wouldn't be possible with just one device. This modular approach also helps keep the glasses lightweight and more wearable, as they no longer need to house all the technology themselves. A practical example of these wearable ecosystems is Meta's Orion smart glasses. The Orion system consists of three key components: the AR glasses, a "neural wristband" for control, and a wireless compute puck that looks similar to a large phone battery pack. The glasses function independently of a smartphone or computer, but the puck is crucial for their operation. If the glasses and puck are separated by more than about 12 feet, the glasses become nonfunctional, illustrating how tightly integrated the components are in this wearable ecosystem.

Generative UI

Generative UI refers to the use of generative AI to automatically create, adapt, or personalize a user interface (UI) based on real-time inputs and context. This approach leverages context-aware computing to dynamically adjust the UI, making it more intuitive, responsive, and aligned with the user's specific needs. The interface could change based on factors like the user's environment, location, or activity, creating a seamless and efficient experience.

However, the true potential of generative UI goes beyond simple context-based adaptations; it reimagines the way we interact with applications altogether. Why rely on a static fitness app when a generative AI system can pull relevant data from multiple sources and create a personalized interface tailored just for you? Imagine a world where no two people have the same interface—where design and layout evolve based on individual preferences. One user might see structured menus, while another might navigate through visually rich, clickable images, depending on how they prefer to interact with information.

Now, imagine instead of switching between websites to shop for running shoes, you simply ask or type your query into a central system that generates the perfect interface, drawing from different sources instantly. Even more radically, the need for explicit, visible interfaces could disappear altogether. As multimodal AI models advance, they will understand and respond to natural language, gestures, and other inputs, allowing for seamless, interface-less interactions where users no longer need to rely on predefined screens or layouts. This opens up a future of fluid, personalized human-AI interaction unconstrained by traditional UI norms.

Accessibility Tech Goes Mainstream

Accessibility technologies, once designed specifically for people with disabilities, are increasingly being adapted for mainstream use, leading to innovations that benefit a much wider audience. Devices like OrCam MyEye, originally created to help the visually impaired by reading text and recognizing faces, now serve non-accessible applications such as hands-free navigation and industrial information access. Eye-tracking technology, developed to help those with mobility issues navigate a computer screen, is being integrated into mainstream applications, enabling anyone to navigate digital interfaces without physical touch. Advanced hearing aids

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have evolved beyond simple sound amplification: Modern versions of these devices feature AI-powered sound processing, which helps improve speech recognition in noisy environments, making them desirable to a broader audience. There are also tactile screen technologies originally designed to allow blind users to read Braille digitally, but that now have the potential to be adapted for more widespread use, such as providing tactile and haptic feedback on touchscreen devices. Accessibility technology is no longer limited to a niche market—it can be adapted to help all people see, hear, and communicate more effectively, broadening their impact far beyond their original purpose.

Wearable Intelligence

Wearable AI refers to devices that integrate artificial intelligence into everyday accessories, enabling more intuitive and personalized interactions. These devices, such as smartwatches, glasses, and rings, use AI to process data and assist users in real time. One recent example is Humane AI's AI Pin, a small device that attaches to clothing and functions as a personal assistant. The pin, launched in 2024, supports voice commands and hand gestures, projects information using a laser display instead of a screen, and includes a camera for photos and visual recognition. However, the Humane AI Pin has faced criticism and a lackluster consumer enthusiasm for inconsistent AI responses, slow processing, and limited functionality. And this concept isn't new; Microsoft Research introduced Skinput in the 2010s, which, like the Humane AI pin, used the skin as an interface but didn't make it to market due to fidelity issues. Other AI wearables, like the Samsung Galaxy Ring, Meta's smart glasses with Ray-Ban, and AI-powered watches, are exploring different ways to incorporate AI into daily accessories while addressing issues like power consumption and internet dependency.

High power consumption is a major energy efficiency challenge for wearable AI. Purdue University researcher Shreyas Sen is developing solutions inspired by the human nervous system to overcome these limitations. His research focuses on chips that enable AI wearables to function offline, reducing energy needs. Sen's team is creating "in-sensor analytics" chips that interpret only necessary data for specific tasks. These chips use electro-quasistatic signals, transmitting information 100 times more efficiently than Bluetooth or Wi-Fi. By creating an artificial "peripheral nervous system," Sen envisions AI wearables performing complex tasks without needing frequent charging or constant internet access.

Flexible Displays

Flexible displays have been an exciting prospect for years, yet widespread consumer adoption has been slow. But 2024 may have been a turning point. One recent example is Samsung's "flex in and out" display technology, increasing the durability and usability of foldable screens. Samsung's US patent "Electronic Device Including Flexible Display" outlines a foldable device with an advanced hinge system, which dynamically adapts to various folding angles to improve both flexibility and audio performance. Samsung has also incorporated a photocurable resin in the adhesive layers, boosting the display's resilience to repeated folding—an essential step in addressing durability issues that have previously hindered flexible screens.

Developing highly flexible displays also depends heavily on new material innovations. Scientists are focusing on 2D materials like graphene, hexagonal boron nitride (h-BN), and transition metal dichalcogenides (TMDs), each offering unique benefits for flexibility and durability. Graphene's excellent conductivity and flexibility, TMDs' light-emitting properties, and h-BN's stability and insulation potential make them ideal candidates for flexible OLED displays. Companies are incorporating these into components such as thin-film transistors, transparent electrodes, and protective layers. But significant challenges remain for 2D materials, particularly in achieving

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uniform quality, scalability, and stability for mass production. Ongoing research aims to refine these processes to produce durable, scalable displays for smartphones, wearables, and foldable laptops. If successful, 2D materials could reshape the industry, enabling high-quality, flexible displays for a new generation of consumer electronics.

Smart Textiles

Smart textiles, powered by multimaterial fibers, are transforming how we think about clothing and wearables, enabling fabrics to become dynamic, responsive, and even intelligent. These fibers—long, thin strands engineered to conduct electricity, emit light, and sense environmental changes—are making it possible to integrate electronic functionality directly into fabrics. By weaving such fibers into garments, researchers are developing textiles that can monitor health, track movement, or even change color or shape in response to stimuli. Researchers recently developed a soft, flexible fiber that interacts with the human body to perform wireless energy transfer and sensory processing without requiring rigid chips or batteries. These fibers can light up in response to touch and offer various forms of feedback, making them a versatile component for digital interactions. Such innovations highlight the potential for creating chipless textile electronics that could redefine wearable tech by eliminating the need for bulky hardware.

Another significant challenge in smart textile development has been the scaling of sensor integration, particularly when it comes to making reliable connections between rigid electronic components and soft fabrics. However, recent research into distributed sensing along fibers has made substantial progress in overcoming this obstacle. A prototype garment using helical auxetic yarn sensors demonstrates how strain can be measured along multiple regions of a single fiber, accurately monitoring joint movements with minimal error. This represents a breakthrough in making smart clothing capable of tracking complex biomechanical data while remaining comfortable and unobtrusive.

PERSONAL COMPUTING

Haptic Holography

Haptic holography merges holography with haptic feedback, enabling users to see, feel, and interact with 3D virtual objects in midair using their bare hands. This approach lets users manipulate virtual objects without physical devices, using ultrasound waves to create the feeling of holding and touching a projected object. Current research in this area includes the University of Glasgow's "aerohaptics" system, which uses controlled air jets to simulate touch sensations, enabling interaction with holographic objects without physical devices. Meanwhile, researchers at UC Santa Barbara have uncovered a new phenomenon fundamental to developing holographic haptic displays, by utilizing focused ultrasound waves in air to create tactile feedback. However, the current technology faces limitations. Advanced imaging and simulations reveal that these haptic feedback systems generate shock waves in the skin, reducing the precision of touch sensations. To advance holographic touch technology, scientists must develop new methods to either mitigate or harness these shock wave effects. As the field progresses, haptic holography has the potential to transform various industries, including virtual and augmented reality, remote surgery and medical training, industrial design and prototyping, and education and interactive learning.

Context-Aware Earwear

Context-aware audio interaction integrates both audio and visual inputs to create smarter, more intuitive ways for users to interact with their devices. Voice is becoming the primary interface for many AI-driven systems, thanks to advancements in natural language processing, allowing for natural communication. However, these interactions require a deeper understanding of context to be truly effective. For example, a request made in a private setting might need a discreet response through earphones, while the same command in a public space could be handled differently. Combined visual and audio input is becoming essential to provide this context, enhancing how devices understand and respond to their users. One way is by integrating cameras into earbuds for various uses, like Meta's "Camerabuds," which include AI-driven object recognition and real-time translation capabilities. Apple is reportedly working on similar technology with additional health monitoring features, showing the potential for multifunctional, context-aware devices. Huawei is also advancing this trend by filing a patent for earbuds with cameras designed for pedestrian safety. These devices would use AI to detect approaching objects or intersections, alerting the wearer to potential hazards—a safety feature that could be especially useful for people navigating busy urban environments. At the University of Washington, researchers have developed an AI system that lets users "enroll" a speaker simply by looking at the person briefly while wearing camera-equipped earphones. The system isolates and plays back only the enrolled speaker's voice, even in noisy environments. This combination of audio and visual inputs allows for real-time, focused listening, improving the user experience in dynamic settings like busy streets or crowded events.

Spatial Audio and 3D soundscaping

Spatial audio and 3D soundscaping involve creating a three-dimensional sound environment that surrounds the listener, enhancing the sense of immersion. This technology positions audio sources in virtual space, making it seem as if sounds are coming from different directions and distances. Using advanced algorithms and binaural audio techniques, spatial audio mimics real-world sound behavior, making it ideal for gaming, virtual reality, and other immersive experiences. A core concept in this technology is the head-related transfer function, which explains how humans perceive the direction of sounds based on differences in timing and frequency as they reach each ear. By digitally replicating these auditory cues, engineers can create a sense of depth and directionality, making the listener feel as if sounds are moving around them. Directional speakers are of-

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ten used to further enhance spatial audio, enabling precise sound targeting in specific areas or to individual listeners. These speakers contribute to dynamic sound environments where sound sources can appear to move around the listener, adding to the immersive experience. Technologies like Dante (Digital Audio Network Through Ethernet) help manage and route audio signals efficiently in complex systems, making it easier to control and direct sound within 3D soundscapes. There are several software platforms that also assist in creating and processing 3D audio. For example, Waves Nx simulates three-dimensional sound through stereo headphones, allowing users to experience immersive soundscapes even in everyday audio settings. As a result, spatial audio and 3D soundscaping have become essential tools in delivering more engaging and realistic sound experiences across various fields.

Neuromorphic Hardware for Audio Applications

Neuromorphic hardware for audio applications refers to specialized hardware that mimics the neural structure of the brain, enabling energy-efficient, always-on audio processing. This technology is ideal for battery-powered devices requiring low power consumption, real-time processing, and on-device computation, offering significant advantages over traditional audio processing methods. By processing audio data locally, neuromorphic hardware enhances privacy and reduces latency, making it perfect for edge devices like smart speakers, earbuds, and security systems. Additionally, neuromorphic hardware excels at pattern recognition, enabling efficient tasks such as keyword spotting, environmental sound classification, and acoustic event detection. This makes it an excellent fit for applications in voice-activated devices, industrial monitoring through vibration analysis, and underwater acoustic detection. A leading example of neuromorphic audio hardware is SynSense's Xylo Audio platform. Built on the Xylo neuromorphic inference core, this ultra-low-power platform supports a variety of audio applications, from in-home event monitoring to underwater acoustic detection. It enables intelligent audio-driven features in battery-powered edge devices, offering commercial and research partners new opportunities to integrate advanced audio capabilities into their products.

SCENARIO YEAR 2032

HAPTIC HOLOGRAPHY

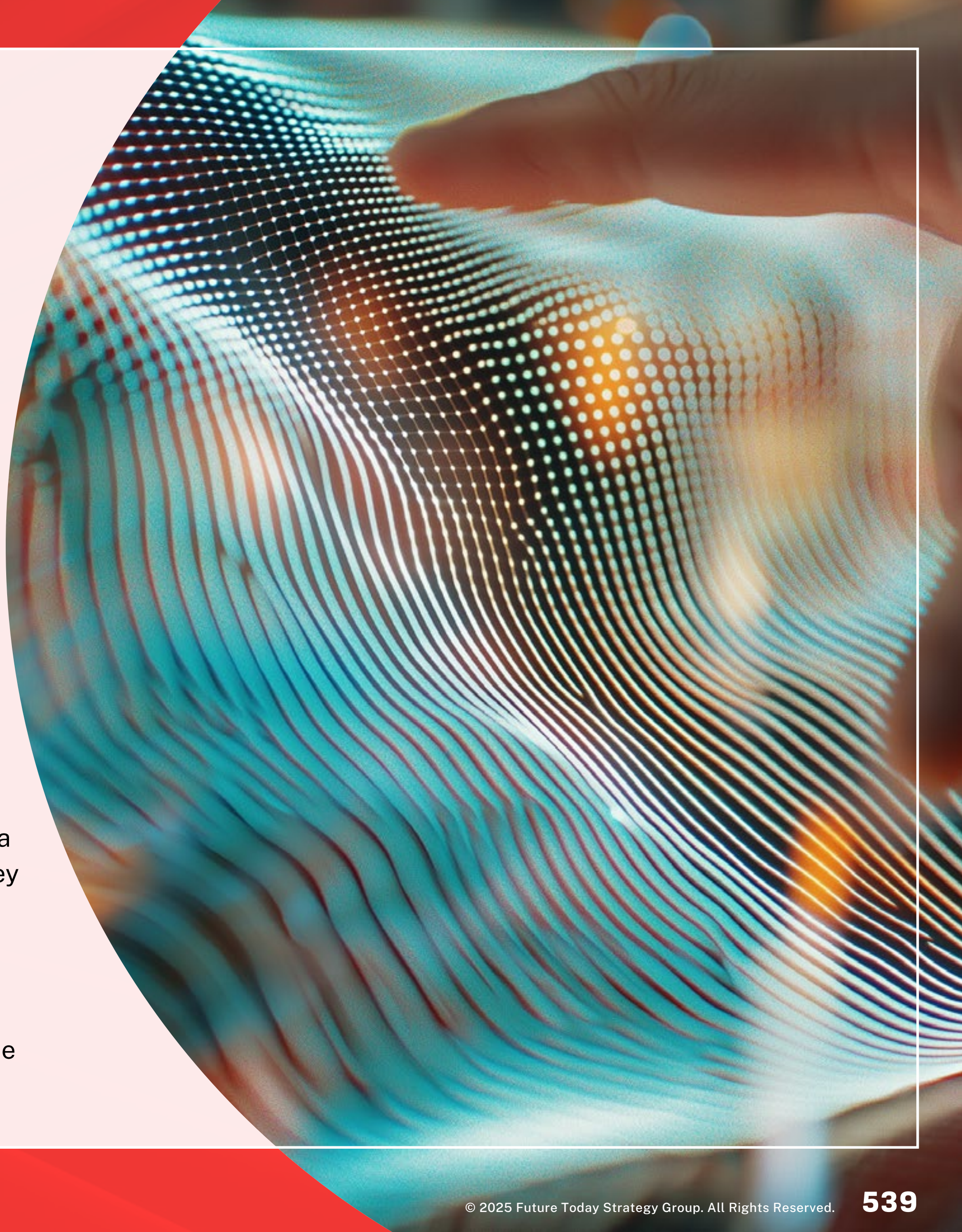
By 2032, passwords have evolved far beyond simple text or biometrics. Now, unlocking devices requires a completely unique, tactile interaction with invisible, holographic objects—an experience that feels astonishingly real but is visible only to the senses. Haptic holography combines 3D holograms with touch feedback, letting users feel virtual objects as if they're real. Using technologies like ultrasound and air jets, it creates sensations like pressing, holding, or manipulating items in midair. Haptic holography has changed device authentication: Not only do users need to "feel" the right object, but they must also perform a specific, predetermined action with it.

The air before Sarah's phone flickers slightly, and though no image appears, she reaches out, instinctively feeling for something unseen. A burst of precisely calibrated sound waves and air pressure creates a sensation in her palm: her grandpa's watch. Sarah had spent countless hours running her fingers over its band and its smooth face. Now this virtual version feels exactly the same—the slight chip on the face from when Grandpa nicked it with a bowling ball, the loose link from the years of taking it off at night and putting it back on again in the morning.

The security sequence requires her to manipulate this phantom watch in ways only she would know—she "winds" the small knob on the side of the haptic hologram watch two times clockwise and once more counterclockwise.

Others might see Sarah standing there with her fingers seemingly dancing through empty air, but she's working through a sophisticated authentication cadence that's unique to her muscle memory. Even if someone recorded her movements, they couldn't replicate the exact pressure she applies to the haptic hologram, the precise angles of manipulation, the specific timing between actions—all deeply encoded in her nervous system through years of handling the real watch.

The beauty of the system lies in its invisibility and intimacy. These haptic holograms respond only to her touch, creating a personal choreography of pressure points and motion that's impossible to forge. It's not just what Sarah does—it's how she does it, the emotional memory built into each gesture, the unique way her fingers remember this treasured object.



BIOLOGICAL COMPUTING

BIOLOGICAL COMPUTING

Neuromorphic Computing

The most energy-efficient computer in existence today is the human brain. Unlike traditional von Neumann architecture, which requires constant data transfer between memory and processor—consuming both time and energy—the brain stores and processes information simultaneously, with remarkable efficiency. This has inspired researchers to rethink computing architectures, leading to the development of neuromorphic computing, which is an umbrella term for computers that aim to mimic the brain's structure and functionality. In 2024, Intel announced the Hala Point system, the world's largest neuromorphic computer. The parallel-processing system is powered by Intel's Loihi 2 processor, enabling 1.15 billion artificial neurons that will be used to address scientific challenges in areas like device physics and informatics, solving problems where traditional AI hardware struggles, particularly at scale.

Sydney-based startup BrainChip recently unveiled the Akida Pico, a neuromorphic chip designed specifically for devices at the extreme edge, such as mobile phones and wearables, where power limitations are critical. Additionally, German startup SpiNNcloud Systems introduced a hybrid computing platform that integrates traditional AI accelerators with neuromorphic computing. The systems, available in various configurations, include a flagship model capable of simulating 10 billion neurons—approximately one-tenth the capacity of the human brain—bringing brain-inspired computing closer to practical applications.

Organoid Intelligence

In 2023, researchers at Johns Hopkins University outlined a vision for biocomputers powered by human brain cells in a paper published in Frontiers in Science. Led by Thomas Hartung, the team presented a roadmap for "organoid intelligence," aiming to develop biological computing using 3D cultures of human brain cells. These tiny 3D organoids, no larger than a pen tip, contain neurons and circuitry capable of supporting basic functions like learning and memory. Unlike neuromorphic computers that mimic brain function using silicon, organoid intelligence utilizes actual human biology for computing operations. Although traditional computers can process calculations much faster than humans, human brains excel at complex decision-making tasks, such as distinguishing between a dog and a cat. Implementing AI on organoids could be crucial for achieving human-like complex decision-making abilities in machines.

This technology is already being adopted for commercial and research purposes. A Swiss company, FinalSpark, offers cloud-accessible computing services using real organoids through its Neuroplatform. The system, which has been functioning continuously for more than four years, is comprised of 16 organoids, maintained in microfluidic incubators at body temperature (37°C). These organoids can transmit and receive electrical signals, learn, and perform tasks through electrical stimulation. Researchers can employ chemical stimulation, such as dopamine release, to "reward" the organoids. Designed for biocomputing research and wetware computing experiments, the platform includes a Python-based API to interact with these organoids. FinalSpark asserts that its system could be up to a million times more energy-efficient than conventional computers.

DNA Storage and Compute

Researchers are exploring DNA computing as an alternative storage medium to resource-intensive data centers, due to DNA's immense storage capacity and long-term stability. The primary challenge has been efficiently storing, retrieving, and computing data using DNA, where information is encoded in nucleic acids rather than binary code, which has hindered the full realization of DNA's potential as a storage medium. Until recently, DNA technology was viewed as useful mainly for long-term data storage, with limited potential for performing all the functions of electronic computing in a repeatable, programma-

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ble manner. This has changed with recent research from North Carolina State University and Johns Hopkins University: Researchers have developed a DNA-based system capable of performing a full range of data storage and computing operations. The breakthrough system can store, retrieve, compute, erase, and rewrite data using DNA as the medium, demonstrating that DNA technologies can now rival traditional electronic systems in versatility. This development marks a significant step forward in DNA computing, as previous technologies could only complete some, but not all, of these operations. It shows that DNA-based computing and data storage may one day provide a viable and efficient alternative to electronic devices, especially for long-term and large-scale data management.

Living Wearables

A “living wearable” is a device that blends living biological elements with traditional wearable technology, often using synthetic biology. These devices combine the features of regular wearables with the unique abilities of living organisms, allowing the wearable to interact with the human body and environment in ways that traditional wearables cannot. By integrating living biological components—like engineered bacteria or cell-free synthetic circuits—into flexible substrates and textiles, these devices can monitor physiological and environmental changes in real time, broadening applications for health care, environmental safety, and even national security. One major benefit is noninvasive health monitoring, where biosensors within these wearables can detect specific markers or pathogens, including disease indicators or environmental toxins, by using synthetic biology techniques like engineered biological circuits. For example, a face mask with embedded CRISPR technology has been developed to detect SARS-CoV-2 by merely pressing a button. This capability, offering laboratory-level detection at room temperature without complex procedures, demonstrates how living wearables can provide immediate, precise diagnostic capabilities.

Living wearables also open the door to self-sustaining systems for prolonged use, which is especially relevant in settings where traditional power sources are limited, such as space exploration. Photosynthetic wearables, for instance, use cyanobacteria to produce oxygen, potentially supporting life in closed environments or enabling sustainable energy production for bio-powered devices. Additionally, skin patches that incorporate living cells could not only monitor health markers but also release therapeutic compounds in response to physiological needs.

Implantable BCI

Recent developments in implantable brain-computer interfaces (BCIs) have created new possibilities for enhancing human-machine interaction, particularly in the field of health care. In 2024, Neuralink successfully implanted its BCI device, dubbed “Telepathy,” in a second patient, Alex, following its first test on Noland Arbaugh, a man paralyzed from the neck down. This new implant enabled Alex to break world records in BCI cursor control. Despite significant advances, Neuralink encountered early technical challenges and continues to face skepticism. In Arbaugh’s case, 85% of the device’s flexible threads retracted from his brain within a month after implantation, which affected the overall performance of the device. Another significant milestone comes from UC Davis Health, where researchers developed a BCI capable of translating brain signals into speech with 97% accuracy. This technology was successfully implanted in a patient with ALS, enabling near-fluent communication. Also significant: Synchron implanted an ALS patient with its BCI technology, and the patient was then able to interact with Amazon’s Alexa device to control his environment. These advancements demonstrate the profound potential to transform the quality of life for individuals with neurodegenerative diseases or severe paralysis, offering them innovative methods to communicate, interact, and engage with the world. Beyond accessibility, BCIs could revolutionize human-machine interaction

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by drastically increasing the bandwidth between the brain and digital systems, potentially by a factor of 1,000 or more. This technology holds the promise not only of enhancing cognitive capabilities but also enabling ultra-fast, seamless communication between people, pushing the boundaries of how we connect and collaborate.

External BCI

While brain-computer interfaces (BCIs) have the potential to drastically improve mobility and communication for people with disabilities, most consumers are unlikely to embrace implanted devices in the near future. This hesitation suggests that noninvasive BCIs will dominate the commercial market in the short term. Noninvasive BCIs are appealing for being cost-effective, safe, and accessible to a broad range of users. However, because these systems record signals from the scalp rather than directly from the brain, their signal quality can be limited. But recent breakthroughs are addressing these limitations. Researchers at Carnegie Mellon University demonstrated a novel approach to noninvasive BCIs by using focused ultrasound stimulation in combination with a wearable electroencephalogram (EEG) device. Their study, involving 25 human subjects, is the first of its kind to integrate focused ultrasound stimulation for bidirectional BCIs—meaning it can both encode and decode brain waves using machine learning. The technique targets specific neural circuits, enhancing both signal quality and the overall performance of noninvasive BCIs. This work could significantly boost the capabilities of external BCIs, making them more viable for broader applications. Last year saw a growth in noninvasive wearable BCI technology investment, with companies exploring EEGs, ultrasounds, and magnetic stimulation. Magnus Medical, for example, has developed transcranial magnetic stimulation to treat major depressive disorder. While these wearable BCIs provide less insight into the deeper brain regions compared to implanted devices, their ease of use and noninvasive nature make them a promising avenue for wider adoption in both health care and consumer markets.

SCENARIO YEAR 2040

LIVING TACTICAL

Through the ruins of a darkened city, US troops move like shadows. Each soldier wears a neural helmet—a living wearable that meshes with their body, monitoring vitals and enhancing senses. These bio-integrated devices link to the External Sensory Network, connecting them to silent drones patrolling overhead. The swarm maps the battlefield in real-time, feeding environmental data directly to the soldiers. To the enemy, they are invisible; to each other, they are omniscient.

A gunshot cracks the night. Within seconds, the drones pinpoint the shooter through audio triangulation. The helmets respond, releasing precise doses of performance enhancers to steady hands and sharpen focus. If chemical weapons appear, the neural interface stands ready to inject countermeasures directly into bloodstreams. The soldiers adjust their approach wordlessly, human and machine moving as one.

The drones unleash another tactic: They project phantom sounds across the battlefield—helicopter rotors, tank treads, marching boots. The enemy scatters, chasing ghosts. The helmets pick up on rising hostile heart rates as confusion spreads.

Silent, calculating, alive, the helmets make their soldiers both human and something more. Each step forward is guided by invisible maps and bio-data; every breath monitored, every heartbeat measured. The troops close in on their objective as the enemy falls further into the illusions, fearing threats that aren't real, trusting senses that betray them.

In this new warfare, victory belongs to those who master the symphony of combat. Every footstep tells a story, every echoed command reveals a position, and sound itself becomes both weapon and shield. The soldiers advance through their acoustic realm, invisible in the darkness but seeing everything through the perfect clarity of sound.

QUANTUM COMPUTING

“

Significant adoption of quantum computers is around the corner. Quantum is one of the biggest, most important technological races of our generation.

Itamar Sivan, Co-founder & CEO of Quantum Machines

QUANTUM COMPUTING

Quantum Advantage

When Google unveiled Willow, many overstated its capabilities. While Willow achieved key breakthroughs—such as surpassing the threshold for quantum error correction and improving coherence times—it did not demonstrate quantum advantage. Quantum advantage refers to the theoretical point where quantum computers can outperform classical computers in solving specific tasks, such as optimization, simulations, or computations. When achieved, it will mark a major milestone in quantum computing; at that point, these machines could tackle problems that are currently beyond the reach of even the most powerful classical supercomputers. But the big hurdles in the way include developing quantum hardware and algorithms that surpass classical methods in both speed and accuracy.

For now, we are in an intermediate stage that is often called quantum utility, where quantum systems begin to outperform classical computers on tasks related to quantum mechanics itself, such as simulating quantum circuits. And while quantum advantage has yet to be conclusively demonstrated on a real-world problem, several significant advancements have brought us closer to this goal. For example, Fujitsu and Osaka University's Center for Quantum Information and Quantum Biology achieved a major milestone by demonstrating that a quantum computer could estimate material energy in just 10 hours—a task that would take a classical computer five years. This was achieved using only 60,000 qubits, fewer than previously believed necessary for fault-tolerant quantum computations. Additionally, companies like Kipu Quantum and Pasqal are advancing quantum optimization and scalability. Kipu Quantum tested the largest quantum optimization problem on a 156-qubit processor, while Pasqal successfully loaded over 1,000 neutral atoms in a single shot, a critical step toward scalable quantum processors and eventual quantum advantage.

Global Quantum Competition

The global quantum competition is intensifying as major powers race to dominate the field, seeking both strategic and economic advantages. The stakes are high: the first country to harness quantum computing at scale could potentially crack existing encryption methods, disrupt secure communications, and develop highly precise quantum sensors, reshaping military, cybersecurity, and economic landscapes. China and the US are the main players in this race, each with distinct strengths. China excels in quantum communication, having built the world's longest quantum key distribution network between Beijing and Shanghai and launched the Micius satellite for secure quantum communication. However the US still holds the advantage in quantum computing hardware and practical applications. Patent filings tell a similar story: China dominates in domestic quantum communication and sensing patents, while the US leads in quantum computing patents. Other nations are also making moves: Saudi Arabia is set to deploy its first quantum computer in collaboration with French company Pasqal, aiming to install a 200-qubit machine by 2025. Japan is investing heavily as well, with plans to develop a 10,000-qubit quantum computer in partnership with IBM, supported by a $31.7 million government investment. As the quantum landscape evolves, the stakes are high: The first country to achieve quantum breakthroughs will not only gain a military and strategic advantage but also stand to capture a market projected to be worth $1 trillion by 2035.

Hybrid Quantum-Classical

Hybrid quantum-classical computing is emerging as a solution to overcome the current limitations of quantum technology. Instead of replacing classical computing, quantum computers are being integrated with classical systems to solve complex problems more efficiently than either could on its own, and allowing for computations that were previously unachievable. This partnership aims to harness the strengths of both technologies to push beyond

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the computational limits of traditional systems. IBM calls this concept "quantum-centric supercomputing," and several leading supercomputing centers, such as Germany's Jupiter, Japan's Fugaku, and Poland's PSNC, are preparing to incorporate quantum-computing hardware into their systems. IBM's Heron system, with 156 qubits and 5,000 gates before errors occur, is an early step in this direction. By 2025, IBM plans to introduce its Flamingo system, which will connect seven quantum chips, expanding the total qubits to more than 1,000. Such advancements are geared toward optimizing quantum systems for parallel workloads alongside classical computing systems, making the best use of each technology's strengths. Hybrid quantum-classical systems are expected to play a critical role in advancing fields like drug discovery, materials science, and cryptography by running computations that exceed the capabilities of even the most powerful classical supercomputers.

Circuit Knitting

One of the key developments in the space of hybrid quantum-classical is a technique called "circuit knitting." This method divides a single quantum problem into multiple smaller quantum problems that can be processed in parallel by quantum processors. Classical computers then "knit" the results of these smaller quantum calculations together to produce the final solution. By incorporating classical and quantum processes in tandem, the system efficiently solves complex quantum circuits despite the limitations of current quantum hardware. This addresses the ongoing issue of qubit scarcity, which remains a significant barrier to the widespread use of quantum computers: Hybrid approaches like circuit knitting help by breaking down large quantum circuits into manageable subcircuits that fit onto smaller quantum devices, though at the cost of added simulation overhead. Circuit knitting also explores the use of classical communication to improve the efficiency of these local quantum computations.

Scaling the Qubits

Quantum computers, while promising, have not yet demonstrated practical advantages over classical supercomputers. The main issue is the limited number of qubits and their vulnerability to environmental noise, which easily disrupts their quantum state. This noise causes computational errors, forcing researchers to dedicate a large number of qubits solely to error correction. Consequently, a substantial increase in the number of qubits is needed before quantum computers can become truly useful for real-world applications. Leading tech companies are racing to achieve this goal. IBM, for instance, has announced plans to build a 100,000-qubit machine within the next 10 years. The vision is to combine the power of quantum systems with classical supercomputers to drive breakthroughs in areas such as drug discovery, fertilizer production, and battery performance. Similarly, Google has set an ambitious target of scaling up to a million qubits by the end of the decade. However, due to error-correction needs, only about 10,000 of those qubits would be available for actual computation. IonQ, a Maryland-based company, aims to achieve 1,024 "logical qubits" by 2028, with each logical qubit being constructed from 13 physical qubits for robust error correction.

It should be noted that focusing solely on the number of physical qubits can be misleading. The way qubits are constructed greatly influences their performance, particularly in terms of their resistance to noise and their operational stability. For this reason, companies often measure quantum performance through metrics such as "quantum volume" and "algorithmic qubits." These metrics provide a more accurate representation of how well a quantum computer can perform meaningful computations, considering both the quality and scale of the qubit system.

Quantum Error Mitigation

Quantum error mitigation refers to techniques that reduce the impact of errors in quantum computations without completely eliminating them. These methods are essential for current quantum devices, often

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called noisy intermediate-scale quantum devices, which lack the hardware needed for full error correction. The goal is to improve the accuracy of results despite the presence of noise; instead of relying on hardware changes, error mitigation is done at the software level, after a quantum circuit has been executed. IBM has demonstrated a practical approach to error mitigation: Its method involves running quantum programs and analyzing how noise affects the outputs. From this analysis, a noise model is created to simulate the system's imperfections, and then classical computing techniques are applied to estimate what the results would have been without the noise. This process allows for more accurate outputs from noisy quantum circuits. Error mitigation techniques like these are crucial for making near-term quantum devices more reliable, bridging the gap until full error correction becomes feasible.

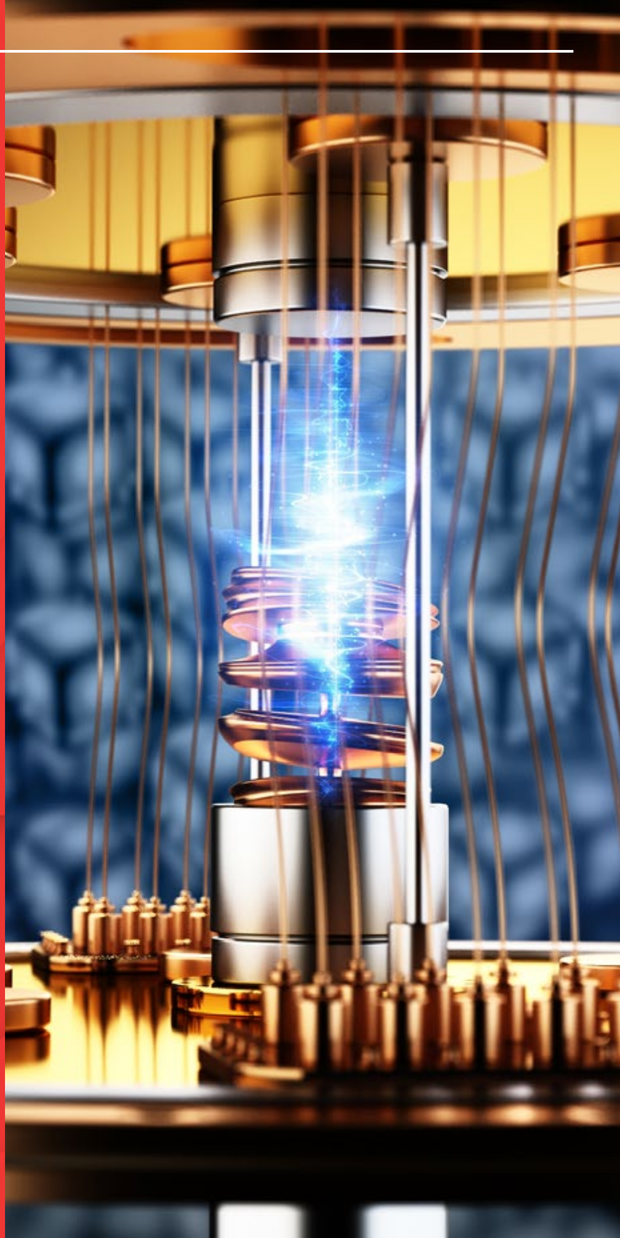
Quantum Error Correction

Unlike error mitigation, which only handles errors after the fact, quantum error correction (QEC) is a critical method that detects and corrects noise during the computation process. This allows quantum computers to run more reliably by fixing mistakes in real time. QEC is more versatile because it doesn't require a specific noise model to work, and it scales effectively even as quantum circuits become more complex. However, it comes with a significant cost—QEC requires many more qubits, additional connections between them, and more operations. For each qubit involved in a calculation, many more qubits are needed for error correction.

Google's Willow chip, announced in December 2024, reached a key milestone by achieving below-threshold error correction, a critical step toward scalable quantum computing. It demonstrated that error rates halve exponentially as more physical qubits are added, enabling faster error correction than error accumulation. This breakthrough paves the way for reliable, large-scale quantum systems capable of performing complex computations, with real-time error correction ensuring integrity throughout operations. Researchers elsewhere also made progress. At the Korea Institute of Science and Technology, they have developed world-class QEC technology with a fault-tolerant architecture that achieves a photon loss threshold of up to 14%, the highest currently known. Their method is also more resource-efficient compared to other techniques, using less compute power and energy to achieve the same level of photon consumption.

Quantum Noise Reduction

Quantum noise reduction aims to prevent errors in quantum computations by improving the underlying hardware and control systems. Unlike error correction, which addresses errors after they occur, noise reduction works at the hardware level to reduce the likelihood of errors arising in the first place. This approach includes techniques like dynamic decoupling and



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improved qubit designs, which enhance the stability of qubits and minimize error rates. By focusing on reducing the occurrence of errors, noise reduction can be combined with other error-handling methods, such as error correction or error mitigation, to further improve quantum computation accuracy.

Google Quantum AI has made significant progress in this area by developing a quantum memory system that operates with error rates below the critical threshold needed for effective quantum error correction. Their system's logical qubit outperformed its best physical qubit by more than double, highlighting the enhanced stability and reliability achieved through advanced error suppression techniques. This breakthrough demonstrates the potential for scaling up quantum computing systems while maintaining low error rates.

Researchers at the University of Trieste are also working on a quantum noise reduction method that involves linking the main quantum system to an extra, adjustable system. By carefully designing how these systems interact, they can create a special state that protects the quantum information, making it more stable and less likely to be affected by errors. This approach helps improve key quantum states, like NOON states, where particles, like photons, exist in a superposition of being entirely in one place or another at the same time. These states are key to making precise quantum measurements and advancing quantum computing, but they are fragile, so researchers are developing methods to protect them from errors and environmental noise. The technique could be applied using certain types of interactions between particles, and it shows the range of creative solutions being developed to reduce noise and make quantum systems more reliable.

Quantum Sensing

Quantum sensing leverages the unique properties of quantum systems, such as entanglement, quantum interference, and quantum state squeezing, to achieve highly precise measurements. This enables the detection of extremely small changes in physical quantities, like electric and magnetic fields, down to the atomic level. Such precision opens the door to a wide range of applications, and these quantum sensors are already being used to advance biomedical research. For example, wearable sensor helmets are being developed to record brain activity with unprecedented precision.

A significant advancement in quantum sensing comes from an international team at Forschungszentrum Jülich and the IBS Center for Quantum Nanoscience. They have developed a quantum sensor capable of detecting tiny magnetic fields at the atomic scale. This sensor, based on a single molecule, functions like an MRI for quantum materials, providing an unparalleled level of spatial resolution. Unlike traditional sensors that depend on defects in crystals to detect fields, this new tool uses a more direct approach, allowing scientists to study electric and magnetic properties with greater precision. In another advancement, physicists at Harvard have made progress with "spin squeezing," a quantum technique that enhances the precision of quantum sensors by reducing uncertainty in measurements. Traditionally, spin squeezing required complex interactions between many atoms, but the Harvard team discovered a method to achieve this using natural magnetism, such as that found in everyday fridge magnets. This could lead to more portable and practical quantum sensors, with potential applications in biomedical imaging and atomic clocks, further advancing the field of quantum sensing.

Encryption Breaking Quantum

Recent developments in quantum computing have sparked concern over the potential impact on global cybersecurity. Chinese researchers recently claimed to have used D-Wave's quantum annealing systems to crack widely used encryption methods like RSA, sparking headlines about the end of modern cryptography. Published in the Chinese Journal of Computers, the paper outlined their approach to breaking

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encryption, suggesting quantum computers could accelerate attacks on symmetric encryption systems as well. However, these claims were significantly overhyped. While there have been advancements in using quantum computing for cryptographic attacks, this progress is incremental rather than revolutionary and doesn't yet pose an immediate, large-scale threat to current encryption systems. Still, the potential consequences of a true breakthrough in quantum code-breaking would be huge, making even these incremental advancements noteworthy.

Meanwhile, researchers are continuing to improve quantum algorithms with the goal of making quantum code-breaking more feasible. At MIT, a team has proposed an optimized version of Shor's algorithm, which is specifically designed for breaking encryption. Introduced in 1994, the algorithm demonstrated that quantum computers could, in theory, break RSA encryption far faster than classical computers. However, the challenge remains in building quantum computers large and stable enough to run this algorithm effectively. MIT's new approach improves upon previous designs by integrating a faster algorithm from NYU with more efficient memory use. This makes the quantum circuit smaller and less noisy, bringing the practical application of quantum computers for encryption-breaking one step closer. While this improvement is promising, it will still take time to determine whether these advancements can truly challenge today's encryption methods.

Post-Quantum Cryptography

While white hat teams attempt to break encryption, other researchers are working on developing quantum-safe cryptography to replace the widely-used encryption methods that secure much of today's digital information. Traditional encryption, such as RSA or ECC (Elliptic Curve Cryptography), relies on the difficulty of factoring large numbers or solving discrete logarithms—problems that quantum computers could solve exponentially faster using algorithms like Shor's. This means that sensitive data, from financial transactions to government communications, could become vulnerable to attacks. In August 2024, the US National Institute of Standards and Technology approved three post-quantum cryptography algorithms for mainstream development. These algorithms are designed to secure a broad range of data, from private emails to online transactions, against the potential threat posed by quantum computers, which could break current encryption methods within the next decade. IBM, which developed two of the approved algorithms, is now integrating these solutions into its products, including IBM z16 and IBM Cloud, as part of its broader Quantum Safe roadmap. IBM has also introduced Quantum Safe Transformation Services to assist clients in transitioning to quantum-safe technologies. In addition, the company has developed the Cryptography Bill of Materials, a standard for managing cryptographic assets across software and systems, which aims to enhance the security of digital infrastructure.

While quantum computers are not yet capable of breaking encryption, the data being encrypted today could be harvested and stored by adversaries, only to be decrypted once quantum technology matures. This threat is known as "harvest now, decrypt later." Without post-quantum cryptography, future advances in quantum computing could expose confidential information retroactively.

The Quantum Internet

The quantum internet is a proposed network that would link quantum devices to exchange quantum information. While a global quantum internet is still theoretical, significant progress is being made toward its development. In 2024, physicists at Harvard University demonstrated the longest quantum network using existing fiber-optic cables in the Boston area, successfully linking two quantum memory nodes 22 miles apart. The technology overcomes a significant issue in quantum communication: Traditional materials for boosting signal strength over long distances don't

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work with quantum information. Instead, the team used specialized diamond nodes to capture, store, and correct quantum data as it was transmitted. Meanwhile, a research team in China has advanced quantum internet by creating a multi-node quantum network across a metropolitan area. Previously, quantum networks were limited to two-node setups in lab environments, which are far from practical for large-scale quantum communication. By establishing entanglement across three nodes in a metropolitan area, the research team demonstrated that it's possible to expand quantum networks to more nodes and greater distances, which is crucial for building a functional quantum internet.

A major challenge in developing a quantum internet is transmitting quantum information over long distances while maintaining entanglement. Researchers from the University of California, Santa Barbara addressed this by improving photon emitters, which carry quantum data. Photons are ideal for this task because they interact weakly with their environment, but generating them efficiently at telecom wavelengths for fiber-optic networks has been difficult. The team found that atomic vibrations in materials reduce photon emission efficiency at these wavelengths. By optimizing materials and engineering vibrational properties, they improved emitter performance.

Quantum Software

Quantum software is a critical component of the quantum computing ecosystem, enabling the development, testing, and execution of quantum algorithms on quantum hardware and simulators. It includes quantum algorithms—like Shor's algorithm for factoring and Grover's algorithm for search tasks—which leverage quantum computing's unique properties like superposition and entanglement. Quantum programming languages like IBM's Qiskit, Google's Cirq, and Microsoft's Q# are used to develop these algorithms and run them on quantum processors. One notable application of quantum software is its use in biotechnology. Researchers at Moderna and IBM used Qiskit to predict mRNA secondary structures—a task crucial for designing RNA-based therapies. Additionally, quantum simulators and emulators are important tools for testing quantum algorithms in classical environments. Simulators like IBM's Matrix-Product State provide a quantum-like environment for testing algorithms without needing direct access to quantum hardware. These tools are essential for refining and optimizing quantum algorithms before they are executed on real quantum devices. Quantum software, though in its early stages, is rapidly advancing fields like cryptography, optimization, and drug discovery, and will play a central role in the broader adoption and application of quantum computing.

Quantum Microprocessor Chips

Researchers at Hong Kong Polytechnic University have developed a quantum microprocessor chip for molecular spectroscopy simulations, especially for large, complex molecules. Classical computers

> **This year, quantum computing will reach a pivotal moment as error correction breakthroughs and scalable hardware architectures converge to enable the first commercially viable systems that could revolutionize fields from drug discovery to financial modeling.**
>
> Amy Webb
> CEO • Future Today Strategy Group

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struggle with the computational demands of these tasks, but quantum computers excel by using quantum phenomena like superposition and entanglement. This chip, featuring a 16-qubit system, integrates both hardware and software, including a photonic network and quantum light sources, enabling more accurate simulations. Applications of this technology include drug discovery, materials design, and advanced quantum chemistry, where classical methods fall short.

Meanwhile, Oxford Ionics, a spinoff from the University of Oxford, has also made remarkable progress in the quantum chip field. Its new high-performance quantum chip has set new records for quantum computing without relying on error correction. This development is particularly significant as the chip can be manufactured using existing semiconductor fabrication processes, making it more scalable and commercially viable. Oxford Ionics anticipates that a fully functional and practical quantum computer could be available within the next three years. These advancements in quantum microprocessor chips, both for molecular simulations and broader applications, are accelerating the timeline for real-world quantum computing use, paving the way for breakthroughs in numerous industries.

Quantum Cooling

Quantum cooling is the process of reducing temperatures to near absolute zero to enable quantum mechanical systems, such as quantum computers, to operate effectively. Achieving these extremely low temperatures is essential because quantum computing components, like qubits, are highly sensitive to thermal noise, which disrupts their delicate quantum states. Without sufficient cooling, qubits cannot maintain coherence, making reliable quantum computation nearly impossible.

To address this challenge, engineers have developed a device that converts heat into electrical voltage at temperatures colder than outer space. This device advances thermoelectric technology and enables more efficient cooling for quantum systems. It uses the Nernst effect, where a magnetic field applied perpendicular to a temperature gradient generates voltage. The device's two-dimensional design allows researchers to control efficiency electrically, making it more adaptable and effective for quantum applications. Additionally, NIST has achieved a breakthrough in refining pulse tube refrigerators (PTRs), essential tools for reaching the ultra-low temperatures required in quantum research. PTRs, a staple for more than 40 years, are known for their high energy demands and operational costs. NIST's innovative redesign incorporates a specialized valve that contracts as temperatures decrease, significantly reducing helium waste and enhancing efficiency. This advancement allows PTRs to reach near-absolute zero temperatures up to 3.5 times faster than previous models, cutting both setup time and energy use. By making low-temperature environments more readily available and cost-effective, this improvement could accelerate experimental progress, reducing barriers to further advancements in quantum computing.

Quantum Machine Learning

Quantum machine learning (QML) combines quantum computing with machine learning to speed up and enhance algorithm performance using principles of quantum mechanics. By applying quantum properties like superposition and entanglement, QML aims to improve traditional machine learning techniques, particularly for large-scale data processing and complex pattern analysis. It has promising applications, including optimizing complex algorithms, speeding up classification tasks, enabling high-dimensional data analysis, improving feature selection and dimensionality reduction, generating realistic data models, and uncovering intricate patterns in data. QML also shows potential for advancing solutions in quantum chemistry problems.

Researchers are developing fully quantum algorithms that depend on large-scale quantum computations to manage complex machine learning tasks. These algorithms

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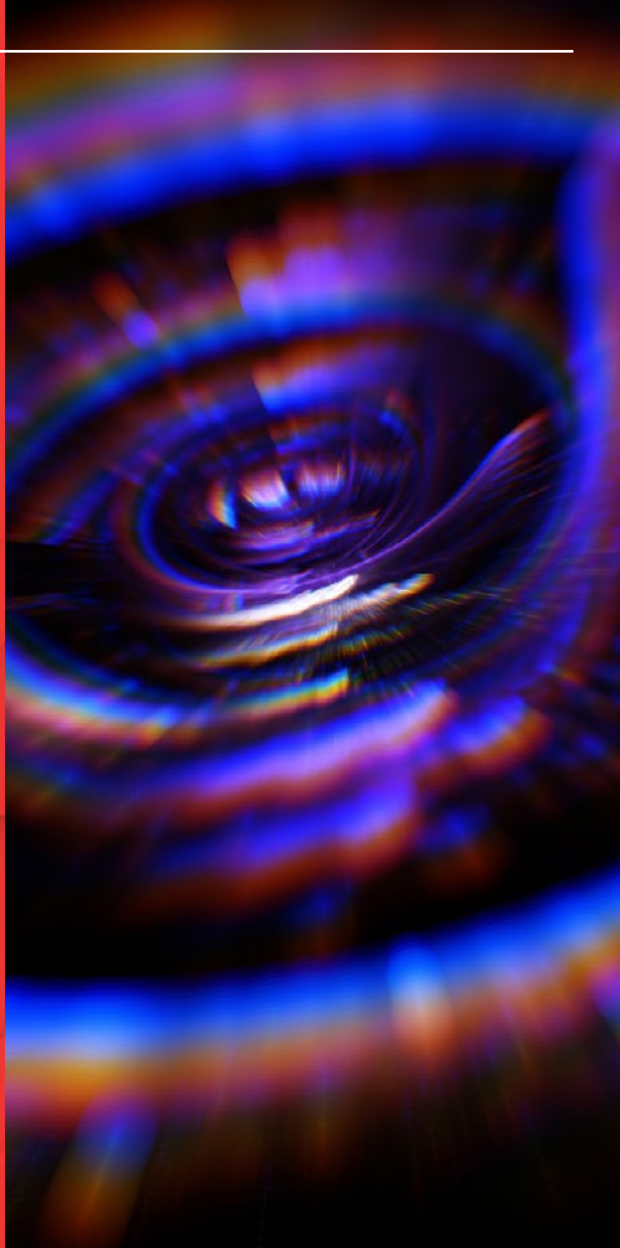
could offer exponential speed improvements over classical methods, especially for large datasets and intricate models. Key advancements include quantum neural networks, which are inspired by classical neural networks but operate with quantum mechanics for faster training and inference, and quantum support vector machines, which use quantum kernels to better separate complex data patterns. As QML evolves, it could lead to major advancements in data processing and analysis across various scientific and technological fields.

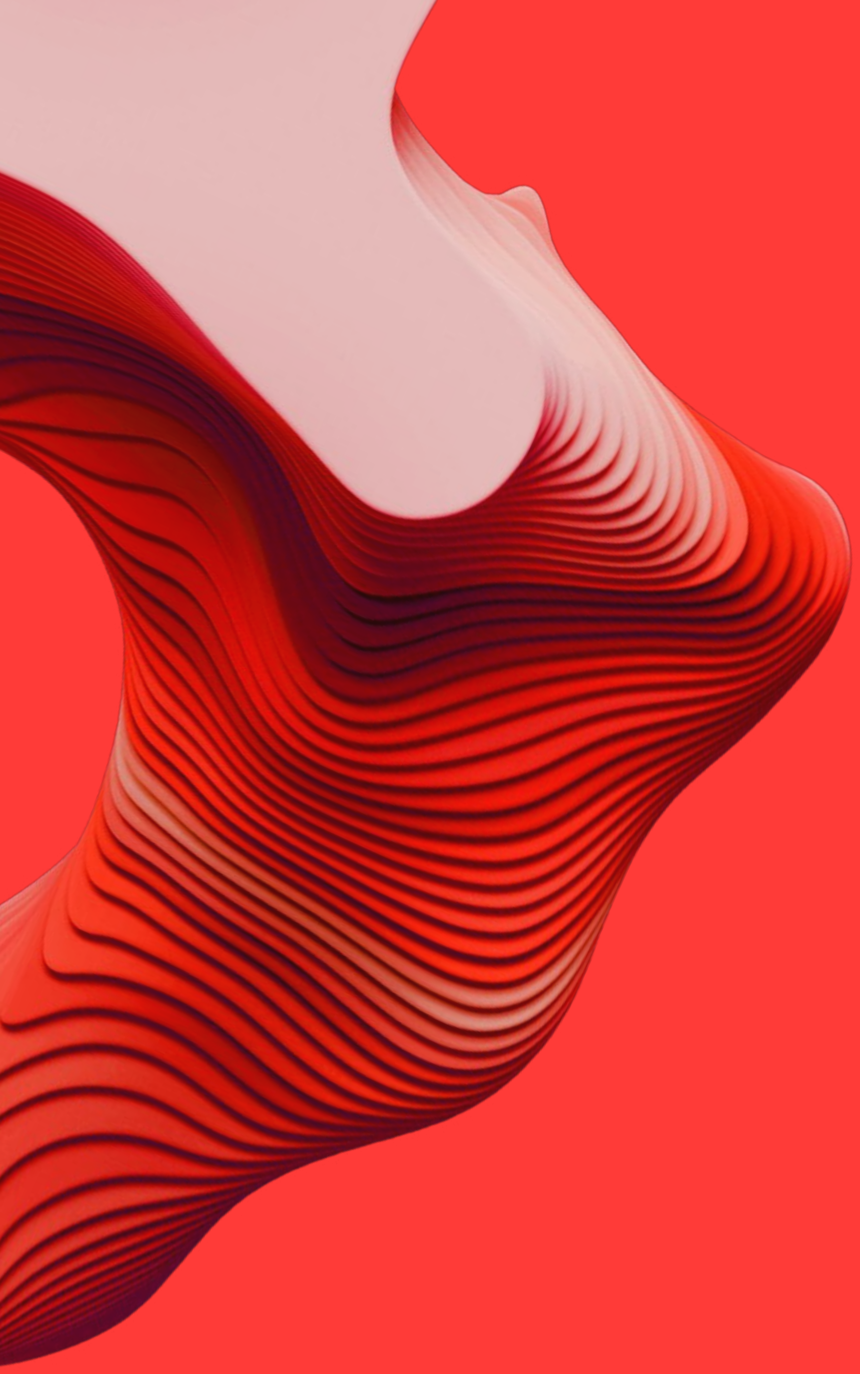
Spintronics

Traditional electronics rely on electron movement (charge) alone to store and process information. But in the emerging field of spintronics, short for spin transport electronics, scientists harness the quantum properties of an electron's charge and spin, offering a pathway to reduce energy consumption and increase processing speed. Recent advances at BESSY II, a joint German-Spanish research facility, demonstrated enhanced quantum effects in layered structures of graphene, cobalt, and iridium that stabilize "spin textures"—organized electron spin patterns essential for spintronic functionality.

A groundbreaking development in late 2024 at the Fraunhofer Institute for Applied Solid State Physics demonstrated spin-based computing using diamond quantum systems. The SPINNING project created qubit registers using color centers in diamond's crystal lattice, achieving entanglement between two six-qubit registers across 20 meters. This achievement delivered impressive results with coherence times over 10 milliseconds and error rates below 0.5%, marking a significant advance in quantum computing using electron spins.

The potential of spintronics is particularly relevant for applications requiring high processing power with minimal energy loss, such as data centers, artificial intelligence, and portable electronics. Spintronics could improve these areas by reducing battery drain and energy costs, a major advantage over traditional semiconductor-based electronics. The University of Utah recently achieved a breakthrough by turning ordinary LEDs into spintronic devices at room temperature, eliminating the need for magnetic fields. This demonstrates how existing electronics can be converted into spintronic devices, paving the way for energy-efficient, high-speed electronics.





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6G

In 2018, 5G began rolling out. By 2022 and 2023, it expanded globally, albeit more slowly than anticipated. Now in 2025, 6G is in early development with potential market introduction in the early 2030s. Featuring extremely low latency, 6G aims to enable deeply immersive experiences across various applications. A major initiative is Nvidia's 6G Research Cloud, combining generative AI and Omniverse tools to simulate and test next-generation wireless networks. This platform incorporates Nvidia's neural radio framework, enhanced radio access networks, and digital twins, helping developers experiment with and define 6G features. Research is pushing 6G forward, notably in terahertz communications, which allow transmission rates potentially reaching terabits per second. For instance, a University of Adelaide team has developed a polarization multiplexer, doubling communication capacity while minimizing data loss and enabling cost-effective mass production. In parallel, researchers at the University of Glasgow have introduced an advanced antenna leveraging metamaterials; it's designed for high-speed performance in the 60 GHz mmWave band, a critical frequency for 6G's envisioned ultra-fast data transfer and robust connectivity. This research will not only lead to higher-speed, more reliable communication but also supports new applications for 6G in areas like sensing and imaging.

AI-RAN

AI-RAN, short for AI-driven Radio Access Networks, integrates artificial intelligence directly into mobile network infrastructure to optimize performance, enhance reliability, and reduce power consumption. By embedding AI algorithms across core functions—from the physical network layer to resource management—AI-RAN facilitates the development of AI-native networks that are self-organizing, self-optimizing, and self-managing. This intelligent infrastructure can dynamically adjust network parameters, boosting efficiency while supporting high-performance, low-latency applications. Launched in February 2024, the AI-RAN Alliance includes T-Mobile, Nvidia, Ericsson, Nokia, SoftBank, AWS, Arm, DeepSig, Microsoft, and Samsung Electronics, among others, aiming to unify advancements in AI-RAN technologies. SoftBank, for instance, has collaborated with Nvidia to establish a research lab in Santa Clara, California, focused on AI-RAN's potential at the network edge, also known as multi-access edge computing (MEC). By deploying AI processing near devices, MEC can handle AI tasks with minimal latency, a capability essential for real-time applications, remote operations, and highly interactive experiences. This collaborative approach among telecoms, cloud providers, and AI companies under the AI-RAN Alliance represents a significant step forward in transforming mobile networks, enabling them to intelligently adapt and evolve with minimal manual intervention.

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Photonic-Enhanced Wireless Communication

Photonic-enhanced wireless communication combines photonics (light-based technology) with traditional high-frequency radio waves to boost wireless data transmission. Traditional wireless networks are often limited by bandwidth and face congestion, especially as data demands increase. By using millimeter-wave photonics alongside high-speed electronics, photonic-enhanced wireless expands the available bandwidth, enabling data transfer across a much broader range of frequencies, typically from 5 GHz up to 150 GHz. This wider frequency range means data can move faster, and at much higher capacities, by accessing less crowded, higher-frequency channels. Researchers at University College London recently set a record by transmitting data at 938 gigabits per second across this wide spectrum, marking a speed over 9,000 times faster than typical 5G download rates. This breakthrough leverages the combined strengths of radio and light-based technologies, supporting high-speed data flow ideal for applications in future high-speed communications, mobile networks, and more. This approach may be commercially viable within three to five years, potentially transforming how networks handle data-intensive applications.

AI at the Edge

In the ideal state of edge AI, intelligent devices like wearables, smart homes, and industrial sensors would process data independently, right at the point of data collection. This would allow them to respond instantly to changes, keep user data private, and operate continuously without needing cloud connectivity. Imagine a wearable health monitor detecting an irregular heartbeat in real time or a smart home adjusting lighting based on activity—each action would be immediate, efficient, and private. However, reaching this ideal state presents challenges. Artificial neural networks (ANNs), which power much of AI, are computationally intensive, requiring significant power and processing capabilities. IoT devices, inherently small and low-power, struggle to meet these demands; they often lack the processing speed, memory, and battery life to run complex algorithms. As a result, many edge devices still rely on cloud servers to handle intensive tasks, a habit that creates latency, consumes more power, and can compromise data privacy.

A recent breakthrough by researchers at Tokyo University of Science could help overcome these limitations: a new training algorithm for a specific type of ANN, called a binarized neural network (BNN), designed to run efficiently on IoT devices. By implementing this algorithm within a computing-in-memory architecture, they have enabled devices to perform AI tasks more effectively with far less power. This advance could unlock a future where wearables, smart homes, and other IoT devices operate with full AI capabilities at the edge, minimizing the need for cloud dependency, reducing energy consumption, and improving response times—bringing us closer to the ideal state of edge AI.

Satellite Internet

Starlink has revolutionized satellite internet by making high-speed, low-latency internet accessible in remote and underserved regions worldwide. Unlike traditional satellite providers that use geostationary satellites orbiting 22,000 miles above Earth, Starlink operates a constellation of low-Earth orbit (LEO) satellites positioned about 350 miles up. This proximity reduces latency and dramatically improves connection speeds, making satellite internet viable for applications previously limited to terrestrial networks. At the time of this writing, SpaceX has deployed more than 5,000 Starlink satellites, with plans to expand this constellation by thousands more. This network, now available in more than 50 countries, has had a profound impact on areas lacking traditional infrastructure, offering new possibilities for education, health care, and economic development. With a special focus on expanding service in Africa, Starlink is reshaping how and where people can access the internet without requiring government-funded infrastruc-

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ture projects. SpaceX has even introduced a more compact version of its equipment, the Starlink Mini, which makes the service more accessible and easier to deploy. While Starlink leads the way, some competition is emerging. Amazon's Project Kuiper aims to launch more than 3,000 LEO satellites to establish its own global internet network. Similarly, China is developing the GuoWang constellation to create a self-reliant satellite internet option and compete internationally. LEO satellite constellations are disruptive because they eliminate the need for traditional infrastructure. Unlike cable and fiber providers, which rely on extensive physical networks, Starlink's LEO satellites deliver internet directly from space, reaching remote and underserved areas. This approach is especially valuable in regions where building infrastructure is prohibitively expensive or logistically difficult.

Connected PCs

Why do we still rely on Wi-Fi to connect our PCs to the internet, or turn to mobile hotspots when Wi-Fi isn't available? Apple is aiming to change that. In early 2025, the company plans to debut its custom-built 5G modem chip in devices like the iPhone SE, a budget iPad, and the iPhone 17 "Air." This rollout will serve as a testing ground before integrating the chip into flagship products over the next three years, potentially including Macs. A Mac equipped with a 5G chip would be able to connect directly to cellular networks, eliminating the need for Wi-Fi or mobile hotspots. Some PCs, like the Lenovo ThinkPad X1 Nano, HP Elite Dragonfly G3, Dell Latitude 9430, and Microsoft Surface Pro X, already support cellular connectivity. This technology offers clear advantages: internet access in most areas with cellular coverage and greater security, as cellular networks are typically safer than public Wi-Fi. However, the rise of satellite internet raises questions about the future of cellular connectivity. If satellite-based internet becomes ubiquitous and reliable, will cellular capabilities still be necessary for connecting our devices?

SCENARIO YEAR 2032

JOHN DEERE, THE TELECOM PROVIDER

By 2032, John Deere is the digital lifeline of rural America. What began as a push for connected farm equipment in the 2020s has transformed Deere from an agricultural machinery giant into a powerhouse of rural telecom and digital infrastructure. Early partnerships with SpaceX's Starlink laid the groundwork, as Deere brought satellite internet to remote farms, enabling game-changing tools like autonomous tractors, ExactShot precision planting, and See and Spray weed detection. These innovations let farmers run data-driven operations even where cellular networks fell short, and soon, Deere realized its future was far beyond tractors.

Today, John Deere isn't just a farm machinery brand—it's a proprietary satellite and 6G network delivering high-speed, low-latency internet across rural landscapes. DeereLink powers Farm Hubs, localized small data centers that turn farming into a fully digital service. These small hubs analyze environmental factors, store rich farming insights, and manage regional agricultural data—close to the farm itself—supporting Deere's farming-as-a-service (FaaS) packages. Farmers can subscribe to modular, autonomous machines that handle planting, watering, and harvesting, all guided by DeereLink's intelligence network.

But Deere's impact reaches far beyond the fields. The Rural Grid extends its connectivity to entire communities, linking schools, health care centers, and municipal offices. Farm Hubs double as community compute centers, providing internet access, immersive remote education, and AI-driven telehealth, making it possible for rural families to access resources once reserved for urban areas.

By 2032, John Deere has redefined its mission. No longer a manufacturer of heavy machinery, it has become the invisible backbone of rural connectivity—a digital infrastructure titan linking America's countryside to cutting-edge computational power and data insights, ensuring rural regions are as connected and empowered as any metropolis.

We extend our gratitude to the NYU Stern MBA students from the Fall 2024 Strategic Foresight class for their exceptional contributions in crafting this scenario.

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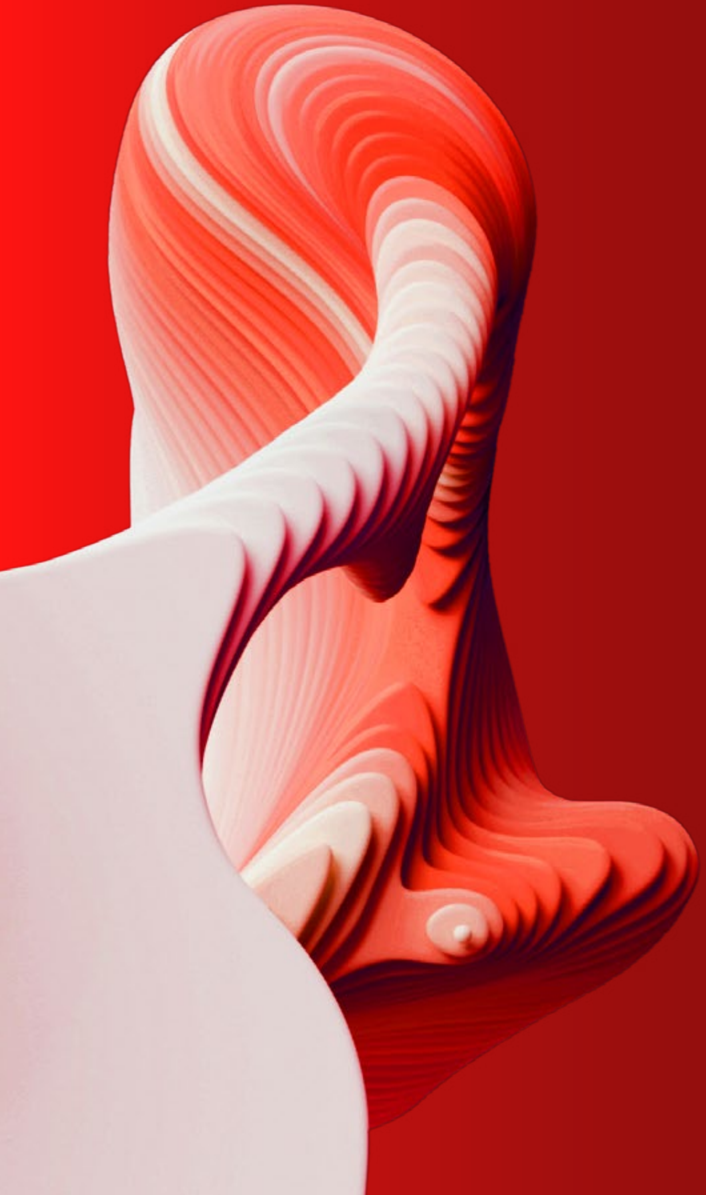

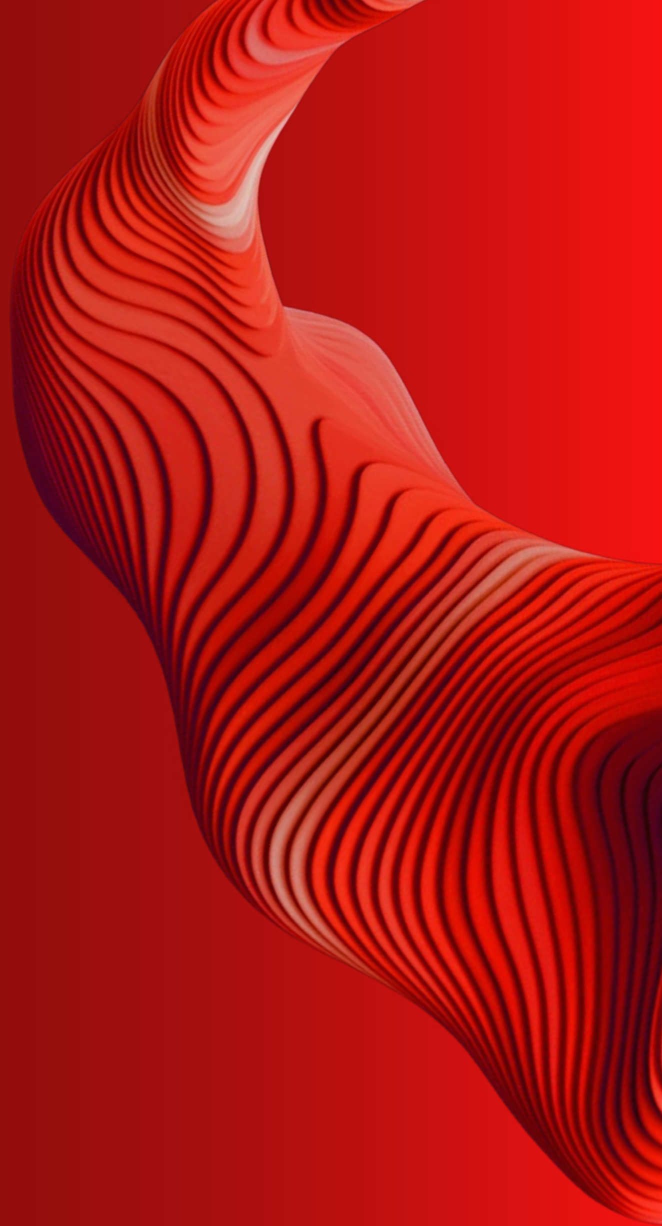

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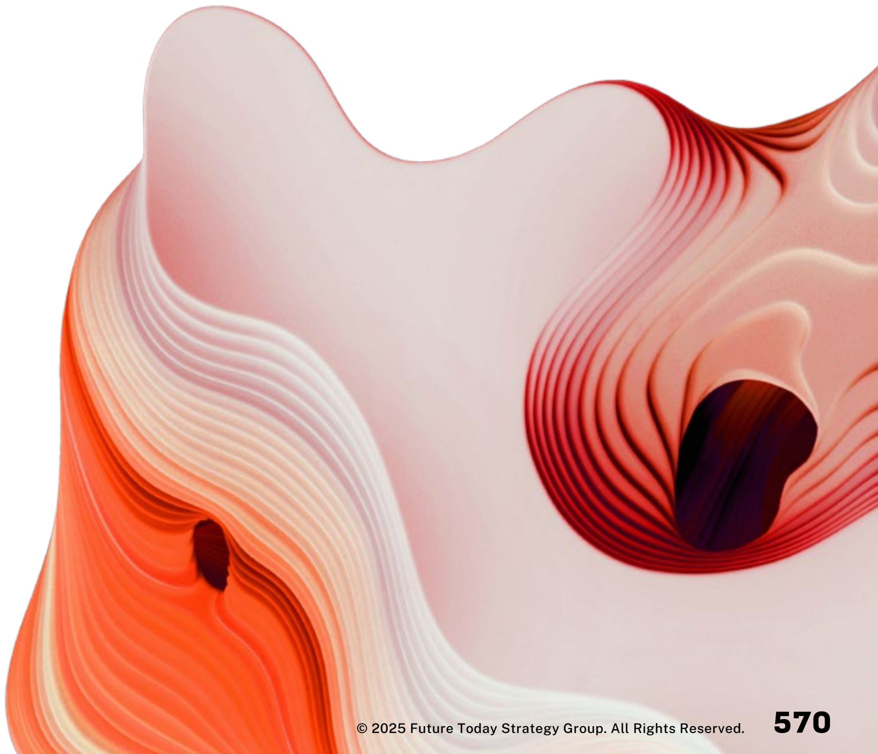


Mark Bryan
Built Environment Lead

Building a resilient and dynamic future.

As we look beyond 2025, we find ourselves at a pivotal moment, one that requires moving beyond the comfort of traditional thinking and established practices. The challenges and opportunities in the built environment industry demand a visionary approach, an openness to uncertainty, and a readiness to embrace new paradigms. Responsible for the foundation of civilization, this industry must now take the lead in guiding the world toward a more sustainable and resilient future. This journey forward necessitates more than just incremental improvements; it calls for a fundamental shift in how we design, construct, and manage built spaces. The integration of emerging technologies like AI-driven design, digital twins, and smart materials will help create buildings and infrastructures that not only meet today's demands but are also resilient and adaptable to tomorrow's uncertainties. Any traditional, linear design processes must give way to more iterative, collaborative cycles that allow for continuous innovation and responsiveness.

Part of this means adopting regenerative design principles, where what is produced from new projects and products actively contributes to communities. Rethink urban planning to prioritize self-organization in convergence with biotechnology that promotes well-being. The vast historical and institutional knowledge within the industry should serve not just as a foundation but as a launchpad for pioneering solutions that address the looming threats of climate change, demographics shifts, and infrastructure degradation. By embracing sustainable practices, harnessing advanced technologies, and fostering a culture of looking ahead, the industry can create interconnected, adaptable spaces, systems, and products that foster thriving communities and new ways of living in a connected and augmented life.

The built environment has always been more than just the physical structures we inhabit; it is the canvas upon which life unfolds, communities flourish, and the future takes shape. There is the opportunity to build a future that is not only sustainable but also vibrant, dynamic, and full of possibility.

Aging infrastructure and climate change are creating risks that can no longer be ignored.

1

Residents move into a new $10.3 billion smart city at the foot of a volcano

Toyota's Woven Smart City near Mount Fuji, where the company will test prototypes of renewable, self-driving vehicles, is set to welcome its first 2,000 residents.

2

Baltimore bridge collapse highlights declining infrastructure

Nearly one in 10 of the 617,000 bridges in the US are "significantly compromised," with Americans making 178 million trips daily on structurally deficient bridges.

3

Sustainability targets are not being met

Despite some reductions in energy intensity, overall energy demand and emissions from buildings have increased, indicating that current efforts are insufficient to meet global climate targets.

4

Extreme weather spells disaster for property care and costs

Heatwaves, droughts, and heavy rainfalls in Brazil and the UAE led to significant loss of life and property damage, marking some of the worst climate-related disasters in history.

5

Luxury office costs rise while demand for lower-end spaces declines

The cost of Miami office space hit a new record last year with rents hitting around $200 a square foot, double 2022 prices.

The industry will choose commoditization or transformation—and the decision has yet to be made.

The built environment industry is standing at a crossroads of either commoditization or transformation, provoked by a convergence of technological innovations, demographic shifts, and environmental challenges. Technological advancements, particularly in modular construction, digital tools, and AI-driven automation, are becoming increasingly critical for enhancing efficiency, cost-effectiveness, and flexibility in construction projects. These technologies are especially vital in fast-growing regions such as Africa and Asia, where rapid urbanization and population growth are driving unprecedented demand for housing, infrastructure, and digital services. But the sector is also grappling with significant challenges, including rising labor costs, supply chain disruptions, and the need for sustainable practices in response to global climate goals.

In regions like Australia and the Middle East, public sector investments in large-scale and “giga” projects are laying the foundation for future growth by meeting the infrastructure needs of expanding urban populations and creating opportunities for companies to participate. Meanwhile, in Europe, Asia, and emerging markets, the push toward net-zero carbon emissions is spilling over to construction projects, with regulatory pressures and shifting consumer expectations prodding both governments and corporations to integrate sustainability into operations. And, pretty much everywhere, critical infrastructure continues to age, underscoring the urgent need for investment.

At the same time, the built environment is being reshaped by iconic projects such as the Grand Egyptian Museum in Giza, the restoration of Notre Dame Cathedral in Paris, and innovative developments in Asia like the Beijing City Library, Kaohsiung Station, and the solar-powered Sun Rock facility. These projects not only exemplify ongoing investment in cultural and public spaces but also highlight the increasing emphasis on sustainability. To succeed and thrive, the built environment industry must move past stagnation to embrace new practices and innovations. The integration of advanced technologies, sustainable practices, and a focus on adaptability will be essential in shaping the future of the built environment.

Changes in cities and processes are fueling advancements.

APRIL 2024

Laser-Induced Graphene MDF

Medium density fiberboard with laser-induced graphene surfaces is developed to sense touch, heat, and pressure.

MAY 2024

Flea-Size Cobots for Inspections

These micro-cobots are made to conduct detailed inspections and repairs in confined construction spaces.

JULY 2024

Dubai's Green Spine Project

The plan is to turn 40 miles of highway into parks, with a million new trees, for urban cooling.

JULY 2024

Mobile Scanning for Digital Twins

GeoCue's mobile scanning systems update digital twins in real time during site walkthroughs.

AUGUST 2024

South Korea's Hydrogen Apartments

The first-ever hydrogen-powered apartment complex uses regenerative energy systems.

« PAST

Governments and municipalities will focus heavily on infrastructure development and maintenance in the near future.

FUTURE »

EARLY 2025

Data-Driven Design Verification Becomes Standard

Clients will increasingly require integrated data models during preconstruction phases to ensure predictability and proof of financial performance for projects.

MID 2026

Public-Private Partnerships for Smart Infrastructure Expand

Governments and private companies will ramp up collaboration on smart infrastructure projects, including grid modernization and urban safety systems.

EARLY 2027

Rewilding Gains Momentum as Mental Health Initiative

Governments worldwide will adopt rewilding initiatives to support mental health, using natural spaces for therapeutic and community activities.

MID 2028

Demand for Resilient Infrastructure Peaks

In response to escalating extreme weather events, architects and engineers will integrate climate-resilient features into urban and regional infrastructure projects.

MID 2030

Distributed Manufacturing Networks Take Hold

Regional 3D printing hubs will become mainstream, enabling companies to reduce costs by manufacturing parts closer to their points of use.

Emerging built environment trends will revolutionize operations, workforce needs, and technology strategies.

Commoditization Unlocks New Services

Many aspects of built environment projects can be commoditized by technology—a threat that is increasingly becoming a possibility. However, this also presents new opportunities for services and business models that could offer more stability for some companies.

Processes Are Changing

As trends like automated design and augmented construction scale, project and product development will potentially become expedited. The process is also changing at the city and client level due to new trend developments that will change how professional services integrate with both the city and their clients.

Community Integration Is Possible and Necessary

Many communities are putting a premium on boosting their social infrastructure so their members can have a say in decision-making at the local level, but access to the development process is often elusive. Communities will increasingly now have an informed voice in what should be built and created.

Today's Talent Lacks Tomorrow's Skills

With institutional knowledge leaving the industry in droves, those who remain are struggling to maintain the pace of work, let alone the pace of leveling up their skills to prepare for the future. New skills development can become a new service platform or a method of attraction and retention for tomorrow's projects.

Digitization of Assets Is Lacking

The problematic lack of digitized historical data so far has no clear solution. Businesses that make a point of understanding the industry's future direction can plan for what materials should be digitized and in what format.

Risks Are Increasing

Cyber and environmental risks continue to climb. Companies should shore up their processes and tools to prevent hacks and prepare for extreme weather and climate disasters—and to provide assurance to clients and partners.

These individuals are at the forefront of development and transformation in the built environment industry.

- **Baharash Bagherian, CEO of URB,** for leading this ambitious initiative, which aims to transform Sheikh Mohammed Bin Zayed Road into the world's greenest highway.

- **Carlos Moreno, scientific director at the Sorbonne Business School,** for promoting the 15-minute city model and its integration with technologies like citizen participation platforms.

- **Dr. Joseph Paradiso, professor at MIT,** for innovatively transforming waste textiles into functional electronic fabrics.

- **John Folan, professor and head of the Architecture Department at the University of Arkansas,** for The Wave Layered Timber project, which addresses housing shortages with an innovative glue-free timber system.

- **Young-Jin Kim, professor at Korea Advanced Institute of Science and Technology,** for research into creating graphene-based smart materials.

- **Diane Hoskins & Andy Cohen, co-CEOs of Gensler,** for their book on the ways design can help address some of the world's most pressing issues.

- **Franz-Josef Ulm, professor at MIT,** for work using cement and carbon black to store renewable energy.

- **Coen van Oostrom, founder and CEO at Edge,** for the continued development of intelligent buildings and built environments.

- **Zack Jackowski, general manager at Boston Dynamics,** for his work using Spot robots for construction.

- **Robert Piconi, CEO at Energy Vault,** for his work on gravity energy storage systems that can turn skyscrapers into energy storage.

- **Misak Terzibasiyan, principal architect for UArchitects,** for the Community for Refugee project, which uses modular housing for displaced people.

- **Melodie Yashar, vice president of Architecture & Building Performance for ICON,** for her work on space architecture and additive construction.

Technology enables community input and advanced experiences...

...but, technology shouldn't replace traditional talent and trusted practices.

OPPORTUNITIES

Citizen Participation Platforms

Digital technologies that enable citizen participation in urban planning can lead to more inclusive and democratic urban development, the kind of city projects that align with residents' needs.

Advanced Deconstruction Technologies

Integrating machine learning, robotics, and optimization into deconstruction processes enhances the efficiency and safety of material reuse, opening up more sustainable practices.

Smart Home Holography

Innovations like holographic telephony and AI-driven personal assistants can create more interactive and personalized living spaces, making home automation more intuitive and engaging.

Additive Manufacturing for Cultural Customization

New additive manufacturing capabilities will make truly unique, community-connected projects possible.

THREATS

Overreliance on AI in Urban Planning

A heavy dependence on AI may marginalize other communities that don't have access to technology, potentially exacerbating social inequities.

Regulatory Challenges for Metamaterials

The introduction of metamaterials for noise reduction and other urban applications may be slowed down by regulatory hurdles, limiting their potential impact.

Cultural Insensitivity in Global Immersive Experiences

The worldwide expansion of XR experiences may lead to cultural insensitivity or homogenization, where local traditions and values are overshadowed by standardized experiences.

Cybersecurity Risks in Intelligent Buildings

The increased reliance on intelligent building systems makes them vulnerable to breaches that compromise building operations and occupant safety.

It's time for companies in the built environment industry to invest in earnest in emerging technologies.

Businesses must fully commit to the development and deployment of digital twins. As this technology advances, the emergence of digital twin mesh networks will revolutionize how data is shared and utilized across projects.

Clients will expect to have a choice of AI versus human work, and firms should strategically evaluate how AI-driven efficiencies might impact pricing models. Companies will need to decide new value models for human and AI work, and predict which clients will prioritize which type of work.

In light of the growing capabilities of additive manufacturing, it's time to rethink the location of production facilities. Embracing localized production not only aligns with sustainability objectives but also enhances responsiveness to project needs.

The construction industry, a sector historically slow to adopt new technologies, must address its growing technological debt, or else the widening gap could hinder its competitiveness and efficiency.

As climate change and unpredictable global events continue to challenge urban infrastructures, the emphasis on resilience is no longer optional. Cities must pivot their focus toward new investments, prioritizing resilient projects over traditional ones to secure a safe and adaptive future.

The absence of clear guidelines and protections for AI creates significant risks as the technology continues to be embedded in business operations. By establishing these safeguards now, companies can ensure that AI initiatives are secure, ethical, and aligned with long-term strategic goals.

Technology Deployment
Capital Expenditure
Talent Development
Regulatory Influence

Important terms to know before reading.

ADAPTIVE REUSE
The process of repurposing existing buildings and infrastructure for new uses, reducing the need for new construction and preserving cultural heritage, while aligning with sustainability goals.

ADDITIVELY MANUFACTURED (AM) PRODUCTS
Items or materials produced through additive manufacturing, including 3D printing, where layers of material are added sequentially to create a final product. This process is increasingly used for customized, sustainable, and efficient production across various industries.

AUTONOMOUS VEHICLES (AVS)
Vehicles that operate without human intervention using a combination of sensors, cameras, artificial intelligence, and advanced computing power. AVs include cars, drones, and other transport solutions that are transforming logistics, urban planning, and mobility services.

BUILDING INFORMATION MODELING (BIM)
A digital representation of physical and functional characteristics of a facility. BIM serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle, from inception onward. Unlike digital twins, BIM models typically do not update in real time.

BIODIVERSITY
The variety of life in all its forms and levels, including species, ecosystems, and genetic diversity. In 2025, the focus on biodiversity includes the integration of biological diversity into business practices and urban planning to ensure sustainable development.

BUILT ENVIRONMENT
The human-made surroundings that provide the setting for human activity, encompassing architecture; interior design; civil engineering; mechanical, electrical and plumbing (MEP) engineering; structural engineering; landscape architecture; product design; manufacturing; construction; experiential design; and urban planning. This field is increasingly influenced by smart technologies and sustainability imperatives.

CIRCULAR DESIGN
A design philosophy aimed at minimizing waste and making the most of resources. Circular design principles encourage the development of products and environments that will be repurposed, reused, or recycled, contributing to a regenerative economic model.

CROSS-LAMINATED TIMBER (CLT)
A type of mass timber product made by stacking layers of wood perpendicular to each other and gluing them together, for high strength and stability. CLT is used in various applications, including walls, floors, and roofs.

DIGITAL TWINS
Highly detailed, dynamic digital replicas of physical objects, systems, or environments that use real-time data to mirror and predict their real-world counterparts' performance. Digital twins are integral in optimizing operations and facilitating decision-making across industries, from urban planning to manufacturing.

ENVIRONMENTAL, SOCIAL, AND GOVERNANCE (ESG)
A framework used by organizations to guide their practices and policies in the areas of sustainability, social responsibility, and corporate ethics. ESG criteria are increasingly expected for investment decisions and regulatory compliance.

EXPERIENTIAL DESIGN
A multidisciplinary approach to creating environments, products, and services that prioritize user experience and engagement, often incorporating sensory and interactive elements. This design practice is central to developing immersive experiences in retail, entertainment, and digital spaces.

EXTENDED REALITY (XR)
An umbrella term that includes augmented reality (AR), virtual reality (VR), and mixed reality (MR). XR technologies are used to blend digital and physical worlds, enhancing how we interact with environments, products, and each other in real time.

GLULAM (GLUED LAMINATED TIMBER)
An engineered wood product made by gluing together individual pieces of lumber. Glulam is used in large structural components, such as beams and columns, in mass timber buildings, to achieve both high strength and flexibility.

INTERNATIONAL CODE COUNCIL (ICC)
An organization that develops model codes and standards used to design and build safe, sustainable, affordable, and resilient structures. The ICC's codes are widely adopted and influence construction practices in more than 50 countries, playing a key role in global building safety and compliance.

INTERNET OF THINGS (IOT)
A network of physical objects embedded with sensors, software, and other technologies to connect and exchange data with other devices and systems over the internet. IoT enables smart environments, from homes to cities, and drives innovation in industries such as health care, manufacturing, and logistics.

ISOCHRONE MAPPING
A method of mapping areas that can be reached within a specific time frame using various modes of transportation. It is used in urban planning to evaluate accessibility and mobility.

LARGE LANGUAGE MODELS (LLMS)
Artificial intelligence models trained on extensive datasets of text to perform language-related tasks such as translation, summarization, and content generation. LLMs are foundational in developing AI applications, particularly in natural language processing and conversational interfaces.

LIGHT DETECTION AND RANGING (LIDAR)
A remote sensing method that uses light in the form of a pulsed laser to measure variable distances to the Earth. Lidar is critical in applications ranging from autonomous vehicles to environmental monitoring and urban planning.

MASS TIMBER CONSTRUCTION
A construction technique using large or solid engineered wood products for structural components. Mass timber is gaining popularity for its sustainability, carbon storage capabilities, and potential to reduce the environmental impact of buildings.

MECHANICAL, ELECTRICAL, AND PLUMBING (MEP)
The three key technical disciplines involved in building design and construction. MEP systems ensure the comfort, safety, and efficiency of buildings and are increasingly integrated with smart building technologies.

METAVERSE
A collective virtual shared space that converges virtually enhanced physical reality and physically persistent virtual reality. In 2025, the metaverse is expanding beyond entertainment into areas like work, education, and commerce, driven by advances in XR, blockchain, and AI.

MODULAR CONSTRUCTION
A method of construction where buildings are made from prefabricated sections (modules) that are manufactured off-site and then assembled on-site. This approach offers faster construction times, cost efficiencies, and reduced waste, and is being increasingly adopted for a variety of building types.

NET ZERO
A state where the amount of greenhouse gases emitted is balanced by the amount removed from the atmosphere. Net-zero projects are designed to minimize energy consumption and maximize the use of renewable energy sources, while aligning with global sustainability goals.

OCCUPANT-CENTRIC CONTROL (OCC)

Building systems designed to optimize environmental conditions (e.g., temperature, lighting) based on real-time data about occupants' preferences and activities, ultimately to improve comfort and energy efficiency.

PARTICIPATORY DESIGN

A design approach that involves stakeholders, including community members, in the design process, often enhanced by immersive tools like VR to simulate user perspectives and improve collaboration.

PROXIMITY-BASED URBAN MODELS

Urban planning models that emphasize the importance of spatial relationships and proximity between different functions and services in a city. These models integrate digital technologies to connect makers, citizens, and services, fostering distributed economies and localized governance.

REALITY CAPTURE

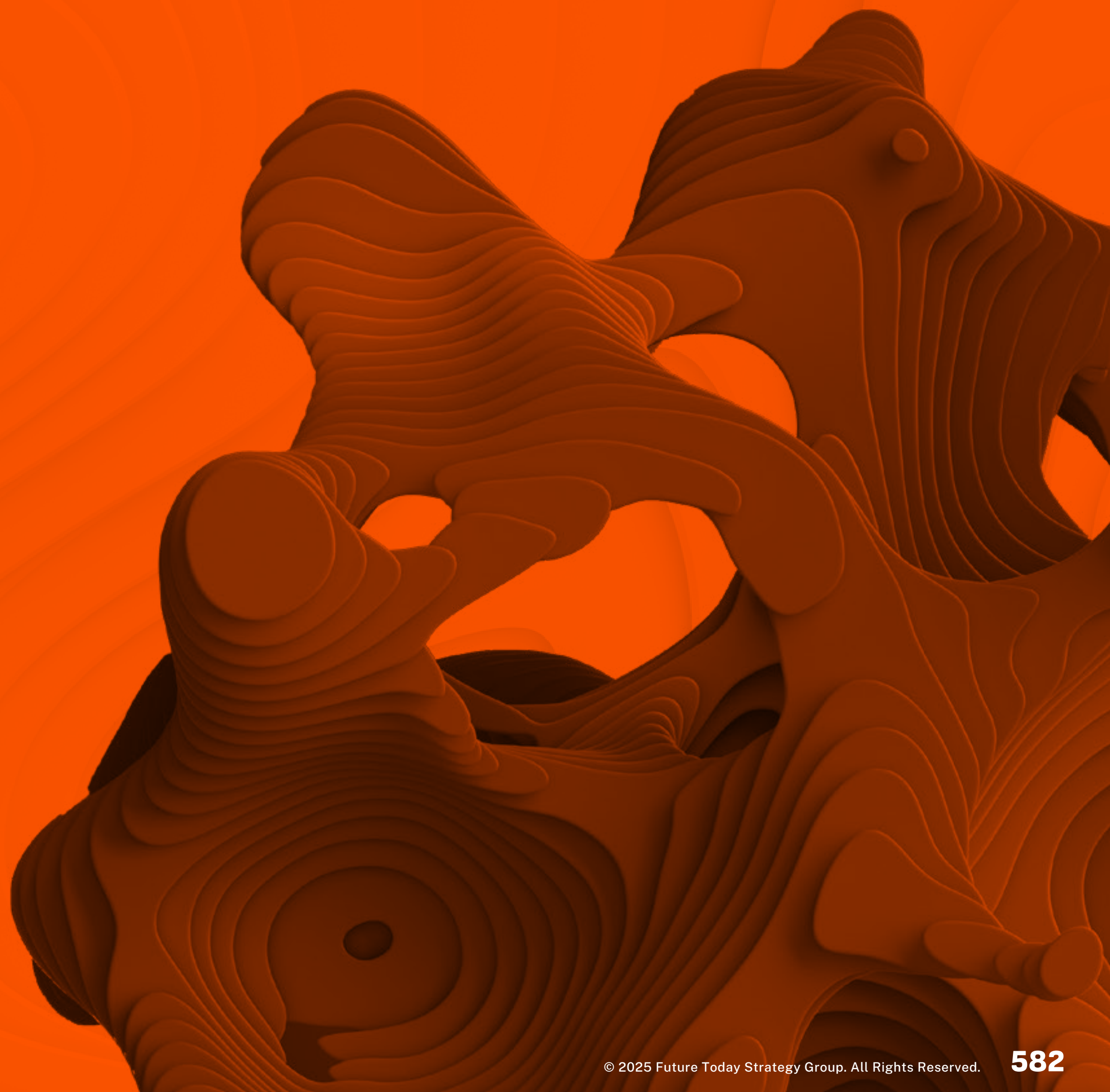
The use of technologies such as laser scanning, drones, and lidar to create detailed digital models of physical environments, for planning, deconstruction, and adaptive reuse purposes.

UNMANNED AERIAL VEHICLES (UAVS)

Aircraft systems that operate without a human pilot on board. UAVs, commonly known as drones, are used for various applications, including surveillance, delivery services, environmental monitoring, and agricultural management.

URBAN CENTER

Traditionally the central area of a city where commerce, culture, and governance converge. In 2025, urban centers are increasingly redefined by smart city initiatives, green spaces, and mixed-use developments that promote sustainability and livability.



BUILT ENVIRONMENT TRENDS

ADAPTIVE URBAN ENVIRONMENTS

2ND YEAR ON THE LIST

CHRONO-URBANISM

WHAT IT IS

Sometimes referred to as "15-minute cities," chrono-urbanism seeks to enhance urban living by making essential services, amenities, and work opportunities accessible within specific time frames, typically within a 5-, 10-, or 15-minute walk or bike ride.

HOW IT WORKS

Chrono-urbanism embraces the concept of focusing on incremental changes rather than complete urban overhauls. In South Korea, the city of Busan has a 15-minute city model aimed at enhancing residents' quality of life by increasing public facilities and distributing a "15-minute life card" that encourages them to engage with local programs. Recent research is taking technology's role in chrono-urbanism to a new level, by using it to connect makers, designers, citizens, and digital fabrication/3D printing sites and create distributed economies through proximity-based urban models and policies. The goal is to integrate digital production tools like 3D printing at key city locations to support future chrono-urbanism efforts.

Other chrono-urbanism innovations include Citizen Participation Platforms, which give residents the ability to engage in urban planning and ensure projects meet community needs. Additionally, a study in Hamilton, New Zealand, used GIS technology to identify areas suitable for the 15-minute city concept. And in Chengdu, China, researchers aimed to make chrono-urbanism more practical by moving beyond walkability. Their work expanded the 15-Minute Community Living Circle concept to include multiple transportation modes—walking, cycling, public transportation, and driving. Then residents would have enhanced access to health care and other daily necessities, based on spatial accessibility and real-time travel data.

WHY IT MATTERS

While the concept has yet to achieve widespread adoption, ongoing research and pilot projects highlight chrono-urbanism's transformative potential in urban planning. By prioritizing accessibility and proximity, cities can reduce long commutes, lower environmental impact, and strengthen community ties. And by integrating digital technologies and real-time data systems into urban management, cities can better optimize their services and allocate resources.

Practical challenges such as existing infrastructure, high population density, and economic constraints hinder the full-scale implementation of chrono-urbanism. Additionally, the concept of walkability, though appealing, may not be feasible in all urban contexts, particularly in sprawling or rapidly expanding cities. Despite these challenges, chrono-urbanism presents a compelling vision for the future—one where cities are less reliant on vehicles for mobility, more sustainable, and better aligned with the daily lives and needs of their residents. The framework could redefine how we live and interact within urban environments, making them more resilient and responsive to both current and future demands.

2ND YEAR ON THE LIST

SELF-ORGANIZED PLANNING

WHAT IT IS

Self-organizing technologies are setting the foundation for smarter, more adaptive cities that can plan themselves. These innovations are paving the way for more efficient resource management and sustainable growth in urban environments.

HOW IT WORKS

Traditionally, AI models in urban planning were specific to one geographic location, and struggled to adapt to new environments. But the new InvarNet framework marks a breakthrough by focusing on consistent underlying relationships rather than geography-specific correlations. This approach enhances the reliability and precision of urban planning tools, improving resource management, urban growth prediction, and sustainability efforts.

New remote sensing technologies further complement these AI advancements with unprecedented accuracy in mapping and categorizing land use. AI models trained on high-resolution remote sensing data can now identify land categories with up to 99.19% accuracy, enabling better planning for future resource use. Innovations in urban building energy modeling (UBEM) are also advancing how cities estimate and predict energy demand, aiding sustainable energy planning processes.

Cities like Lebanon, New Hampshire, and Gainesville, Florida, now use AutoReview.AI to streamline development application processing and site-plan reviews, automating time-consuming tasks and accelerating urban planning. Additionally, some cities are using AI through LLM frameworks like multi-agent collaboration and fishbowl discussion mechanisms to stimulate citizen input. This ensures more inclusive and participatory urban planning—and ultimately more equitable and effective decisions.

WHY IT MATTERS

As urban populations expand and environmental concerns intensify, the ability to manage resources efficiently and plan for sustainable growth becomes increasingly critical. To realize the full potential of self-organizing planning, firms will need to incorporate seamless workflows, prioritize data transparency, and implement continuous reinforcement learning. And to derive future work from cities, they may need to adjust their project development process to accommodate these changes.

However, there are potential misuses to be wary of, such as AI being employed to identify and disperse homeless encampments. While AI can streamline many aspects of urban planning, it shouldn't entirely replace human input. The advancements in AI, particularly those that reduce the technology's former reliance on geographic specificity and allow for it to help in the planning process, have shown to lead to better outcomes in resource management, infrastructure development, and environmental protection. These technologies also democratize the planning process, encouraging greater citizen participation and ensuring that urban development reflects the needs and desires of the community.

2ND YEAR ON THE LIST

REWILDING

WHAT IT IS

Urban rewilding initiatives are reshaping cityscapes, enhancing biodiversity, reducing carbon emissions, and fostering community engagement through innovative uses of AI, urban planning, and community-driven projects.

HOW IT WORKS

In Dubai, the Sheikh Mohammed Bin Zayed Road is being turned into a 40-mile "Green Spine," with parks, community gardens, and more than a million trees improving air quality and reducing temperatures. The Dubai Mangroves initiative plans to plant 100 million mangroves along 43 miles of coastline by 2040, to capture carbon and create a natural barrier against erosion.

Community-driven efforts like urban beekeeping are also advancing rewilding. Capgemini's Tech4Positive Futures Challenge, in partnership with Pollenize, developed an urban rewilding tool to help residents plant native, pollinator-friendly vegetation. Others are exploring using trees to reduce noise pollution: Researchers studied how trees interact with the soil to dampen vibrations, and identified strategic tree placement that block specific vibrations from urban trains.

By integrating natural elements with technology this way, we could have healthier, more livable cities. AI advancements suggest what such efforts could look like. AI models like image-to-image translation and inpainting create realistic visualizations, aiding planners in integrating green spaces. In Denmark, the technology has been applied to a rewilding framework for identifying and prioritizing rewilding sites that could be adaptable to cities worldwide.

WHY IT MATTERS

Urban rewilding represents a crucial response to the challenges posed by climate change and urbanization. By restoring natural elements within cities, it can mitigate the effects of urban heat islands, improve air and water quality, and provide residents with spaces that enhance mental and physical well-being. Pretty soon, residents may prioritize cities with rewilding projects, as they will be viewed as more climate stable. For the many firms and products that do not currently consider rewilding, incorporating these aspects could be a point of true innovation for the industry. This could take the form of products and places that include the ability to grow local plants once installed.

The use of AI in these efforts is particularly important, as it allows for precise planning and visualization of urban green spaces. Some new AI tools facilitate community-driven initiatives, which empower local residents to take an active role in improving their environment. As cities continue to expand, it will be increasingly essential to integrate both soft technology (such as plants and trees) and hard technology (like AI) into urban planning. Rewilding will create resilient urban environments that are better equipped to handle future environmental challenges.

“

We must rewild the world. Rewilding the world is easier than you think. A century from now our planet could be a wild place again.

Sir David Attenborough

REGENERATIVE PRACTICES

2ND YEAR ON THE LIST

ADAPTIVE REUSE AND DECONSTRUCTION

WHAT IT IS

Adaptive reuse and deconstruction are redefining urban renewal and sustainability by repurposing existing structures and materials, reducing waste, and preserving embodied carbon.

HOW IT WORKS

Adaptive reuse repurposes old buildings, structures, and materials, reducing the need for new construction and preserving embodied carbon—the energy used to create original materials. This approach minimizes demolition waste and revitalizes aging infrastructure, such as the transformation of Kansas City's Rock Island Bridge into an entertainment district or London's 8 Canada Square from an office building into a sustainable mixed-use space, while reducing carbon impact.

Recent innovations include employing AI and machine learning to assess residential buildings' potential for reuse, by evaluating their structural integrity and suggesting sustainable strategies, such as retaining the structure or conducting a selective demolition. Deconstruction now uses machine learning to predict costs, assess material reusability, and optimize waste categorization. Robotics enhance safety and efficiency in separating and removing building components. Laser scanning, UAVs, lidar, and XR technologies capture detailed building data, reducing the work that goes into deconstruction planning and making decisions easier. But adaptive reuse goes far beyond buildings: The textile industry is upcycling waste fabrics into multifunctional electronic textiles, and exploring end-of-life solutions for its products.

WHY IT MATTERS

Amid rising costs, many projects will only move ahead if they reuse existing infrastructure, and the significance of adaptive reuse and deconstruction lies in their contribution to sustainability and urban renewal. By repurposing existing structures and materials, these practices reduce the environmental impact of construction and demolition, preserve cultural heritage, and create vibrant new spaces. The integration of advanced technologies in deconstruction not only enhances efficiency but also supports the circular economy by maximizing material recovery and reuse. As cities and industries continue to prioritize ESG goals, adaptive reuse and deconstruction will play a critical role in the projects that are greenlit to move forward, potentially shifting funds for current and future investments.

For industry professionals, adaptive reuse and reconstruction could add to their current design and practice processes, while the advanced technology will cut down on time and expense. As cities and industries continue to prioritize sustainability, professionals who master adaptive reuse and deconstruction will be at the forefront of shaping smarter, greener, and more resilient urban environments.

2ND YEAR ON THE LIST

METAMATERIALS

WHAT IT IS

Metamaterials are engineered materials whose properties enable them to exhibit unique abilities not found in nature, including new ways to address noise control, structural resilience, and adaptive textiles.

HOW IT WORKS

While metamaterials that can heal themselves or exhibit other man-made properties have been around for years, now there are metamaterials that have a unique ability to manage acoustic energy. Researchers are developing versions that can redirect sound waves, effectively rendering objects acoustically “invisible.” This acoustic cloaking is promising for reducing noise pollution in urban areas. Additionally, these materials are being designed to absorb the energy from earthquakes, making them ideal for use in seismic zones. Some metamaterials can even convert sound into electrical energy, adding a sustainable energy-harvesting capability.

At TU Delft in the Netherlands, researchers have developed an AI tool that accelerates the discovery and fabrication of customized metamaterials. This “inverse design” process starts with desired properties and works backward to create the necessary structure, taking into account the practical limitations of 3D printing. The result: highly durable and efficient materials that overcome previous design limitations.

These advanced materials also have applications in smart textiles. MIT’s FibeRobo fiber changes its properties with temperature, potentially leading to fabrics that adapt to weather conditions. Researchers at the Okinawa Institute of Science and Technology have created a polymer that glows brighter under mechanical stress, which could be used to identify weaknesses in bridges or buildings.

WHY IT MATTERS

Metamaterials are redefining how we address structural resilience, energy efficiency, and noise reduction in urban environments, leading to innovations in infrastructure that are both sustainable and adaptable. However, very few firms are experimenting with these new materials. This offers an opening for startups or new players to capitalize on this trend, and clients may be willing to pay a premium—especially for products that can last longer and are reconfigurable. It also changes the design paradigm by offering living and dynamic materials.

Metamaterials also provide an opportunity to enhance the resilience and functionality of cities, particularly in areas struggling with noise pollution and structural challenges. The ability to incorporate sound management directly into building materials means future urban environments could become not only quieter but also more energy-efficient and sustainable. Additionally, the development of smart textiles and adaptive materials, which respond dynamically to environmental conditions, opens new possibilities for personal and structural applications, from wearable technology to buildings that can adjust their properties based on external stimuli.

SCENARIO YEAR 2044

QUIET POWER

By 2044, cities have turned nuisance sound into a valuable resource, creating urban environments that are both quieter and more energy-efficient. Imagine walking down a busy street—except it's not as noisy as you'd expect. That's because the buildings, sidewalks, and even streetlights are equipped with smart materials that absorb and redirect sound, cutting down on the usual urban din. But these materials do more than just quiet things down; they actually convert the captured sound into electricity. So, the chatter from a crowded sidewalk café or the hum of traffic isn't just noise—it's energy being funneled into powering streetlights, public Wi-Fi, and electric vehicle charging stations.

Public parks and squares have become hubs for both community activities and energy production. Now, a lively street fair in the heart of the city not only entertains but also helps power the nearby public transit system with the sound energy generated by the crowds. Sound-harvesting tech built into the ground and nearby structures captures the vibrations from the music and crowd noise, converting them into electricity to keep the transit system running. And it's not just about fun and games—cities have also become smarter about using sound to improve safety. Buildings in earthquake zones are now fitted with acoustic cloaking systems that can redirect seismic waves around them. So, when a quake hits, these buildings remain standing, keeping critical services like hospitals and emergency response centers operational. It's a world where sound doesn't just fade into the background—it's actively shaping the way we live, work, and play, making urban life in 2044 more sustainable, resilient, and connected than ever before.

2ND YEAR ON THE LIST

RESILIENT DESIGN

WHAT IT IS

The rise of resilient design in response to climate change, disease, and humanitarian disasters is transforming the built environment.

HOW IT WORKS

The need for resilient infrastructure has led to new methods for tilt detection and crack analysis, and increasingly AI is being used to identify potential structural failures before they occur. Similarly, new digital twins are using cloud-based geospatial dashboards to provide a visualization of potential flood impacts to better understand risks. Similar systems combine real-time monitoring with predictive analytics to identify and classify harmful substances, such as pollutants or toxic gases.

At the same time, researchers are exploring new ways to integrate resilient design into urban infrastructure. In Spain, they're testing prototypes of cooling bus stations to help combat extreme heat in urban areas. Similarly, in California, they're developing resiliency hubs as community centers that can offer shelter and resources during emergencies. Newly created hydrogels enhance resilient design by providing sustainable, scalable, and durable protection against wildfires, keeping buildings and infrastructure safe even under extreme conditions. Inside buildings, innovations like new antiviral flooring and the integration of beneficial bacteria into interior surfaces and air systems can potentially transform furniture and fixtures into active elements that promote healthier indoor environments. New research from Carnegie Mellon on using drones to explore collapsed buildings could also change how interior spaces are created in disaster-prone regions.

WHY IT MATTERS

The growing impact of climate change is forcing a rethink of how we design, build, and manage our infrastructure. Resilient design, supported by cutting-edge technologies like digital twins, AI, and advanced sensors, offers a pathway to creating urban environments that are not only more resistant to disasters but also more sustainable and adaptable to changing conditions. And while currently, resiliency is mainly thought of in terms of climate change, the concept goes much deeper to encompass topics like mental health where resiliency interventions can make humans better prepared for their daily lives.

As the demand for resilient products, projects, and spaces grows, there is a clear opportunity for companies to offer resilience planning as a service. This could involve consulting to help cities and property developers design more resilient buildings and neighborhoods, or it could mean developing new products specifically tailored to address these challenges. For example, companies might create modular, deployable structures that can be rapidly assembled in disaster-prone areas, or they might develop software solutions that integrate digital twins and AI to provide real-time monitoring and decision support.

2ND YEAR ON THE LIST

ADDRESSING HOUSING SHORTAGES

WHAT IT IS

Technological advancements and policy changes are driving new solutions to address global housing shortages, with a focus on efficiency, affordability, and sustainability.

HOW IT WORKS

Affordability challenges have intensified worldwide, and technological innovations like AI are emerging as crucial solutions. One example is a new system that uses a graph neural network to evaluate affordable housing applications; it assesses risks and enables real-time, accurate decision-making, significantly speeding up the approval process. Additionally, financial tools like Walker & Dunlop's Apprise platform are enhancing the real estate valuation process. By integrating data from multiple sources into a centralized system, Apprise improves the accuracy and speed of appraisals, which is critical for securing financing and accelerating the development of affordable housing projects.

In Kazakhstan, Central Asia's first 3D-printed house was completed in five days, reducing both time and costs, while also being designed to withstand severe environmental conditions such as earthquakes and extreme temperatures. This project highlights how 3D printing can make affordable housing more accessible and sustainable.

In the US, the University of Arkansas is advancing affordable housing through its Wave Layered Timber (WLT) system, a glue-free timber construction method that uses a wave shape to interlock components, providing structural strength without adhesives. This innovative approach not only reduces the environmental impact but also offers a scalable solution to meet the growing demand for sustainable housing.

WHY IT MATTERS

The convergence of AI, 3D printing, and sustainable construction methods represents a significant step forward in addressing global housing shortages. These technologies not only promise to make housing more affordable and accessible but also introduce new standards for sustainability in construction. As governments and industries adopt these innovations, the potential for alleviating one of the most pressing global issues—the widespread housing crisis—grows over the long term. However, many cities are not prioritizing these innovations and are instead relying on outside developers to address their housing problems.

When these advancements are pursued, they must be fully integrated into mainstream construction practices to make a substantial impact. However, for these innovations to truly address the housing crisis on a global scale, they must overcome significant hurdles. High initial costs, the need for extensive testing, and the challenge of integrating these technologies into existing construction practices are major barriers. Governments, industries, and financial institutions must collaborate to create incentives, funding mechanisms, and regulatory frameworks that support the adoption and scaling of these technologies. Ensuring these solutions are both scalable and profitable will be crucial for their success in the broader market. This approach not only addresses immediate housing needs but also will set a new standard for future construction.

2ND YEAR ON THE LIST

REGENERATIVE DESIGN

WHAT IT IS

Regenerative design is a holistic approach to built environment projects and products, making them contributors to greater community health or the environment rather than just addressing sustainability.

HOW IT WORKS

Regenerative design embraces the principle that projects and products can enhance the environment by using sustainable materials and energy sources. NASA's Mycotecture Off-Planet project is a prime example, where astronauts use mushroom-based materials to grow sturdy structures in space—it's a minimal-impact construction method.

In the energy sector, South Korea's hydrogen-powered apartment complex exemplifies regenerative design by using hydrogen fuel cells for 100% of its energy needs, reducing reliance on fossil fuels and presenting a replicable urban energy model. Similarly, Trane Technologies' cold-climate air-source heat pumps utilize the natural environment more effectively to help create buildings that are more in tune with their surroundings. MIT's new concrete can turn buildings into energy hubs by storing energy within the structure, while its new ultralight solar cells use printable electronic inks to make energy production more decentralized and resilient. While these are currently standalone initiatives, their implications are that they could one day provide regenerative energy to communities.

Urban projects like IoT-equipped community gardens optimize resource use while enhancing local food security. In Philadelphia, repurposing wood waste into building materials integrates sustainability into urban development and supports urban forestry.

WHY IT MATTERS

Traditional sustainable practices focus on reducing harm, but regenerative design aims to give back to the environment—and change the parameters around what substantial completion of a project means. A building built with regenerative practices can provide its community with tangible immediate benefits, which could be in the form of carbon credits, free electricity, new jobs, or increased resiliency. This approach addresses the obvious urgent need for sustainable practices in the face of climate change and resource depletion, but also has the potential to address other community-wide needs.

By leveraging advanced materials, energy systems, and self-sustaining technologies, regenerative design can help create resilient, self-sufficient structures that contribute positively to their surroundings. This trend could eventually push projects and products to go beyond sustainability, perhaps by addressing food shortages or other basic human needs, which in turn will mean new design parameters and consultant services. As these innovations scale, they ensure that our built environments will give back more than they take from the planet.

SCENARIO YEAR 2032

DISASTER GLOW

"It would be heartbreaking if it weren't so pretty" is the general sentiment of Tokyo residents, hours after an earthquake hit the city causing chaos and damage. Now, in the aftermath, disaster glow has begun. Tokyo was one of the first cities to adopt the seismic stability platforms being integrated into new buildings and bridges, and part of the seismic restoration parameters put in place by the Tokyo Metropolitan Government in 2026 included the use of the new glowing polymer that indicates structural damage. Now, while the earthquake has caused pervasive damage, its harm was minimal to these residents. As they walk through the streets after the disaster, they marvel at their surroundings, which are lit by a soothing light creating intricate patterns on the buildings, sidewalks, and nearby structures. As they watch, drones fly through the air to capture and document the damage, feeding this information into the city's AI-based system to evaluate and prepare repair plans.

AUGMENTED PRACTICES

2ND YEAR ON THE LIST

IMMERSIVE AND SENSORIAL EXPERIENCES

WHAT IT IS

Immersive technologies and advanced sensorial systems are revolutionizing how we design and interact with built environments, creating the opportunity for individualized experiences anywhere.

HOW IT WORKS

Immersive experiences are rapidly expanding in public and recreational spaces, as demonstrated by attractions like Singapore's Sentosa Sensoryscape, where digital light art, soundscapes, and AR interactions create a multisensory environment that deeply engages visitors. The city of Harbin in China showcases advanced XR technologies in its indoor ice and snow theme park, using lighting and synchronized sound systems to bring ice sculptures with edible pigments to life. In retail, Xydrobe's collaboration with Harrods involves a multisensory VR cinema that enhances storytelling by immersing customers in brand experiences.

Emerging technologies are further enhancing interactivity in environments through holograms and digital signage. Innovations like foldable holographic displays and AI-powered assistants, such as Emma, offer new ways to engage with interactive and immersive content almost any place. Additionally, no-code AR/VR platforms democratize content creation, making immersive experiences more accessible for personal and professional use, fostering creativity and innovation across sectors.

Advancements in XR are also being leveraged for mental health, with research indicating their potential to manage conditions like seasonal affective disorder and ADHD through therapeutic lighting environments. The use of these technologies could lead to more personalized immersive spaces and products.

WHY IT MATTERS

The integration of immersive and sensorial technologies in our built environments is a significant development, reshaping how we interact with the spaces we inhabit. These technologies are not merely about visual or auditory stimulation; they engage multiple senses, creating experiences that are richer, more engaging, and more memorable. This shift is crucial in both public and private spaces, as the demand for environments that cater to personalized emotional and psychological needs keeps increasing, and it also provides new service opportunities for selling shared virtual senses.

This shift towards integrating immersive and sensorial technologies in built environments is also about rethinking the way we interact with our surroundings on a fundamental level. By allowing for pre-experiencing and adjusting environments before they are physically realized—for example by letting potential residents walk through amenity spaces—XR and other advanced technologies help reduce waste, improve user satisfaction, and ensure that spaces better align with human needs. This approach makes sense for our increasingly complex and multifunctional environments that need to adapt to a wide range of users.

2ND YEAR ON THE LIST

AUTOMATED DESIGN

WHAT IT IS

The automation of design processes can enhance creativity, efficiency, and accessibility—and it's rapidly having an impact on the architecture, landscape design, and engineering sectors.

HOW IT WORKS

Automation in design has become integral in the built environment. Landscape architects use these tools for detailed renderings and master plans, while designers leverage AI to generate color palettes and unique conceptual inspirations. Automation similarly has revolutionized building information modeling (BIM). The Semantic Reconstruction for Building Information Modeling (SRBIM) framework automates the conversion of existing 3D models into accurate, standardized BIM models. Engineers can now also easily convert outdated CAD files into modern BIM systems, significantly reducing time and labor.

Recent advancements have introduced "prompt to plan" capabilities, enabling users to generate entire design plans by inputting parameters like the number of bedrooms or roof styles. A dynamic graphical user interface allows even those without architectural training to engage in the design process. New models also include real-time compliance checks, automatically evaluating design changes against local building codes, reducing errors and costly revisions.

Besides its usefulness to professionals, this technology can empower nonprofessionals to design their dream homes, making sophisticated design accessible to a broader audience. This democratization of the design process marks a significant shift for the industry.

WHY IT MATTERS

The integration of automation into the design process is not just about speeding up tasks; it represents a paradigm shift in how design is conceived and executed. For architects and engineers, these tools facilitate faster iterations and more collaborative efforts, enabling teams to explore a wider range of design options without the traditional time constraints. This leads to better-designed structures, as more possibilities can be tested and refined in less time.

The implications extend beyond individual projects. As more firms adopt automated tools, the industry as a whole could see a significant reduction in costs associated with design and construction. Real-time compliance checking, automatic adjustments for structural integrity, and enhanced visualization tools reduce errors and rework. Additionally, this shift may prompt a reevaluation of industry practices and governance, as firms seek to balance the benefits of automation with the need to retain critical human expertise and creativity. However, the widespread adoption of these technologies also raises important questions about the future of the design profession. As automation handles more routine tasks, the primary responsibilities of the human designer may move toward more strategic, high-level decision-making. Firms will need to navigate these changes carefully to make sure that automation enhances rather than diminishes the creative process.

2ND YEAR ON THE LIST

METAVERSE ENABLING

WHAT IT IS

As the concept of the metaverse evolves, it's clearly becoming more than just a virtual world; it's a hybrid space that merges physical and digital realities. This new environment is leading to the development of metaverse architecture that is adaptive and responsive.

HOW IT WORKS

The integration of metaversal hybrid technologies is driving the creation of shared virtual spaces where users interact in real time with both physical and digital worlds. Retailers are leveraging worldbuilding techniques, commonly used in storytelling, to create immersive brand narratives that blend both types of environments. To ensure these environments are secure, AI will monitor for security threats, while blockchain maintains data integrity and privacy. Spatial computing enhances cognitive and sensory interaction within these hybrid spaces, enabling environments to adapt based on user input and surrounding factors. AI-driven placemaking offers additional support by creating culturally relevant environments that evolve with user behavior, strengthening community connections in the digital realm.

In participatory design, stakeholders can use metaverse tools to engage directly with 3D models, overcoming the challenge of uninformed design decisions due to a lack of input. Similarly, an "Automatic Space Generation" method leverages AI to design metaverse spaces based on user activities, improving efficiency over traditional 3D modeling. By analyzing behaviors and preferences, AI creates personalized, innovative virtual spaces, free from physical constraints. Feedback on these designs highlights AI's potential to tailor environments to individual needs, suggesting a pivotal role for AI in future virtual architectural design.

WHY IT MATTERS

The integration of the metaverse in the built environment is transforming how we design, use, and experience spaces. By merging physical and digital worlds, hybrid environments are emerging that offer new opportunities for interaction and engagement. This shift challenges traditional notions of space and place, pushing the boundaries of urban design and architecture. Architects and designers will need to adopt new tools, frameworks, services, and offerings that provide both virtual and physical user experiences. As these technologies mature, more personalized and dynamic spaces will proliferate and potentially lead to novel forms of interaction and engagement across work, leisure, and community activities.

Exploration in the metaverse will also mean stretching traditional design forms and function, opening up even more innovations in the built environment. How these innovations evolve will look different, as the metaverse can serve as a place of collaboration with communities and stakeholders—reducing travel costs even while increasing inputs. AI's and blockchain's roles in ensuring safety and privacy will be necessary for keeping these dynamic spaces secure.

2ND YEAR ON THE LIST

INCLUSIVE DESIGN

WHAT IT IS

Innovative technologies are increasingly enabling designers to better understand and accommodate the needs of individuals with disabilities. This shift is fostering a more inclusive built environment, enhancing the lives of those with visual, motor, and sensory impairments.

HOW IT WORKS

Something we forecasted years ago is now a reality today: VR is being used to simulate the challenges faced by disabled individuals in public spaces, letting non-disabled users experience these barriers first-hand. This immersive experience is designed to foster empathy and understanding while encouraging more inclusive design practices. In addition to VR, new AR and AI tools are being developed to provide enhanced situational awareness for those with sensory impairments through devices like AR glasses, which can translate visual information into auditory cues or haptic feedback, to help users navigate their surroundings. Occupant-centric control technologies achieve thermal inclusivity by optimizing building temperatures based on an individual's needs.

Advancements in robotics are making significant strides in mobility accessibility. For instance, robotic wheelchairs are being designed to adapt to a user's environment. They know to avoid obstacles and choose the most comfortable paths. Researchers are developing robotic exoskeletons to assist with movement in complex environments, such as staircases or uneven terrain, to improve users' independence. Increasingly, robots are also becoming emotionally intelligent companions. One example is the creation of robotic dogs that utilize AI and wearable technologies to detect and respond to human feelings. They're not just functional aids; the robotic dogs provide emotional support and companionship, addressing mental health and well-being.

WHY IT MATTERS

These advancements in inclusive technologies are crucial for creating environments that are accessible to all, regardless of ability. As the global population ages, the demand for such technologies will only increase, making it imperative for designers and developers to prioritize accessibility in their projects. Designers should begin by considering the impact on spatial allowances based on a user's actual needs rather than generalizations. Engineers will need to consider the impact on urban infrastructure and power consumption due to new robotic companions and enablers. Manufacturers will likely need to create companion products that meet the diverse needs of individuals while also adjusting durability parameters.

By integrating these technologies, firms can create spaces and products that not only meet regulatory standards but also enhance the quality of life for individuals with disabilities. The focus on inclusive design should not just be about compliance, however; it should be about recognizing and addressing the varied needs of all people, ensuring that everyone can participate fully in society—especially as humans are starting to live longer.

2ND YEAR ON THE LIST

REAL-TIME DATA FOR ENHANCED DECISIONS

WHAT IT IS

Cutting-edge technologies are turning built environment materials, products, and spaces into intelligent, data-collecting tools, enabling real-time monitoring and control.

HOW IT WORKS

The integration of sensors is turning various materials, such as wood and plywood, into data-collecting surfaces. One breakthrough is the creation of laser-induced graphene on medium-density fiberboard (MDF). By using a femtosecond laser, the MDF's surface becomes a highly conductive material that both collects data and functions as touch, heat, and pressure sensors and controls. The applications of this technology could create sensors and controls for any surface.

A significant application of this technology is in furniture, particularly chairs, which are increasingly being embedded with health monitoring sensors—everything from sensors that monitor and provide feedback on the user's posture, to radars that track heart health. These advancements could make furniture a part of personal health management, offering real-time insights into physical well-being.

Another example is Tagnoo, a type of plywood embedded with RFID tags. This plywood can sense the presence of objects and activities within a room in real time, making it a valuable tool for creating responsive, data-collecting environments. Like conventional materials, this plywood functions like ordinary wood in construction but has the added benefit of computational abilities, a plus for smart buildings.

WHY IT MATTERS

The potential for integrating sensors directly into building materials represents a significant leap in smart technology. By turning walls, floors, and even furniture into interactive surfaces that collect data, this technology can enhance automation, provide new sources of information, improve energy efficiency, and increase comfort and safety in residential and commercial spaces. These innovations also reduce the need for additional electronic devices, which can lead to more aesthetically pleasing designs and lower energy consumption. Fully realizing this integration will require changes to production, manufacturing, and electrical planning, as well as increase the need for connectivity within the built environment.

The convergence of health monitoring with smart environments underscores the growing importance of technology in enhancing everyday life, from comfort to wellness. The new data collection and sensor integration could turn more spaces into places of care and extend the health care system into homes and offices. As we move towards smarter environments, the ability to embed technology seamlessly into our surroundings will be a key driver of change, making our interactions with our spaces more intuitive, smart, and personalized.

SCENARIO YEAR 2034

INCLUSIVE AGING FACILITIES OF THE FUTURE

March 18, 2034—Today marks a groundbreaking moment in senior care as the highly anticipated VidaFutura Senior Residence opens its doors, setting a new standard for how we support our aging population. This state-of-the-art facility, located in the heart of Madrid, combines cutting-edge technology with compassionate care to create an environment where seniors can live comfortably, safely, and independently.

At the heart of VidaFutura's inclusively designed facility is its fully integrated smart furniture and wearables: seemingly-ordinary items like the living room coffee tables are anything but ordinary, and deliver a new level of convenience and care. Embedded with advanced touch controls, these tables offer a seamless blend of functionality and design. With just a simple touch, residents can adjust the room's lighting, control the volume of music, or start their favorite TV show. The tables also include temperature-controlled coasters that monitor the heat of a cup of coffee, automatically cooling it to the perfect drinking temperature or sending a reminder if it's getting cold. For those with sensory impairments, wearables help by translating visual information into auditory cues or haptic feedback, making navigation and daily activities more accessible. And of course, there's VidaFutura's most remarkable feature: personalized comfort. The entire building utilizes occupant-centric control technologies, optimizing temperatures based on individual needs, ensuring that every resident feels just right in their living space.

This focus on thermal inclusivity is just one example of how VidaFutura is leading the way in creating environments that adapt to their residents, rather than the other way around. VidaFutura Senior Residence stands as a beacon of what's possible when technology and care come together. This facility not only offers a glimpse into the future of senior living but also provides a model that will undoubtedly inspire similar advancements around the globe.

SMART CITY IMPLEMENTATIONS

2ND YEAR ON THE LIST

INTELLIGENT BUILDINGS

WHAT IT IS

The next generation of intelligent buildings, structures that can think and operate on their own, is focusing on both exterior innovations and the integration of advanced interior systems, to significantly enhance energy efficiency, sustainability, and security.

HOW IT WORKS

New intelligent building technologies include exterior features like walls with rotatable units that automatically open for ventilation or close for insulation based on real-time data, to optimize energy and comfort. Designs are now integrating kinetic, movable architectural elements with AI, leading to more dynamic and responsive exteriors. And intelligent, interconnected buildings are using networked photovoltaic glass to share surplus energy, creating efficient microgrids.

Inside, significant progress has been made with new platforms like Honeywell's Advance Control for Buildings, which integrates cybersecurity, faster network speeds, and autonomous decision-making tools. This platform meets the rising demand for energy-efficient, intelligent buildings by identifying maintenance issues, reducing emissions, and improving operational efficiency.

Security systems have also advanced, incorporating deep learning-powered facial recognition for better identity verification, even in complex scenarios. Smart devices' voice controls are more sophisticated, enhanced with speech recognition systems that better distinguish between words and background noise, for user-friendly interactions. New AI-driven platforms can now, on their own, optimize separate subsystems like HVAC, lighting, and security by making simultaneous real-time adjustments to all of them.

WHY IT MATTERS

The shift toward intelligent buildings is significant for several reasons. For one, it reduces the need for constant supervision and manual processes in facilities. It also addresses the growing demand for sustainable and energy-efficient solutions in urban environments. But these innovations are also paving the way for a more interconnected urban infrastructure. As intelligent buildings become more sophisticated, they can offer better protection against intrusions, optimize work environments, and even improve the overall quality of life for occupants. The convergence of AI, IoT, and advanced building materials is driving a new era of design, where structures, places, and spaces are not just passive spaces but active participants in their communities or within a company.

While the exterior of buildings is becoming increasingly intelligent, kinetic elements may soon go beyond simple adjustments like adjusting window shades or lighting, evolving into fully adaptable architectural features that respond to the needs and preferences of occupants in real time. As exterior elements become more dynamic due to AI integration, so too will interior spaces, creating opportunities for self-managing intelligent space allocation.

2ND YEAR ON THE LIST

SMART HOME AUTOMATION AND MONITORING

WHAT IT IS

Smart home automation is rapidly advancing with adaptive systems that optimize energy efficiency, safety, and comfort.

HOW IT WORKS

One of the most innovative developments in smart homes involves using AR to proactively identify and mitigate potential hazards. Based on sensor data, the system detects risks such as slippery surfaces or low-hanging obstacles. The AR then generates a visual overlay that suggests actions like placing a rug or adjusting an object's height, so homeowners can address safety concerns before they escalate. Other advancements significantly enhance automation and monitoring. Equipped with sensors, these systems continuously gather data on environmental factors like humidity, temperature, and air quality across various rooms. The core innovation lies in AI algorithms that process this data in real time, filtering out noise, detecting anomalies and reacting. For example, if the humidity reaches uncomfortable levels, the AI automatically activates a dehumidifier, to maintain optimal conditions without unnecessary energy use. Companies like LG, with new platforms like ThinQ, analyze user behavior and environmental data to automatically adjust lighting, temperature, and other settings based on the time of day, personal preferences, or weather conditions. Beyond comfort, AI plays a critical role in detecting hazardous anomalies. If these systems notice risks like water leaks or fires, they can execute preprogrammed responses, such as shutting off water or activating fire suppression, to mitigate potential damage based on insurance parameters.

WHY IT MATTERS

In the era of remote work and rising prices, homes continue to evolve. The increased expense of homeownership means people are staying put; they are preferring to do renovations over buying a new home and keeping multiple generations under one roof. More renovations could become about smart home integration, but since most construction and renovation companies don't offer these services, it may open the door for new players to enter the built environment market. AI's inclusion in smart home systems looks to not only enhance comfort and convenience but also play a critical role in energy efficiency and home safety. By automating responses to environmental changes and potential hazards, smart home technology reduces the need for constant human oversight, freeing up homeowners to focus on other tasks. As these technologies become more sophisticated, they will likely influence broader aspects of daily life. For example, AI-powered home management systems could eventually integrate with broader smart city infrastructures and contribute to more sustainable urban environments. Additionally, as the technology matures, it may offer more personalized living experiences that adapt to the specific needs and preferences of individual occupants in real time.

2ND YEAR ON THE LIST

SMART PARKING AND ROADWAYS PREDICTABILITY

WHAT IT IS

AI-driven advancements in parking and roads are poised to create safer, more efficient urban environments by optimizing traffic flow, parking logistics, and city management.

HOW IT WORKS

The US Department of Transportation has allocated $15 million to the Complete Streets AI Initiative, which aims to enhance street infrastructure by addressing data gaps in traffic and pedestrian patterns. A new patent looks to explore the potential of UAVs and drones to monitor roadways and patrol streets for issues like crime and congestion. In parking facilities, AI-based systems continue to dynamically improve space management and vehicle movement. New patents are exploring vertical parking along with automated parking and storage of bikes and cars. Meanwhile, AI upgrades to streetlights and cameras are making driving safer: A new bio-inspired event camera system, integrated with AI, detects obstacles and pedestrians much faster than traditional cameras by capturing motion instantly, without the delay of sequential frames. This technology, up to 100 times faster than current systems, helps autonomous vehicles and other systems respond rapidly to changes and safety issues. Researchers are also developing AI-driven highways to help autonomous vehicles navigate more safely by processing real-time data from vehicles, traffic signals, and environmental sensors. These highways provide that information to the vehicles to reduce accident risks.

WHY IT MATTERS

The complexity of future urban environments requires smarter, more responsive infrastructure, with AI playing a critical role. By improving traffic flow and managing parking dynamically, AI reduces congestion, lowers emissions, and enhances urban mobility and safety. It also brings economic benefits, such as better space utilization in parking garages. For city governments, the integration of AI into street management can reduce the costs associated with traffic incidents and infrastructure maintenance. The use of UAVs for real-time city monitoring allows for proactive management, addressing issues like road damage before they get worse. As our on-demand world grows, these AI advancements lay the foundation for smarter, more resilient cities capable of meeting future demands.

As UAVs and other new methods of transportation continue to be developed, the structures that house them and the roadways they use will need to evolve. However, because most infrastructure lags behind on today's technology, municipalities should look for ways to leapfrog into what is needed for tomorrow. Cities should also begin to develop a communication plan for what these tech-enabled roadways and parking structures will be able to do so that residents do not default to today's use strategies.

2ND YEAR ON THE LIST

UBIQUITOUS SENSOR DISTRIBUTION

WHAT IT IS

Sensors—embedded in everything from bridges and buildings to public utilities and roadways—make smart cities possible. New ways to deploy the sensors and transmit their data will spread their use even further.

HOW IT WORKS

Sensors in smart cities collect a vast amount of data. They're essential for monitoring and running these cities. But one hurdle in the way of more extensive sensor networks is the need for reliable power and regular maintenance. Researchers are addressing this with triboelectric nanogenerators with sensors that harvest ambient kinetic energy, such as vibrations from traffic, which will provide continuous operation without external power.

Sensors now can feed data into existing platforms like Software AG's Cumulocity IoT, which Itron uses to enhance utility management. The platform's support for Lightweight M2M allows for the efficient integration of devices like smart meters and streetlights, crucial for cities with limited connectivity. Other new adaptive transmission systems for indoor multi-lidar sensor networks adjust data size in real time, prioritizing critical 3D sensing data and enhancing the safety and efficiency of autonomous systems. Two patents for audio-based sensors look to analyze sound patterns and noise monitoring, using IoT and edge computing, to identify high-noise-pollution areas; this data could help urban planners decide, among other things, whether to implement zoning regulations or design noise barriers. The success of these sensor-driven systems hinges on education and skilled labor, exemplified by Saudi Arabia's Vision 2030, which trains engineers in IoT sensors to support the development of NEOM, a smart city focused on sustainability.

WHY IT MATTERS

The potential for smart cities to transform urban life is immense. The deployment of sensors across smart cities and homes significantly increases the amount of structured data available—data that's vital for powering informed decisions to improve urban living conditions, enhance infrastructure resilience, and support the development of sustainable smart cities. As cities evolve, these sensors will become even more central to their operation, but many new buildings and infrastructure projects are not planning for their full-scale use. Training workers on sensor integration like what is being done in Saudi Arabia needs to rapidly increase, and data collection practices should be folded into upskilling and current education models. We will also need to begin to add new services for repairing and replacing sensors in ways that do not disturb finished surfaces. While it may seem apparent that sensors and data collection can benefit residents, they will need to know what sensors are being deployed where and how to manage their own data. Messaging from developers, city officials, and all built environment professionals needs to begin immediately so that the public embraces the technology and is on board when sensors become an everyday presence in their cities.

2ND YEAR ON THE LIST

DIGITAL TWIN PREDICTIVE PLANNING

WHAT IT IS

Digital twins are replicas of physical structures that evolve alongside their real-world counterparts, thanks to continuous input from sensors and other technologies, making them invaluable for predictive maintenance and planning.

HOW IT WORKS

Building information modeling (BIM) has long been essential in architectural planning, streamlining design with detailed, data-rich models. Digital twins are the next step up. However, just as with initial BIM models, creating digital twins has been time-consuming and costly. Now, advanced 3D scanning is revolutionizing the process. These scanners rapidly produce accurate digital models from physical prototypes, drastically reducing modification time. Companies like GeoCue are advancing the field with mobile scanning systems that enable real-time updates to digital twins as technicians walk through sites. This feedback will benefit industries requiring precise monitoring and quick decision-making, such as manufacturing and urban planning.

Engineers, designers, and manufacturers are also using digital twins earlier in product development and throughout a project's lifecycle, simulating building material performance and design changes, and optimizing energy efficiency and occupant comfort. Researchers are developing blockchain-based encryption to secure the vast data these digital twins generate, for integrity reasons and to facilitate smooth project completion handovers. Emerging technologies are also making digital twins more accessible by enabling voice-controlled searches through natural language processing. These advancements make digital twins more of a management tool beyond mere predictive reports.

WHY IT MATTERS

With the ability to provide real-time insights and predictive analytics, digital twins are set to become a cornerstone of the built environment, offering unprecedented levels of control, efficiency, and sustainability. They're also rapidly becoming more than just a tool to generate predictive reports for engineers and architects—they are evolving into comprehensive advisors that can guide decision-making throughout the lifecycle of a building or product.

Digital twins will become an essential part of the built environment. They will also drive innovation and offer new opportunities for efficiency and sustainability. Soon, everything could have a digital twin. The next step will be to enable larger digital twin mesh networks so that these technologies can speak to one another. These two potential futures present vast challenges to an industry barely managing to create smart BIM models. Products and spaces in development today can benefit from planning for future conversion into digital twins. Companies should consider finding partners that can convert existing BIM assets into digital twins to increase their connective capacity in the future. They should also be prepared to connect with a city's digital twin for project planning, bidding, and reviews.

1ST YEAR ON THE LIST

INTELLIGENT URBAN MANAGEMENT

WHAT IT IS

Smart city intelligent management systems promise to automate spaces and communities by optimizing resource allocation, monitoring health and safety, and improving access to city services.

HOW IT WORKS

A new patent is upending urban management by using AI and machine learning to monitor and predict pedestrian traffic in public spaces like parks and entertainment venues. The system divides areas into subsections, and analyzes real-time data and historical patterns to forecast crowd density. When pedestrian volume nears capacity, alerts prompt city operators to take action, such as redirecting visitors or closing areas, to prevent overcrowding and ensuring safety. AI is also improving health and safety through automated route planning for tasks like street cleaning and dust suppression. These systems analyze environmental data to optimize routes, reduce pollutants and also conserve resources. This automation leads to cleaner, safer streets with less manual effort. Other new systems look to optimize police patrols, fire rescue allocation, and respond to resource requests. And tools like New York City's MyCity portal are augmenting how residents interact with city services. The AI-powered platform streamlines access to services, so that residents can check eligibility, apply, and track applications in multiple languages. This reduces bureaucratic hurdles and boosts resident satisfaction, especially in cities facing urban decay. Other intelligent platforms are more tactical for uses like property management, such as TruBoard Partners' asset management and monitoring platform that integrates with existing systems to provide real-time updates and predictive analytics for the real estate industry.

WHY IT MATTERS

As urban populations grow, the need for smarter, more efficient city management systems becomes critical. The integration of AI into urban planning not only enhances safety and efficiency but also significantly improves residents' quality of life. In particular, these innovations can benefit cities facing rapid growth or struggling with urban decay. By making city services more accessible through advanced apps and portals, local governments can improve resident satisfaction and engagement, helping to revitalize areas in decline. These technologies also provide cities with agility to respond to unexpected events, such as natural disasters or public health emergencies.

Underserved communities may be wary of these systems, as they already struggle to keep up with newer developments. However, properly created and utilized management systems could help highlight and allocate resources to these impoverished areas—as long as they are accounted for in the initial data. Ultimately, these intelligent urban management systems represent a significant potential step forward in creating smart cities that are better managed to meet the needs of their inhabitants.

SCENARIO YEAR 2032

FIRES RAGE AROUND FOREVER PARK

It's a warm summer evening in 2032, as families gather in Forever Park for a picnic and children play on the resilient playground equipment. Suddenly, a small fire ignites in several trash bins near the park's entrance. The sparks that lit the trash were from a nearby wildfire that suddenly shifted course. At first, families were alarmed, but the park's UAV broadcast an XR alert to their wearables to remind them that this park was prepared for just such an occasion. When the park was built, all of its equipment was additively-made using self-healing materials, with a topcoat of fire-retardant smart gel to extinguish the flames. Park workers selected trees and shrubs to resist the flames, and any damaged materials will be picked up for reuse in a local additive manufacturing hub. As the families watch, UAVs run by the city's smart hub appear and the fire is extinguished almost as quickly as it started, leaving only a faint trace of smoke. Nearby, the fire-resistant trees stand unaffected, and the park's self-healing benches and playground equipment quietly begin to repair the minor damage caused by the heat. Within hours, the park looks as if nothing had happened at all.
In the days following the fire, the park's automated systems continue their work. Areas that were slightly scorched are already being assessed, with new fire-resistant plants scheduled for replanting, so that the park remains as vibrant as ever. Forever Park stands as a testament to the future of urban design—where technology not only enhances the resilience of public spaces but also enables them to evolve and adapt, to keep them sanctuaries of safety, sustainability, and natural beauty for generations to come.

CONSTRUCTION PRACTICES

2ND YEAR ON THE LIST

MASS TIMBER CONSTRUCTION

WHAT IT IS

Mass timber construction is set to transform architecture and sustainability by pushing technological and structural boundaries.

HOW IT WORKS

Mass timber, including cross-laminated timber (CLT) and glulam, is gaining popularity for its ability to reduce carbon footprints and speed up construction. Increasingly, these timber structures contain other innovations like real-time moisture sensors that could soon help prevent mold and mildew, to enhance durability. Robotic automation patents in mass timber panel production aim to further improve precision and efficiency, by having robots manage tasks like cutting and assembling large timber elements for rapid onsite assembly.

A key advancement is an adaptive lumber management system, which optimizes CLT panel creation. Using X-rays, lasers, and multichannel vision systems, the system analyzes each piece of lumber in detail. AI-driven optimization ensures each board is positioned for maximum bondable area and visual quality. The industry is also exploring new wood species, such as hardwoods, for CLT production. Researchers are identifying optimal resins, pressures, and processes to certify these materials, potentially expanding the range of mass timber options globally.

Mass timber's appeal also includes aesthetic and environmental benefits. Vertiv's TimberMod data centers, built with mass timber instead of steel, reduce carbon footprints by up to threefold. Timber structures meet structural requirements, are attractive, and withstand extreme conditions like seismic activity and high winds.

WHY IT MATTERS

As urbanization accelerates and environmental concerns mount, mass timber offers a renewable, carbon-sequestering alternative to traditional construction materials. Projects like the proposed 55-story timber skyscraper in Milwaukee highlight the scalability and potential of mass timber in high-rise construction, pushing the envelope on what's architecturally possible. Timber, being renewable and requiring less energy to produce than steel or concrete, is an attractive option for increasing sustainability in the built environment. Also, the integration of advanced sensor technology and robotics in timber construction enhances durability, safety, and precision, making it a more competitive choice for developers who traditionally have shied away from this construction method because of costs and longevity concerns.

These advancements signify a pivotal moment for the construction industry, where mass timber could become a mainstream material for various types of buildings, from residential to commercial and industrial projects. This trend not only supports the push for greener cities but also addresses the need for faster, more efficient construction methods. As mass timber technologies continue to evolve, we can expect to see more ambitious projects and broader adoption across the globe.

2ND YEAR ON THE LIST

ADDITIVE CONSTRUCTION

WHAT IT IS

Additive manufacturing, commonly known as 3D or 4D printing, is expanding beyond its traditional boundaries, scaling up in both practice and innovation. These developments are helping to make the additive construction of structures, materials, and buildings become more of a norm.

HOW IT WORKS

ICON's Phoenix, a robotic-arm-mounted 3D printer unveiled at SXSW in 2024, is pushing the boundaries of large-scale 3D printing by constructing fully enclosed, multistory buildings from a low-carbon mixture. This innovation allows for complex structures, such as domed roofs, which are currently being prototyped in Austin. Meanwhile, photonic chip integration with 3D printing is revolutionizing rapid prototyping. These chips can steer light beams to print 2D patterns at unprecedented speeds, with applications in device manufacturing and on-site engineering.

The sustainability potential of 3D printing is exemplified by Ecoalf's Madrid retail space, featuring a 3D-printed interior made entirely from 3,300 kilograms of recycled plastic, reducing its environmental footprint. In Barcelona, La Manso's store incorporates 3D-printed elements that echo the city's architectural heritage, demonstrating how 3D printing can blend modern design with cultural motifs, offering customization that traditional methods struggle to achieve. However, speed remains a challenge, especially for detailed work, where the resolution of printed layers—ranging from low (faster, less detailed) to high (slower, more detailed)—dictates the balance between speed and quality. Innovations in 3D printing materials, such as plant-based composites and recyclable natural-material floor panels strong enough to replace steel, are also driving more sustainable building practices.

WHY IT MATTERS

The scaling of additive construction is set to have a profound impact on multiple industries throughout the built environment. However, most companies think of 3D printing as still being in its infancy, a judgment that puts them at risk of disruption. They'll be unprepared for how to design additively made spaces and products. The rapidity of the printing methodology and its possibilities for creating reactive materials will mean that firms that embrace this technology will win out over their competitors who do not. To fully realize these benefits, the industry must overcome the challenges of speed and material limitations, and ensure that additive manufacturing can scale efficiently across various applications.

As additive manufacturing continues to mature, it promises to reduce the environmental footprint of construction, lower costs, and provide innovative solutions that are not feasible with traditional building methods. The ability to incorporate local cultural elements into designs offers new opportunities for spaces and products to connect with users and communities in new and meaningful ways. The technology's applications for humanitarian efforts like housing should prompt cities and governments to heavily invest in its adoption, which will require relevant training and education for future professionals.

“

I can’t think of any other industry for which you prefer the hundred-year-old thing instead of the brand new thing.

Jason Ballard, Co-founder & CEO of ICON

2ND YEAR ON THE LIST

INTERACTIVE PROJECT MANAGEMENT

WHAT IT IS

Interactive project management platforms are transforming construction management by integrating data acquisition, decision-making, and real-time feedback.

HOW IT WORKS

The construction industry is undergoing a major transformation with intelligent project management platforms that manage the entire project lifecycle. These platforms leverage advanced AI and neural networks to handle complex 5D data, including city, security, quality, progress, and cost information. A key innovation is Sage's native-cloud solutions, particularly the Sage BidMatrix platform, which simplifies the subcontractor selection process, enabling estimators to manage bids, assess risks, and optimize strategies effectively. The new web interface, integrated with Microsoft's Power BI, enables real-time collaboration and detailed analysis of centralized estimating data among all team members.

Managing change orders, traditionally a cumbersome process, is also revolutionized by platforms like Clearstory. The company handles over 19,000 change orders every month, but uses AI to automate categorization and reviews, reducing administrative burdens and increasing project transparency. This not only saves time but also minimizes costly errors, leading to more efficient project completion. Platforms like Trunk Tools further streamline operations by automating scheduling and documentation through its AI-powered Schedule Agent, which proactively identifies and addresses potential issues. INGENIOUS 2.0 exemplifies this shift with an upgraded interface and real-time project tracking, enabling managers to oversee complex projects with precision.

WHY IT MATTERS

Through interactive project management systems, construction companies will be able to address long-standing issues such as inefficiencies in cost estimation, the complexity of managing change orders, and the cumbersome nature of project scheduling. By automating these processes, AI platforms help construction teams deliver projects more quickly and with greater accuracy, all while staying within budget.

For an industry that has traditionally lagged in digital adoption, these AI-driven tools represent a critical step forward. They can help managers, teams, and clients to respond to issues as they arise, rather than after the fact. This proactive approach minimizes the risk of project delays and cost overruns, which are common in large-scale construction projects. These advancements also bring to light the industry's persistent challenges, particularly the digitization of historical data, which remains a costly and cumbersome process. However, the adoption of AI and cloud-based tools is driving significant improvements in efficiency and project outcomes, signaling a shift that firms must embrace or risk falling behind. Construction companies waiting for proof of financial savings should begin by experimenting with these new systems in order to not fall completely behind as they are outbid by competitors using their new tools.

2ND YEAR ON THE LIST

MODULAR CONSTRUCTION

WHAT IT IS

Modular construction is evolving beyond traditional applications, driven by innovations in office design, temporary housing, and renewable energy infrastructure.

HOW IT WORKS

Modular construction, known for its efficiency and sustainability, is evolving thanks to advanced technologies. Designers can use AI-driven generative design to quickly optimize layouts, especially for open-plan offices, through performance-based algorithms. Recent patents further drive this trend: A new modular desk frame that is collapsible and movable is transforming office layouts, enabling flexible, nontraditional workspaces. Additionally, a modular floor assembly, including adjacent walls, is designed to speed up construction by simplifying on-site integration.

The need for resilient infrastructure has led to innovations in modular materials that can be assembled and reconfigured by robots. These building blocks are used to create large structures for disaster recovery. In the Netherlands, modular construction is being applied to build transportable and reusable housing for refugees to promote self-sufficiency and long-term community integration. In energy infrastructure, the m-Presa modular steel buttress dam system is transforming the construction of pumped storage hydropower facilities. By using prefabricated steel modules, this system cuts costs and construction time, making renewable energy storage more feasible as cities face aging infrastructure and increased demand for disaster-resistant construction.

WHY IT MATTERS

This trend and the signals underlying the trend represent a potential paradigm shift in the industry. The integration of AI and generative design into modular construction not only accelerates the design process but also improves the adaptability and functionality of built environments. As global cities grapple with the need for rapid, cost-effective, and sustainable building solutions, modular construction offers a pathway to meet these demands. This is particularly important in a post-pandemic world where the flexibility of workspaces and residential areas is paramount. The expansion of modular construction into renewable energy and temporary housing sectors underscores its versatility and relevance in addressing contemporary challenges. The ability to quickly construct and deploy modular structures in response to crises—whether due to natural disasters or humanitarian needs—demonstrates its potential as a tool for resilience.

For urban planners, architects, and policymakers, the trend represents an opportunity to rethink how we build and maintain our cities. It offers a scalable solution that can be tailored to specific needs, from temporary housing to permanent infrastructure. The technology's evolution puts the modular construction industry in a position to shape the future of urban development, making it more responsive to the needs of a rapidly changing world.

2ND YEAR ON THE LIST

AUGMENTED CONSTRUCTION

WHAT IT IS

The use of robots and other automated processes is changing construction practices and reporting, reducing both project timelines and worker risk.

HOW IT WORKS

AI-driven platforms like Buildots monitor the progress of tasks such as laying concrete or installing windows by creating a digital twin of the building, using data from strategically placed sensors and cameras. This real-time tracking system helps to keep construction projects on schedule and enables quick decision-making to address delays. While manual inspections still remain vital for tasks requiring human expertise, field engineers can now use mobile apps to verify that installations are meeting both efficiency and quality standards.

Worker health and safety are also improving through augmented safety technologies. Companies like Balfour Beatty have instituted a requirement for AI-powered cameras that recognize human forms on heavy machinery to detect workers near hazardous equipment, reducing accident risks. AI is further revolutionizing construction through advanced simulation frameworks like RoboCasa, which train cobots to adapt to various tasks in virtual environments resembling real-world sites. Additionally, micro-cobots, such as a flea-sized robotic crab developed by Northwestern University, are ideal for detailed inspections and repairs in confined spaces, reducing the need for large-scale interventions and streamlining construction processes.

WHY IT MATTERS

While controversial, this trend holds a potential solution to an industry dealing with a diminishing workforce. It is important that leaders and their teams see that this trend is not about replacing human workers but augmenting their work. It enables new workflows and practices that may be challenging, but the integration of augmented construction technologies is revolutionizing how projects are managed by enhancing both efficiency and safety. These advanced systems offer real-time insights so that companies can act quickly at any hint of a delay, to maintain project timelines. By continuously monitoring and addressing potential hazards, augmented construction tools significantly lower the risk of accidents.

As these technologies evolve, they will redefine industry standards for safety, quality, and operational flexibility. This will be an adjustment for a traditional industry that is already dealing with technological debt. Adopting some of these new capabilities will come at a cost. However, strategic planning can aid in understanding and prioritizing which technologies to adopt first. Companies that embrace these innovations early could be leaders in setting new benchmarks, as augmented tools will become essential for managing complex tasks.

SCENARIO YEAR 2032

REWILDED EARTHQUAKE FORESTS OF SAN FRANCISCO

As I walked through San Francisco's newly unveiled "Rewilded Earthquake Forest," I couldn't believe my eyes. It's hard to describe the feeling of being surrounded by towering trees that aren't just here for their beauty—they're actively protecting the city from earthquakes. As I strolled along the winding paths of this green sanctuary, I learned that these trees, like Mediterranean cypress and coast redwood, were chosen not only for their resilience to fire but also for their incredible ability to absorb and dampen seismic waves. It's like walking through a living, breathing shield that's constantly adapting to keep the city safe.

What really blew my mind was seeing the robot construction workers in action. These aren't your typical construction robots; they're part of a fleet that can move and reconfigure the structures and trees based on what the city needs at any given moment. As I explored more of the park, I realized just how much thought had gone into every aspect of its design. The city's AI system continuously monitors and updates the park, ensuring that every tree and structure is perfectly placed to maximize its protective capabilities. Walking through these parks, I felt an incredible sense of security, knowing that this green belt around the city isn't just a beautiful space—it's a vital, living barrier that adapts and evolves to keep us safe. It's a glimpse into the future of urban living.

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NEWS & INFORMATION

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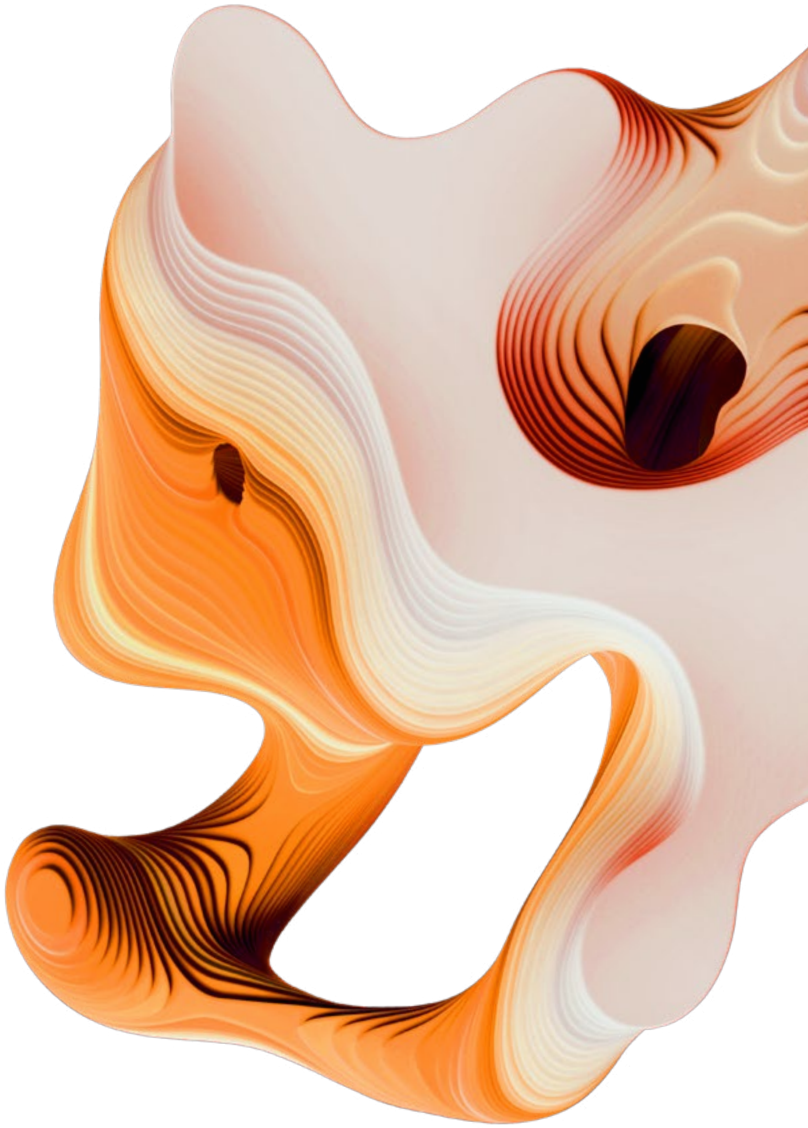


Sam Guzik
News and Information Lead

A chaotic year ahead.

Imagine the news and information ecosystem as a duck swimming on a lake. There was an appearance of serenity last year, as news organizations doubled down on familiar strategies to keep the water placid. Yet just beneath that calm veneer was furious paddling as journalists raced to find applications of generative AI that could keep the industry stable. In 2025, a combination of technologies, regulations, and the political climate will shatter that calm like a hunter with a twelve-gauge shotgun—spooking the duck, sending ripples across the lake, and forcibly creating a new reality.

The technologies that started to transform the information economy last year will keep maturing. Consumers will encounter synthetic media in more places, and advances in generated images and videos will make it even harder to determine what is real: expect to see at least one major publisher fooled by an AI-generated hoax in the coming months. Publishers will keep fighting with tech companies about the value of their content, even as search engines and device manufacturers duke it out for a dominant position in the shifting landscape for content discovery—a fight that will almost certainly leave publishers with a weaker competitive position than before. But none of that is new; the real change in 2025 will be a brutal regulatory and political environment. If Congress repeals Section 230, it might make hosting companies think twice about providing services to aggressive investigative news outlets. We will see newsmakers file more lawsuits to punish or intimidate journalists who publish adversarial reporting. All of this will happen as our dominant social networks divest from content moderation, leaving users vulnerable to coordinated misinformation campaigns and toxic content.

The litany of threats facing the news ecosystem is dire—its collapse would have deep economic ramifications and would upend our civic life. But recognizing the stark reality ahead of us is a step toward choosing a different future. Let 2025 be the year we turn our backs on dated strategies and choose to invest in reinventing our information infrastructure.

Patterns for distributing and discovering information are breaking.

1

AI is driving change and will keep shifting the information ecosystem

The most substantive economic impact of AI to date has been licensing payouts for a handful of big publishers. The competition will start shifting in the year ahead to separate AI “haves” that have positioned themselves to grow from the “have-nots.”

2

News organizations need to adapt to shifting norms

Trust in news is at historic lows. The Trump administration is taking steps to limit the access of independent news organizations. Publishers will need to navigate a hostile landscape as they try to stay relevant.

3

Content verification is getting harder

Journalists and others who depend on accurate information face growing challenges as AI-driven manipulation blurs the line between real and fake media. Tools that both generate and verify AI-manipulated content will drive a technological arms race.

4

Synthetic media is flooding the internet, confounding news discovery

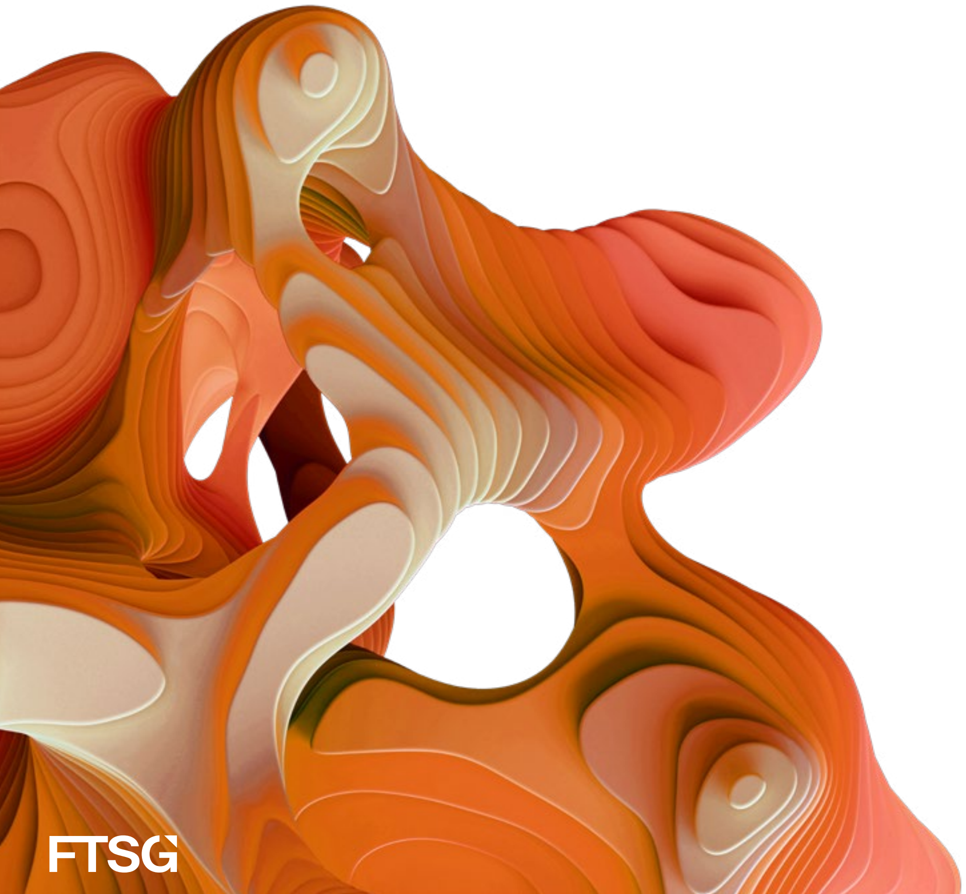
Even though fears of rampant fake news generated by AI have not yet materialized, publishers and creators increasingly need to stand out against the tsunami of derivative summaries and rewrites hitting the internet.

5

Successful applications of AI in news will build on human reporting

AI avatars are creating new distribution channels for news organizations while human journalists handle the reporting and maintain creative control. This strategy is helping publishers engage younger audiences and protect reporters in dangerous areas.

The information ecosystem is fragmenting.



The evolution of generative AI is ongoing, but the contours of the near-term media landscape are taking shape: A gap is growing between early adopters of AI and cautious observers. Large news organizations—and a handful of innovative upstarts—are actively experimenting with how to integrate AI into their operations, while many more outlets sit on the sidelines. But while there is great enthusiasm for AI, the technology's biggest economic impact has been an infusion of cash to large-scale publishers like Axel Springer, the Associated Press, and Hearst Newspapers. All three were among the news organizations that entered into content licensing agreements with tech giants like OpenAI; the long-term wisdom of those arrangements remains uncertain.

A more fundamental disruption looms in how AI might supplant the media's traditional role in building communities and social cohesion. As AI systems become more sophisticated at delivering personalized, contextual information and engaging in natural dialogue, they could satisfy some of the need for connection that news organizations have historically met. This shift is particularly significant given the already fragile state of local community bonds, declining trust in legacy media, and the migration of social discourse to online spaces. While the implications of that change unfold, news leaders may need to reconsider the function and value of their organizations in a world where people are increasingly unmoored from their communities and lack interpersonal bonds with each other.

The power dynamics between tech companies and creators will keep evolving. Publishers may gain more leverage as tech giants search for up-to-date, high-quality content to advance state-of-the-art frontier models. However, newsrooms will need to carefully consider their strategic direction to balance the potential benefits of short-term licensing revenue against the risks of dependency on technology platforms. Regardless of how they proceed, the ultimate challenge for media organizations will be maintaining their essential role in fostering informed communities while adapting to an increasingly AI-mediated information landscape.

A chaotic year where AI established itself as a mainstream force.

JANUARY 2024

The Messenger Folds

A year of layoffs starts with the news site's demise, and staff reductions continue across the industry.

MARCH 2024

Pulitzer Finalists Used AI

Five of 45 finalists for the prestigious journalism prize disclosed using AI tools in their reporting.

JULY 2024

SCOTUS Sides with Social Media

The US Supreme Court blocks state regulation of social media in Moody v. NetChoice.

AUGUST 2024

CA Negotiates News Funding

California gets Google to pay $250 million for news in exchange for not passing a new law.

SEPTEMBER 2024

X Banned in Brazil

Elon Musk's social network is briefly banned for failing to comply with court orders.

« PAST

Technical and regulatory forces will exert new pressure on publishers.

FUTURE »

EARLY 2025

CA News Fund Launches

The News Transformation Fund formally launches; how it distributes funds will be closely watched.

SPRING 2025

Annual Media Impact Forum

The journalism industry's biggest major funders will gather to share ideas.

JUNE 2025

First Amendment Cases

The US Supreme Court has a handful of First Amendment cases on its docket for 2025.

JUNE 2025

NextGen Broadcasting Conference

The standard-setting body for the next generation of broadcasting will hold its annual meeting.

AUGUST 2025

EU Media Freedom Law

New EU rules protecting journalists and regulating transparency in media ownership take effect.

The evolving media ecosystem will shape our society.

We All Need Reliable News to Make Decisions

A growing body of research shows that losing local news outlets leads to more corruption, less competitive elections, and weaker government finances in impacted regions. Business leaders need to follow news and information trends so they can maintain the health of their operating environment. Without vibrant news organizations, leaders won't have the context they need to make informed decisions.

Publishers Will Influence the Future of AI

The development of generative AI models depends on vast amounts of data—and especially clean, well labeled data. A news organization's archive is full of billions of well-structured words. As tech companies look to train bigger models that stay aware of current events, publishers will be in a position to influence the future of AI. If news organizations falter, that could slow the development of new AI systems.

Search and Discovery Is Relevant to All

It's not only news organizations that need to consider how consumers encounter new information: The future of search and discovery is relevant for any business that wants to reach new customers. The shifting search and social media landscapes will make it harder for publishers to distribute news, but the same dynamics will impact retailers and other industries as well.

Verifying Information Is Essential

Journalists aren't the only professionals who need to be concerned with verifying the text, photos, and videos they encounter online: Deepfakes have already been used to perpetrate fraud and make phishing campaigns more believable. The tools that bolster the authenticity of our information ecosystem will help us all feel more comfortable taking action based on media that we encounter.

These Trends Predict Changes to Consumer Behavior

The ways that people consume and access information are changing. That has deep ramifications for publishers but is relevant to any business that depends on consumers getting information and making a decision with it—from finance to consumer goods and more. Understanding how media consumption is evolving will help leaders adapt to shifting customer preferences.

News Deeply Intertwines with the Advertising Ecosystem

News has historically been one of the core tools for building audiences large enough to sell to advertisers. These trends will drive the ongoing fragmentation of the media landscape, informing the strategies and technologies that advertisers need to reach consumers. Anticipating where people will get their information will help businesses that want to get a message out.

These individuals are at the forefront of development and transformation in the News & Information industry.

- **Dr. Manny Ahmed, founder of OpenOrigins,** a technology company dedicated to preventing disinformation caused by generative AI, for advancing content provenance work in media.
- **Matthew Conlen & Harsha Panduranga, co-founders of Realtime,** for prototyping a platform that uses AI to scrape, summarize, and format data in a user-friendly news product.
- **Ezra Eeman, director of strategy and innovation at Dutch Public Broadcasting,** for leading an AI initiative for WAN-IFRA, an organization that supports publishers around the world.
- **Francesco Marconi, co-founder of computational journalism startup Applied XL,** for developing and deploying AI systems that can surface substantive real-time insights.
- **Dr. Sun Joo "Grace" Ahn, founding director of the Center for Advanced Computer-Human Ecosystems at the University of Georgia,** for research on how people are affected by immersive media.
- **Florent Daudens press lead for Hugging Face,** for leading journalism outreach efforts—like publishing working examples to inspire journalists—at the AI company.
- **Araceli Gómez-Aldana, reporter at WBEZ,** for research conducted as a John S. Knight Journalism Fellow about using AI to facilitate the translation of local news into other languages.
- **Mattia Peretti, a 2024 ICFJ Knight Fellow,** for founding News Alchemists, a project aiming to redefine journalism around audience needs and financial sustainability.
- **Dale R. Anglin, director of Press Forward,** for leading a half-billion dollar, multiyear effort to bolster investment in journalism and civic infrastructure in the United States.
- **Dr. Nick Diakopoulos, director of the Computational Journalism Lab at Northwestern University,** for research on AI, automation, and algorithms in news production and distribution.
- **Monsur Hussain, head of innovation at Nigeria's Centre for Journalism Innovation and Development,** for building an AI system to support fact-checking claims on WhatsApp.
- **Nikita Roy, futurist and 2024 ICFJ Knight Fellow,** for systematic efforts to improve the quality of training and strategic conversations about AI in news organizations.

AI can help publishers develop new ways to reach audiences...

...but emerging devices and technologies are intermediating publishers from their users.

OPPORTUNITIES

AI-generated avatars that present news in multiple languages or dialects enable organizations to reach underserved or underrepresented audiences, improving content accessibility and driving higher engagement in new demographics.

With AI-powered search and voice interfaces, news organizations can offer personalized, conversational experiences, increasing user engagement.

AI tools can help news organizations get more value from their archives. With AI search improving, organizations can offer subscription-based access to deep, well-indexed content, making historical news accessible and monetizable.

AI systems can identify emerging trends or uncover hidden stories in large datasets. News organizations that invest in AI will have a competitive advantage uncovering unique, data-rich investigative stories for their audience.

THREATS

AI-generated news summaries risk stripping articles of critical context, particularly in sensitive or complex stories, which could lead to misinterpretations. This threatens journalistic integrity and may cause audience trust to decline.

The increasing sophistication of AI-generated deepfakes makes verifying content harder for news organizations. This erodes public trust and complicates efforts to distinguish authentic journalism from fabricated media.

As devices increasingly incorporate AI-generated summaries, news organizations risk being displaced in the content value chain. When publishers have less control over distribution, it is harder to pursue ad and audience revenue.

AI tools that repurpose original content pose intellectual property challenges. Creators risk losing control over how their work is used, leading to legal battles and tensions between tech companies and media organizations.

With planning, journalists can use AI to create new opportunities.

Reconsider how roles and responsibilities are distributed in your organization. Many news organizations keep technology and product teams siloed as a support function, rather than integrating them with the editorial team. Legacy organizational charts may be resistant to change; look for opportunities to reorganize staff in ways that improve collaboration and allow for faster experimentation.

Build direct partnerships with researchers and universities exploring applications of generative AI relevant to your business. Those relationships could help news organizations get earlier access to emerging technologies—and will let them shape how the field develops without relying on commercial products from big tech companies.

Explore products and experiences built around structured data. While LLMs are well positioned to disrupt the creation of traditional text, video, and audio formats, that's not the only way to meet people's information needs. With the right information architecture and user experience, local news organizations may be able to redefine themselves as purveyors of geographically relevant information.

Journalism schools and industry groups should double down on training that helps reporters verify information and identify manipulated media. The risk of widespread distribution of AI-generated misinformation is real; the time to prepare for a systematic attack on the information ecosystem is now, before false narratives reach audiences.

To trust AI-generated content, publishers should develop a sophisticated understanding of the AI supply chain. News organizations live and die by the accuracy of their products, so they need to be especially careful about "hallucinations" from AI. Now is when publishers should test different solutions, including whether open-weights models like Llama provide better results than commercially available models like Gemini or GPT-4.

The business of news relies on trust, and media companies should explore the particular drivers of trust for their audience. Those insights should inform investment decisions. But regardless of how much publishers decide to use AI or other new technology in their products, now is the time to start thinking about how to communicate those decisions to readers, viewers, and users.

Technology Deployment

Capital Expenditure

Talent Development

Regulatory Influence

NEWS & INFORMATION TRENDS

REPORTING & VERIFYING INFORMATION

4TH YEAR ON THE LIST

COMPUTER-DIRECTED REPORTING

WHAT IT IS

Artificial intelligence is transforming journalism by helping newsrooms analyze vast datasets, generate story leads, and automate some content creation. These tools offer the still-unproven promise of deeper investigative reporting and new modes of audience engagement.

HOW IT WORKS

Newsrooms globally are adopting AI-powered tools to take on meaningful tasks in the story production pipeline. For example, The Washington Post uses an AI tool called Haystacker to sift through large volumes of data. One story analyzed a database of political campaign ads to demonstrate that campaigns use outdated or misleading visuals in nearly 20% of advertisements about immigration.

While much of the experimentation with AI is happening at well-funded commercial newsrooms in the US and Europe, some smaller publishers are seeking out innovative applications of the technology: Pennsylvania's Spotlight PA developed an AI chat interface that provides voters with critical election-related information. This tool helps citizens navigate the complexities of electoral processes by delivering accurate, timely information via natural language responses. In Colombia, Cuestión Pública uses Odin, an AI-based system that generates social media threads based on the data that journalists uncover in their reports. By employing retrieval-augmented generation, Odin ensures that content is fact-based.

A broader trend is the integration of AI into routine news operations. For example, the Associated Press and AppliedXL launched an AI-driven platform that delivers updates on regulatory changes from over 430 federal agencies, helping newsrooms stay current with policy shifts and contextualize stories quickly.

WHY IT MATTERS

AI is shaping the future of journalism by making the news-gathering process more efficient and precise. Economists from the University of Chicago have found that journalists are among the most frequent professional users of AI. These tools help journalists work faster, allowing them to uncover hidden patterns in complex datasets that would be too time-consuming to analyze manually. As AI continues to improve, news organizations can focus more on investigative depth while AI manages routine reporting tasks.

AI tools can also enable enhanced voter engagement by delivering accessible, accurate information. In an era where misinformation can spread rapidly, AI can help verify facts and ensure that news is accurate and contextualized. Tools like Odin prevent hallucinations in AI-generated content, fostering trust between readers and news outlets.

By automating routine tasks, AI offers the promise that journalists could focus more on high-impact stories. Whether that is true, though, will depend on how newsroom leaders choose to use this technology. As more newsrooms adopt these tools, the landscape of journalism will shift toward a blend of human editorial oversight and machine-driven analysis, allowing for a richer, more detailed exploration of societal issues.

2ND YEAR ON THE LIST

SUMMARIZATION AT SCALE

WHAT IT IS

AI-driven summarization is transforming news consumption with the promise of quick, digestible insights available everywhere. As AI features are incorporated into consumer devices, the landscape for news distribution and discovery will change dramatically.

HOW IT WORKS

AI summarization technology is becoming a critical tool for managing the overwhelming volume of digital content. Media companies like USA Today and the Norwegian Broadcasting Corporation (NRK) have integrated AI-generated summaries into their articles, giving readers a quick overview before they dive into full stories. At USA Today, journalists review the three "key points" before publication, and a disclaimer at the bottom of the article discloses that the bullets were generated with AI. NRK's data shows that users who interact with its summaries engage with the article for longer and are more likely to be younger.

The emergence of models optimized for consumer hardware means that the curation function is increasingly integrated into devices, improving security and reducing the cost of generating summaries at scale. This localized processing opens the door for more personalized uses of AI summarization, such as blending news with personal information, emails, or messages.

However, this shift to AI-generated content isn't without challenges. Summarization models are prone to losing critical context, especially in nuanced reporting, which can lead to misinterpretations. In particular, AI models struggle with accurately handling direct quotes—sometimes altering or incorrectly attributing them as factual statements. This presents significant risks for news organizations, where misquoted or decontextualized information can damage credibility.

WHY IT MATTERS

AI summarization is fundamentally altering how we consume information by creating a faster, more efficient way to engage with content. For news organizations, this offers a double-edged sword. On one hand, AI-generated summaries cater to modern consumer habits—quick, skimmable content that fits within the busy lives of readers. On the other hand, this rapid shift comes with substantial challenges. The risk of removing context, misinterpreting content, or misquoting sources is real without careful training. Generative models don't intrinsically understand the meaning of quotation marks in news stories: Incorrectly paraphrasing or altering statements not only threatens journalistic integrity but also exposes organizations to reputational harm. As more platforms and devices embrace AI summaries, the potential for context erosion will only grow, raising concerns about the long-term implications for informed discourse.

As summarization models are increasingly built into devices, control over information distribution shifts away from publishers and into the hands of technology companies. Device manufacturers could potentially dictate what content gets summarized and how it is delivered, impacting the flow of traffic back to original news sources. This consolidation of power could marginalize smaller media outlets and reshape the economics of online journalism, forcing organizations to reconsider their digital strategies to stay competitive.

2ND YEAR ON THE LIST

CONTENT VERIFICATION IN A DEEPFAKE ERA

WHAT IT IS

Content verification tools face growing challenges as AI-driven manipulation blurs the line between real and fake media. Even with advanced verification systems, AI-generated content can still deceive audiences, posing risks to public trust in news and information.

HOW IT WORKS

These tools are designed to authenticate media by using algorithms that analyze digital content for signs of tampering, such as manipulation of video, audio, or images. They can compare an image or video with metadata, track visual inconsistencies, or use AI-based classifiers to determine whether content was digitally altered. Even when they work as expected, the tools can be abused: Shortly after President Biden was diagnosed with Covid in July 2024, conspiracy theories began circulating alleging he was dead. The supposed proof was a video on X showing ElevenLabs' AI Speech Classifier describing an audio recording of Biden as "very likely" AI-generated—but that "proof" had been faked by someone trying to fool viewers.

Leading initiatives like Adobe's Content Authenticity Initiative (CAI) are working to create more robust standards. CAI promotes a three-pronged approach through metadata tagging, watermarking, and visual fingerprinting, built on the C2PA (Coalition for Content Provenance and Authenticity) standard, to identify if content has been altered after creation. Other verification efforts, such as real-time detection systems, aim to incorporate signals of authenticity into the production of media to make it more resistant to tampering. One team at Nanyang Technological University in Singapore developed a system for detecting face manipulation and other types of deepfakes in real time based on how the image responds to vibrations triggered on the capture device.

WHY IT MATTERS

The rise of deepfakes and AI-generated content threatens to undermine the public's trust in media, politics, and even personal communications. The ease of generating fake images, videos, and audio means that even when media is authentic, the specter of manipulation looms large. When running for president in 2024, Donald Trump repeatedly alleged that images of Harris-Walz campaign rallies were faked using generative AI. Even when that notion was rejected by content verification experts and reporters on the ground, the rumor persisted online. The fact that existing tools for detecting whether content is created by AI can be easily defeated places special weight on publishers to build trust with their audience.

The proliferation of tools that both generate and verify AI-manipulated content will drive the next technological arms races in the media industry. The news sector, in particular, faces existential challenges if it cannot reliably prove the authenticity of its reporting. The stakes are high for content creators, journalists, and governments alike as they struggle to stay ahead of AI-based deception. As content verification becomes more necessary, adopting solutions that combine several techniques—like watermarking, metadata, and real-time detection—will be vital to maintaining trust in a world increasingly dominated by AI.

5TH YEAR ON THE LIST

SENSORY JOURNALISM

WHAT IT IS

As immersive headsets and other wearables gain market penetration, there will be new opportunities for journalists to tell stories that tap into their audiences' senses and emotions with emerging technologies like virtual and augmented reality.

HOW IT WORKS

Sensory journalism technologies include augmented reality (AR), virtual reality (VR), and AI to create immersive storytelling experiences that engage more than just sight and sound. The combination of text, visuals, sound, and often interactive elements draw audiences deeper into a narrative, making them active participants rather than passive observers.

While the hype around the metaverse may have faded, these tools continue to advance. The University of Georgia launched the Center for Advanced Computer-Human Ecosystems to explore how to use VR environments for communal storytelling, where audiences "live" the stories together. These immersive technologies enable journalists to create emotionally charged, sense-driven content, increasing empathy and engagement. AI plays a significant role in this trend by automating some storytelling processes and enabling more personalized, emotionally resonant content. El Surtidor, a Paraguayan publication, developed an AI-powered chatbot to tell the story of women's imprisonment in a deeply human way. The entirely text-based experience has users interacting directly with a composite woman's story, fostering a personal and emotional connection with women incarcerated for drug trafficking.

Journalists are also leveraging immersive experiences for training purposes: The 2402 Foundation used VR to simulate dangerous reporting environments to train journalists covering conflict zones in Ukraine.

WHY IT MATTERS

Sensory journalism reshapes how stories are told, making audiences more emotionally connected to the content. They feel like they are a part of the story, which research shows can foster empathy and a more nuanced understanding of complex issues. But there is a risk that immersive experiences could be used, intentionally or unintentionally, to steer public opinion with emotional responses. As journalists experiment with VR and AR storytelling, they will need to update their ethical frameworks.

Future journalists will need to craft narratives that aren't just accurate but also deliver a rich sensory experience. This may open new opportunities for audiences and journalists to co-create stories, but it also demands that resource-constrained newsrooms incorporate new skills into their workforce.

Because the hardware that enables sensory journalism is so new, it's likely that immersive stories produced in the near future will be co-creations with technologists. And because a dominant standard doesn't yet exist for delivering VR content, the audience for the first immersive stories will be limited to who owns the hardware it is compatible with. News organizations should be conscious that their collaborations may be used to shape consumer demand for headsets.

2ND YEAR ON THE LIST

ALGORITHMIC FACT-CHECKING

WHAT IT IS

AI-powered fact-checking tools are transforming journalism by automating misinformation detection at scale. While these tools offer speed and efficiency, concerns over biases in AI models and government-funded research highlight the need for transparency and human oversight.

HOW IT WORKS

Algorithmic fact-checking involves using artificial intelligence and machine learning models to verify the accuracy of information. The process typically starts with an AI model identifying claims in an article, followed by a comparison with reliable data sources. Large language models (LLMs), such as GPT, are used in these systems for their ability to process language and generate fact-based outputs. Some systems also incorporate retrieval-augmented generation, which helps overcome the limitations of static knowledge bases by constantly pulling in updated information from the web.

Fact-checking traditionally relies on manual processes that are labor-intensive and slow. With algorithmic models, AI can prescreen articles, prioritizing certain claims for human review. Der Spiegel, a German news site, built an experimental tool to support its fact-checking process. The system starts by using an LLM to identify all the factual statements in the article. A series of agents then compare those statements to information in a knowledge base and online. The statements of fact are then prioritized for human fact-checkers to review, so they can focus on the information that's hardest to verify.

WHY IT MATTERS

The volume of misinformation in today's media environment presents a growing challenge for news outlets, platforms, and consumers. Manual fact-checking is too slow to keep up with the sheer volume of content produced daily. Algorithmic solutions offer scalability, enabling the rapid evaluation of information and reducing the spread of false claims. However, automated fact-checking systems are not without risks. Models trained on biased data, or influenced by political agendas, can lead to skewed results, potentially reinforcing misinformation rather than correcting it.

The integration of algorithmic fact-checking tools in newsrooms promises to enhance the credibility of reporting by flagging misinformation before it reaches the public. But as these tools are increasingly adopted globally, including in tightly controlled environments like China, the international community must closely scrutinize the influence of these systems. Journalists and media organizations need to remain vigilant about how pretrained models are built and the potential for embedded biases.

As trust in media remains fragile, striking a balance between technology-driven fact-checking and human oversight will be critical in preserving the integrity of news.

1ST YEAR ON THE LIST

AVATARS PRESENT THE NEWS WITH HUMANS IN CHARGE

WHAT IT IS

AI-generated avatars are creating new distribution channels for news organizations even as human journalists maintain creative control. This strategy is helping publishers engage younger audiences and protect reporters in dangerous areas.

HOW IT WORKS

A growing number of news organizations around the world are using AI-generated avatars to deliver news. The synthetic journalists aren't autonomous actors, however: They are backed by substantial teams of human journalists who report, edit, and craft their message. Grupo Fórmula, one of Mexico's leading broadcasters, created three avatars: NAT for entertainment stories, SOFI for political topics, and MAX for general news. These avatars are carefully monitored and guided by teams of journalists who write scripts, verify facts, and oversee production. Grupo Fórmula thinks these approaches will help reach younger audiences, who may not respond to traditional news formats, with avatars whose appearance and speech patterns can be tailored to meet audience needs.

In regions with political unrest, like Venezuela, journalists are using AI avatars to hide their identities while reporting the news in the face of threats. Following Venezuela's controversial election in July, a group of Venezuelan journalists partnered with Connectas, a Colombia-based journalism platform, to launch avatars that obscure their identities.

In Peru, AI avatars are also being used to reach underrepresented groups. The National University of San Marcos developed Illariy, an AI-generated presenter who delivers news in Quechua, Peru's most spoken indigenous language.

WHY IT MATTERS

AI avatars allow news organizations to hyper-tailor content to niche communities, creating new opportunities to reach underserved audiences. This could be especially useful for publishers looking to present news across languages or cultural contexts. While this level of customization could make news more accessible and relevant for some audiences, there are risks: As news becomes more fragmented and customized, the shared experiences that mass media once provided may be lost, weakening the role of journalism in fostering a common public dialogue.

Despite the opportunities for innovation, there are challenges ahead. Audiences may initially question the authenticity or trustworthiness of news delivered by an AI anchor, making it imperative for news organizations to be transparent about the human oversight involved. Additionally, the overreliance on avatars could unintentionally distance viewers from the very human stories being told. The challenge for newsrooms will be maintaining journalistic integrity and fostering public trust while navigating the appeal of tailored, AI-driven distribution.

Above all, this trend complicates the narrative about how AI will impact the media landscape. The emergence of AI-generated presenters doesn't mean journalism jobs will immediately evaporate. Instead, new distribution channels will create demand for new types of reporting and editing roles.

SCENARIO YEAR 2029

ALGORITHMIC FACT-CHECKING GETS HIJACKED

Wherever people gather to share news and information, algorithmic fact-checking is ubiquitous. News feeds automatically reduce the distribution of stories that fail real-time verification tests. Messaging apps run fact-checking algorithms locally to detect and flag misinformation in group chats and direct messages without compromising encrypted communications. On-device AI agents validate information before summarizing it for consumers.

As a result, people generally trust the news they see; they are accustomed to seeing reliability scores and green check marks across platforms. The quality of civic discourse is improved because people can get immediate fact-checks during conversations and casual encounters through wearables. This trust came from years of work: News organizations, researchers, and tech companies worked together to build sophisticated algorithms that grasp reporting nuances.

But even though misinformation is rare, this future is dark. Investigative reporting languishes because the algorithms routinely block controversial stories. Because journalists were focused on building systems to detect the kinds of misinformation that was rampant when fact-checking systems were developing in the mid-2020s, they failed to consider other inputs to the algorithms. And because the open-source tools that became the backbone of the information ecosystem were built by government-funded researchers, the algorithms subtly reject information that challenges official narratives. The tools built to help people trust what they see threaten the truth. As the world grapples with this crisis, one question looms: Who will fact-check the fact-checkers?

SEARCH & DISCOVERY

8TH YEAR ON THE LIST

SEARCH INTERFACES EVOLVE WITH AI AND VOICE

WHAT IT IS

The evolution of search interfaces, driven by AI and multimodal models, is reshaping how users discover information. Search engines are shifting away from offering "10 blue links" and focusing on delivering personalized, AI-powered experiences with higher-quality content.

HOW IT WORKS

Search interfaces are evolving as AI and voice search transform how users find information. Google, for instance, has made significant changes to its search algorithms in the last year, penalizing sites with unoriginal content. Microsoft and Google are both racing to stay ahead of startups that offer native, AI-powered experiences by embedding new AI features on their results pages.

Multimodal AI models, capable of handling text, voice, and images, are poised to further disrupt search by allowing users to interact with AI in a more natural way. Startups like Perplexity AI are using retrieval-augmented generation to offer conversational search experiences without introducing hallucinations. While initially the company faced strong pushback from critics alleging the tool violates copyright by plagiarizing content, Perplexity AI responded by offering an ad-revenue share to publishers that agree to let them summarize their content. Time, Der Spiegel, and Fortune were among the first to participate in the licensing scheme.

AI is also transforming voice search. OpenAI's GPT-4o has demonstrated the potential for deeper, more meaningful conversations, surpassing the capabilities of established voice assistants like Amazon's Alexa. Multimodal AI models are particularly well-positioned to lead this revolution, as they can understand and generate content across different media types, creating richer search experiences for users.

WHY IT MATTERS

The evolution of search interfaces is significant because it fundamentally alters how users engage with digital content—and requires businesses and marketers to rethink their strategies for reaching new users. Relying on traditional SEO tactics no longer guarantees top rankings. Instead, publishers need to double down on their website's user experience while considering how to communicate their brand value in AI-generated summaries. And they'll need to find new ways to attract users even as search engines increasingly look like virtual assistants, with features designed to keep users from leaving. The integration of AI in search may accelerate as model capacity increases and as technologists propose new ways of incorporating information created after an LLM was trained. An international group of researchers proposed a framework in September called MMSearch that lets any LLM act as a multimodal search engine and creates a standard benchmark to compare the results. To date, OpenAI's GPT-4o had the strongest performance. But none of the LLMs performed as well as a human researcher.

These advancements offer the promise of quicker, more accurate answers with less effort for users. Voice search, in particular, has the potential to further streamline how people find information, making search a more conversational and natural process. This shift will likely encourage broader adoption of voice-enabled devices and AI-driven search assistants, leading to more integrated and seamless interactions with technology in daily life.

4TH YEAR ON THE LIST

TEACHING NEWS LITERACY

WHAT IT IS

It is essential to equip the public, especially young people, with tools to critically evaluate information. Initiatives to teach consumers how to identify fake news, media bias, and the role of social media platforms can prepare them to navigate a shifting media landscape.

HOW IT WORKS

News literacy programs are designed to help individuals navigate the increasingly complex information ecosystem. Schools, governments, and news organizations all have a role to play in fostering critical thinking skills to differentiate between trustworthy news sources and disinformation.

Amid rising concerns about global disinformation, the focus has shifted from merely identifying misinformation to understanding the systemic factors that amplify it. The spread of false information is often exacerbated on digital platforms, whose algorithms selectively promote content that maximizes engagement rather than accuracy. Recent research from Northeastern University found that when individuals are educated about how social media algorithms work, they are more likely to recognize and act against misinformation. However, this knowledge is unevenly distributed, and many lack access to critical tools.

AI is increasingly being explored as part of the solution: Researchers from MIT and Cornell have developed AI chatbots capable of persuading individuals to question conspiracy theories, successfully reducing belief in such ideas by 20%. These emerging technologies signal potential for more interactive and scalable news literacy solutions.

WHY IT MATTERS

Disinformation and misinformation pose critical risks to public understanding and democratic processes. In particular, disinformation campaigns by foreign governments—such as those launched by Iran and Russia in recent years—undermine trust in institutions and create social divisions. To counter these effects, news literacy education must evolve beyond traditional media sources and engage with digital ecosystems, with a focus on the algorithms that dictate much of what people see online. Teaching news literacy is not only about recognizing false information but also understanding how information is filtered and spread by platforms like Facebook, X, and YouTube.

As AI-powered tools become more accessible, they may play a significant role in tackling disinformation at scale. News literacy programs equipped with AI assistants could provide real-time fact-checking, debunk conspiracy theories, and offer insight into how personal data influences the news individuals see. The more citizens understand about these systems, the less susceptible they will be to manipulation by bad actors.

By preparing the public—especially younger generations—through educational initiatives, societies can build resilience against disinformation. Teaching news literacy will be vital to ensure that democracies remain robust in an era where information ecosystems are increasingly polluted by falsehoods.

3RD YEAR ON THE LIST

USER DIRECTED MEDIA FORMATS

WHAT IT IS

AI-driven tools are shifting content control from creators to audiences. As the cost of transforming text into audio or images into video decreases, users are poised to have more control to direct how they want to consume media.

HOW IT WORKS

Multimodal generative AI models excel at transforming content from one format to another, and some of 2024's most talked about AI products built on this feature set. Google, for example, added an experimental feature to its note-taking app, NotebookLM, to generate conversational podcast-style audio from documents. Shortly after Google announced the feature, it became common to see the generated summaries flooding social media.

At its Connect event in September, Meta launched a tool that lets users automatically dub videos into another language. The initial tests will run on videos from creators in Latin America and the United States, with translations between English and Spanish.

AI startup OpusClip deployed a tool called ClipAnything that's capable of sophisticated video editing based on natural language prompts. Given a prompt, it can cut a sports highlight reel or excerpt a specific part of the video. The tool's applications include speeding up the production of clips for social media, but the underlying technology could also give users more control over what they watch in the future.

WHY IT MATTERS

The implications of this shift are profound for the future of content creation and media consumption. As the cost of media transformation decreases, audiences are gaining more power in the content creation process, reshaping the relationship between creators and consumers. This audience-directed approach challenges traditional models of media production, where creators held most of the control. With tools that offer more personalized media experiences, user-generated content will dominate, driving platforms to prioritize features that allow seamless media customization.

Furthermore, AI-driven platforms like YouTube that already dominate podcast discovery are poised to capitalize on this trend by integrating advanced AI tools that can help users find or even create new content tailored to their preferences. This democratization of media production will lead to more niche content, blur the lines between professional and amateur media, and potentially disrupt traditional content industries such as filmmaking, podcasting, and journalism. Companies in this space must adapt to these shifts or risk being left behind in a more user-controlled media landscape.

10TH YEAR ON THE LIST

DIGITAL FRAILTY

WHAT IT IS

Digital storage is more vulnerable than we realize, with cultural memory at risk due to data loss, AI misinformation, and sabotage. Studies show significant portions of the web and social media vanish within a decade, compounding the fragility of our information ecosystem.

HOW IT WORKS

Digital frailty refers to the susceptibility of our vast online information systems to corruption, loss, and distortion. A Pew Research Center study found that 38% of websites that existed in 2013 were no longer available a decade later. This trend affects everything from government records to news articles, with 21% of government websites and nearly a quarter of news sources including at least one “dead” link. More than half of the articles on Wikipedia include at least one broken reference.

The problem doesn’t stop with missing websites. Pew reports that nearly one in five tweets disappears within months of posting, with accounts either becoming private, suspended, or deleted. The ramifications are severe for both the preservation of public discourse and historical records, as posts that changed the trajectory of the digital conversation can quickly vanish.

A new dimension of this trend emerges as AI-driven tools, such as generative models, are incorporated into the ways we access and interpret information. Generated answers are vulnerable to hallucination, but people don’t always know how to recognize when they’re not seeing something accurate. Research from MIT Media Lab has found that vulnerability can be compounded because interaction with generative AI systems can distort human memory, making participants three times more likely to form false memories compared to traditional methods.

WHY IT MATTERS

As society relies more heavily on digital platforms to store cultural, historical, and governmental records, the risks of data loss, misinformation, and sabotage are rising. This fragility poses a significant threat to our ability to preserve cultural memory, maintain accountability, and provide accurate information to future generations. And as search engines and AI tools pivot toward generative models, they introduce new risks, further complicating the reliability of information retrieval.

Generative AI, in particular, presents a unique challenge. Although AI models can process and synthesize vast amounts of data, their reliance on probabilistic patterns means they may generate false or misleading information—without any built-in mechanism to distinguish fact from fiction. This has profound implications for sectors like education, journalism, and governance, where accurate, reliable information is critical.

Leaders in digital infrastructure, cybersecurity, and information governance must act now to address the vulnerabilities of digital frailty. This includes creating more resilient, long-lasting digital archives, improving transparency in AI-driven data systems, and ensuring that the tools we rely on for knowledge preservation are equipped with robust protections against manipulation, corruption, and deletion.

2ND YEAR ON THE LIST

THE BATTLE FOR CONTENT VALUE

WHAT IT IS

News organizations face critical decisions regarding AI model training and content licensing. As generative AI reshapes the media landscape, publishers must balance between licensing deals and protecting their intellectual property.

HOW IT WORKS

Generative AI is disrupting the media ecosystem by upending the traditional value chain for news and information. With the rise of large language models (LLMs), news outlets now find themselves in a dilemma: Should they license their content to tech companies to train these models or hold out in an attempt to protect their proprietary value?

AI models require vast datasets to improve, and publishers have vast archives of original, deeply reported content. Some research suggests that AI models start to degrade when trained on AI-generated content; if that finding holds, publishers may get more leverage in negotiations with AI developers. But if companies like Google and OpenAI can find a way to advance their technology with synthetic data, publishers like Hearst and Axel Springer that have entered large licensing deals may not be able to renew those agreements profitably.

Legislators in Australia and Canada passed laws designed to force platforms to pay for displaying news content; a similar law was proposed in California last year. Those laws have had mixed results. For instance, when Meta stopped showing Canadian news on its platforms, news organizations saw dramatic drops in engagement, with no corresponding rise on alternative platforms. Meanwhile, tech companies are exploring ways to bypass reliance on licensed data by using synthetic datasets or fine-tuning models to minimize the need for high-quality real-world data.

WHY IT MATTERS

Licensing deals with AI companies provide immediate financial relief but come with the long-term risk of losing control over proprietary content. News organizations that hold out on licensing deals might protect their value while falling behind competitors that embrace new revenue streams from AI. Moreover, governments stepping in to regulate tech platforms' relationships with news organizations may have unintended consequences. The solution negotiated to avoid regulation in California saw Google dedicating $250 million over five years to the state's publishers. While it's a near-term win, there is no guarantee that Google will offer funding beyond the initial period, and that sum is far less than the bill would have required it to pay.

Right now, tech companies need the publishers' original content because AI models trained on synthetic data tend to underperform, a situation referred to as "model collapse." But as companies work to improve synthetic data generation, tech will reduce its dependence on licensed content and publishers may lose their leverage. If synthetic data remains problematic, news outlets may be in a stronger position to negotiate.

This battle over content value is not just about compensation for today's news stories; it's a contest over the long-term economics of information. AI's role in automating content creation could lead to new ways of monetizing media, but it also raises ethical and practical questions about originality, bias, and the future of journalism.

4TH YEAR ON THE LIST

POLICING THE CREATOR ECONOMY

WHAT IT IS

Content moderation is a battleground where platforms balance user safety, free speech, and regulatory pressure. Major social media platforms are making divergent choices as court rulings, policy updates, and public backlash shape the evolving social landscape.

HOW IT WORKS

Platforms use algorithms, human moderators, and user reporting systems to identify and remove illegal or harmful posts, but this balance between moderation and free expression is always contentious. Last year the Supreme Court struck down laws in Florida and Texas that aimed to regulate how platforms moderate content. In Brazil, a court temporarily blocked X over moderation failures, forcing the platform to soften its stance and comply with local regulations. This incident reflects the increasing pressure on platforms to adhere to national laws while maintaining global standards.

Some platforms, like Twitch, are taking a more educational approach. The video streaming platform introduced a system where users get more information from moderators when they are penalized for breaking the platform's rules, with opportunities to reduce penalties through corrective actions, like educational courses. This system, akin to points on a driver's license, aims to strike a balance between enforcement and rehabilitation.

Content moderation is not just a technical issue; it takes a toll on workers. Facebook's moderators in Kenya have sued the company over poor working conditions, insufficient mental health support, and low wages. This highlights the emotional and mental burden on those tasked with reviewing harmful content.

WHY IT MATTERS

Content moderation shapes the flow of information in today's digital ecosystems, influencing political discourse, public opinion, and social movements. It is not merely a technical issue but a reflection of deep societal debates over free speech, privacy, and responsibility. As governments worldwide push for tighter controls, platforms must navigate a complex landscape of laws, user expectations, and reputational risks.

While social media platforms evolve their strategy for incentivizing and removing content—and as new platforms emerge—creators need to find ways to keep up. When a platform like Facebook makes the decision to deemphasize news in its feed, publishers need to work harder to reach audiences. That can be especially challenging when organizations make business decisions based on their perception of the social media landscape, only to find the ground shifting under them; we saw this play out in the mid-2010s in the industry's disastrous "pivot to video."

The political climate in the United States and abroad will inform how much conflicts about moderation shape the year ahead. Watch to see whether Republicans renew their assault on Section 230 of the Communications Decency Act and whether new regulations are issued under the EU Digital Services Act.

SCENARIO YEAR 2026

WEAPONIZING THE DIGITAL REVENUE STACK

For years, Teen Chic's revitalization as a digital-only publication was a rare bright spot in the US magazine publishing industry. The magazine became a destination for political journalism during the first Trump administration because its leadership team realized that readers in Generations Z and Alpha saw themselves as activists—and expected the same from the brands they followed. Teen Chic engaged honestly and authentically with social justice movements, activists, and progressive politics; that coverage helped it grow a digital audience and a sustainable advertising-supported business model.

In the run-up to the 2026 midterm elections, however, the magazine's voice has become a liability. After publishing a major investigative report about how abortion access has been curtailed since the Dobbs decision, Teen Chic's revenue cratered. The magazine finds itself struggling to monetize its content because its website isn't listed as brand safe on programmatic ad exchanges and YouTube suspended it from video monetization programs. The changes were the result of a coordinated campaign by the Trump administration to pressure the tech companies that enable digital monetization to silence their critics. The campaign culminated with a disastrous fourth quarter, usually a high-point for ad supported publishers. As the losses mount, it's publisher decides to shutter Teen Chic to protect its relationships with advertisers at other titles.

THE INFORMATION ECOSYSTEM

11TH YEAR ON THE LIST

ERODING TRUST IN NEWS

WHAT IT IS

Trust in news has fallen sharply, with only 32% of Americans expressing confidence in mass media's accuracy in an annual Gallup survey. AI's rise further complicates the landscape, yet local outlets and legacy brands show potential for rebuilding trust.

HOW IT WORKS

Trust in the media has steadily eroded, with a record-high 39% of Americans expressing no trust "at all" in mainstream news outlets, according to Gallup's annual survey on the subject. This skepticism extends to established media brands, exacerbated by increased exposure to misinformation and the perception that news is influenced by partisan agendas. Even during critical events like elections, where accurate reporting is essential, the public's confidence in news has dipped to historic lows. Still, legacy media is important: A study of online news consumption during the contentious 2022 Brazilian presidential campaign found that the more exposure that people had to news from "legacy news brands," the less likely they were to believe in electoral misinformation.

Artificial intelligence has introduced new challenges for trust. AI-generated content, even when used for simple tasks such as transcription or grammar correction, is met with suspicion by news consumers. A study by the University of Minnesota found that nearly 94% of news consumers want to be informed when AI is used in the content creation process. Public sentiment remains wary of AI's role in journalism, with more than half of consumers expressing discomfort with AI-generated news articles, even when supervised by human journalists. Despite these concerns, there are pockets of resilience: The Lenfest Institute reported that up to 90% of audiences trust information from the Statewide News Collective, a local news initiative it funds.

WHY IT MATTERS

When people don't trust news organizations, it's not just publishers who suffer—entire social systems are destabilized. Distrust in news can lead to increased polarization, where people retreat into echo chambers of like-minded individuals, consuming only the information that confirms their biases. This amplifies misinformation, making it harder to distinguish fact from fiction. The breakdown of a shared set of facts hampers not just political debate but also public health initiatives, responses to climate change, and societal cohesion at large. For governments and institutions, mistrust in the media complicates the task of communicating effectively with the public, especially during crises, when clear and accurate information is most needed.

This erosion of credibility can quickly lead to journalism's business models becoming unsustainable: Advertisers are less likely to invest in platforms that have lost credibility, and consumers are less willing to pay for news they don't trust.

In an information ecosystem already weakened by decades of media consolidation and retrenchment, the erosion of trust in news is not just a media crisis—it's a societal one. Without trusted news sources, the public loses a critical infrastructure for understanding the world, undermining the ability to address complex, collective challenges.

2ND YEAR ON THE LIST

PIVOT TO PHILANTHROPY

WHAT IT IS

Philanthropic funding has become a critical source of funding for the news ecosystem. The growth of nonprofit news outlets has bolstered reporting in communities that would otherwise be news deserts, but there is increasingly intense competition for limited funding.

HOW IT WORKS

The media landscape is undergoing a fundamental shift as news organizations see advertising provide a smaller share of revenue. Philanthropic funding—whether from individual donors or large foundations—has unlocked a surge of investment in journalism over the past decade. The importance of donations has grown in the last two years as tech giants like Google and Meta reduced their support for journalism. Still, the newsrooms receiving that funding aren't immune to competitive pressures: Nonprofit status is a tax status, not a business model.

That competition is fueling a wave of mergers among nonprofit newsrooms, mirroring the consolidation in the for-profit market. The Markup, a website focused on reporting that investigates technology, joined CalMatters, a website focused on public service journalism in California. Another example is the tie-up between Wisconsin Watch and Milwaukee Neighborhood News Source, which joined forces to pool resources in the hope of better—and more sustainably—meeting their audiences' needs.

Even as they operate in the public interest, the business practices of successful nonprofits are increasingly hard to differentiate from their for-profit peers. Both organization types need sophisticated audience development programs to maintain a pipeline of users moving from discovery to support roles (whether they are subscribers or donors).

WHY IT MATTERS

Philanthropic funding often comes with its own challenges. A recent study on the impact of Google News Initiative's support in regions like Africa, Latin America, and the Middle East revealed that while such grants are essential for innovation, they sometimes come with strings attached. Meeting funders' expectations can place significant operational pressure on news organizations, making them reliant on the same tech ecosystems that disrupted traditional journalism business models. While that research focused on Google's funding, the general principle can apply to all nonprofit news organizations.

Even though it's hard to find fault with more funding for journalism, news leaders shouldn't get complacent about philanthropic support. That's especially true as the information ecosystem is reshaped by the other trends described in this report: Individual and institutional donors alike expect that their money supports reporting that reaches audiences. If it's harder to reach people—or harder to prove exactly how many people were reached—that will impact the viability of future funding. Smart leaders will pursue balanced revenue strategies that mitigate the risk of any single funding stream having an outside impact on the future of the organization.

2ND YEAR ON THE LIST

DISORDERED CONSUMPTION AND NEWS AVOIDANCE

WHAT IT IS

Extreme reactions to a fast-paced and polarized news ecosystem have led to two distinct behaviors: news avoidance and doomscrolling. Some avoid news for mental health reasons, while others get trapped in harmful consumption patterns, highlighting shifts in news habits.

HOW IT WORKS

The relentless 24-hour news cycle, compounded by the rise of social media and algorithm-driven platforms, has created an environment where information is both ubiquitous and emotionally taxing. News avoidance is increasingly prevalent, driven by a perception that people are constantly surrounded by information. Research shows that many people feel they no longer need to seek out news actively; instead, they expect to get key updates through social media or chats with friends and family. As a result, people often choose not to build a regular news consumption habit, particularly when faced with the emotional burden of political or divisive content.

Even when users want to follow the news closely, their consumption may be steered by the design of a platform's algorithms. A group of researchers studied content recommendations on YouTube and found that the site's algorithms have a higher probability of recommending entertainment videos than news content. That research suggests that sometimes news avoidance isn't a user preference but an inherent bias in the algorithms that drive digital distribution.

Researchers have noted that not all news avoiders are disengaging from information entirely. Platforms like Twitch have become alternative spaces for news consumption, where authenticity and direct interaction with content creators are valued over traditional journalistic norms. This shift indicates that while some may avoid mainstream news, there is still demand for more relatable and interactive formats.

WHY IT MATTERS

The trend toward disordered consumption and news avoidance is critical as it shapes the future of how people interact with information, affecting democratic engagement, public discourse, and individual mental health.

News avoidance could exacerbate the current information crisis, leaving consumers vulnerable to misinformation and less informed on critical issues. For democracies, a disengaged or misinformed public is particularly problematic, as it may lead to reduced civic participation and a breakdown in the essential functions of news media.

For news organizations, the challenge is twofold. First, they must navigate an ecosystem where platform algorithms act as gatekeepers, often promoting content that is antithetical to the values of quality journalism. Second, they must address shifting audience expectations, particularly among younger consumers who favor more interactive and less formal modes of engagement.

The rise of news channels on platforms like Twitch presents an opportunity to reimagine news delivery, with a focus on authenticity, real-time interaction, and a more conversational tone.

2ND YEAR ON THE LIST

DATA-ENRICHED BROADCASTING

WHAT IT IS

A new standard for broadcast TV called ATSC 3.0 unlocks new opportunities for real-time media consumption, interactive features, and enhanced emergency alert systems. The new standard paves the way for broadcasting to evolve beyond television and radio.

HOW IT WORKS

ATSC 3.0, also known as NextGen TV, represents a significant shift in the broadcasting landscape by combining traditional over-the-air signals with internet protocol-based data delivery. By leveraging more efficient data transfer methods, ATSC 3.0 enables broadcasters to offer services typically associated with internet streaming, such as the ability to pause, rewind, or restart live broadcasts. It also opens the door for broadcasters to gather deeper analytics on viewer behavior, providing granular insights akin to those utilized by digital platforms.

However, its real breakthrough lies beyond video delivery: ATSC 3.0 supports the transmission of any data type, which can be broadcast over wide geographic areas. This opens up new use cases, such as “datacasting”—the broadcasting of non-video data over vast distances. This data can include anything from weather updates and real-time traffic information to emergency alerts with embedded rich media and geotargeted notifications.

US broadcaster Sinclair is collaborating with global partners to integrate ATSC 3.0 receivers into smartphones. This would let consumers receive live TV and data anywhere within the broadcasting range, making content delivery more accessible and cost-effective.

WHY IT MATTERS

ATSC 3.0 isn’t just a step toward better TV—it’s a way to completely reimagine how broadcast exists in the digital world. The ability to broadcast any kind of data transforms TV frequencies into an alternative to the internet, particularly for rural and underserved regions where broadband access is limited. Datacasting could allow for widespread dissemination of educational resources, public safety alerts, and real-time public service communications without requiring robust internet infrastructure. Additionally, the technology could reduce the strain on cellular networks during major events by offloading traffic onto broadcast networks.

ATSC 3.0’s implications extend globally. Devices with built-in ATSC 3.0 receivers, such as the smartphone planned for the Indian market, could introduce mobile-first populations to broadcast television without reliance on Wi-Fi or 5G. Emergency alert systems, enhanced by precise geotargeting and rich media, could improve public safety and disaster response.

As the rollout of NextGen TV scales, it has the potential to enable hyper-local ad targeting that rivals internet advertising and could create a meaningful alternative to digital display ads. Long-term, ATSC 3.0 could bridge the digital divide by ensuring that large swaths of the population can access critical information and media without needing high-speed internet.

1ST YEAR ON THE LIST

THE SYNTHETIC TSUNAMI

WHAT IT IS

Generative AI is poised to flood the information ecosystem with synthetic content. While fears of rampant fake news have not materialized, publishers and creators increasingly need to differentiate themselves from derivative summaries and rewrites of original content.

HOW IT WORKS

Generative AI has made it easier and cheaper to create all types of media. Commercial and open-source tools can generate everything from news articles and advertising copy to photo-realistic videos that seem authentic at first glance.

Our news feeds and search results are increasingly inundated by benign but low-quality content, sometimes referred to as "AI slop." This content often has the veneer of polish but is ridden with hallucinations and derivative recitation of human-created material. The result is websites and creator feeds that are like empty calories: capable of consuming our time yet lacking any substantive information content.

This trend will accelerate as social platforms like Facebook and Instagram test AI-generated content integrations in their news feeds. For politicians, AI offers new tools for generating hyper-targeted messages, potentially to manipulate narratives. Some AI-generated misinformation has already appeared in political campaigns, including deepfake audio and misleading robocalls impersonating public figures. As the cost of producing convincing AI-generated media continues to fall, we will see a rise in the volume of synthetic content, and the line between authentic and fake media will blur further.

WHY IT MATTERS

News publishers are trying to distinguish themselves from this kind of rote production, but they still need to contend with how it impacts the media ecosystem: As the internet is overrun by AI-generated content, the cognitive and emotional load on consumers rises because of the sheer volume of content they must navigate.This "synthetic tsunami" forces consumers to spend more time and mental energy discerning credible information from AI-generated noise. The constant exposure to shallow, error-prone content can lead to news avoidance or decision fatigue, making it harder for people to evaluate what is trustworthy and what isn't. Publishers should stay vigilant about how content overload might diminish consumers' ability to engage meaningfully with news and information.

While the world has been fortunate to avoid a high-impact misinformation campaign enabled by generative AI, we increasingly see synthetic media deployed as a tactic at all levels of politics. A robocall impersonating then presidential candidate Joe Biden in January 2024 told people not to vote in the New Hampshire primary. A fake 10-second audio clip of a Manhattan Democratic Party leader insulting a sitting state assemblymember briefly upended the tight-knit world of Harlem politics last year. The impact of these kinds of malicious actions will be magnified if consumers develop a sense of apathy or mistrust toward all content.

SCENARIO YEAR 2031

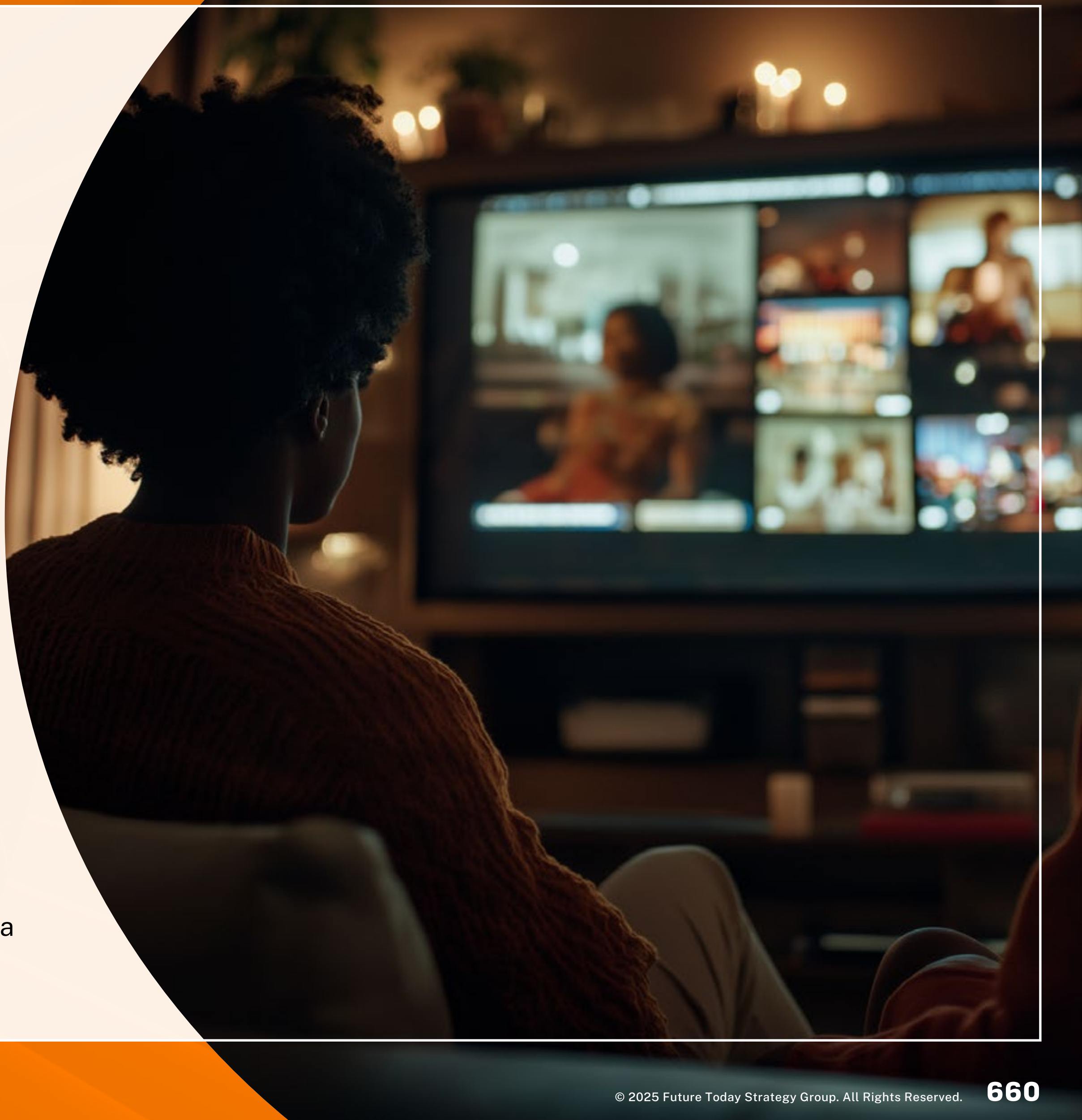
BROADCAST IS THE FUTURE

The internet is mostly over-run with low-quality AI-generated media. Even as search engines and digital assistants try to sift through the vast volumes of content generated every day, consumers spend less time browsing because it is unpleasant—if not impossible—to find what they're looking for.

As the internet became less reliable, innovators spent more time thinking about broadcast. Widespread adoption of the ATSC 3.0 standard revitalized the legacy broadcast network, enabling the delivery of all types of media directly to consumers. Nearly every electronic device comes with a built-in ATSC 3.0 receiver, constantly picking up datacast signals.

The volume of text, video, and audio transmitted across the airwaves is impossible for any individual to sort through. But datacasted information is perceived as more reliable than media published to the internet for two reasons: First, the cost of broadcasting establishes a significant barrier to entry, making it economically infeasible for low-value publishers to distribute content that way. Second, on-device AI models constantly curate broadcast data, creating a personalized stream of news and information that is easier for consumers to manage.

The resurgence of broadcast distribution fuels investment in television stations that have the bandwidth to broadcast across a region. It also opens the door for new regulation of media because the government owns the airwaves.



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HEALTH CARE & MEDICINE

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Amy Webb
Chief Executive Officer

Big Tech is redefining health care.

This year marks a pivotal shift in health care's competitive landscape, with technological advancement catalyzing new business models and redefining traditional market boundaries. As industry giants like Google and Microsoft deepen their health care presence, they're not just bringing technology; they're fundamentally reshaping how care is delivered, accessed, and monetized. Big Tech's deepened role has accelerated the adoption of AI-driven diagnostics, cloud health platforms, and wearable technology. AI has evolved beyond administrative efficiency to enable new care delivery models, with generative AI transforming everything from clinical documentation to real-time decision support. Simultaneously, improvements in electronic health record interoperability have made data sharing seamless while reducing errors. Telemedicine, combined with remote patient monitoring, has become essential in chronic disease management and is expanding care access globally.

We're also witnessing breakthrough developments in emerging diagnostics and treatment capabilities that are creating new centers of value. CRISPR-based diagnostics and liquid biopsies could revolutionize early detection programs, particularly in oncology. Meanwhile, continued research into in-womb therapies and nanotechnology will enable innovative treatments of genetic disorders. The development of advanced implants and prosthetics, such as bioresorbable devices and brain-computer interfaces, will one day help patients regain mobility and recover quicker.The FDA has already started to approve clinical trials.

As health care enters this new era, success will depend on the ability to adapt to a rapidly evolving competitive landscape where traditional boundaries between payers, providers, and technology companies become fuzzy. With AI accelerating both research and care delivery, and precision medicine moving into the mainstream, 2025 should see the emergence of new business models that challenge conventional approaches to health care. The organizations that thrive will be those that can navigate this transformation while building sustainable competitive advantages in an increasingly dynamic market.

Digital health is putting patients in the driver's seat.

1

Telehealth adoption drives revenue stream diversification

As telehealth use continues even post-pandemic, health systems have opportunities to expand market share and reduce care delivery costs. Remote monitoring programs could improve patient care over time, reducing readmissions and facilitating chronic disease management.

2

Consumer health care disruption threatens traditional relationship models

The rise of direct-to-consumer prescription services and virtual-first providers is reshaping patient expectations and challenging traditional referral patterns, requiring health systems to reevaluate their digital front door strategy.

3

New devices present data integration challenges and opportunities

The proliferation of patient-generated health data from wearables creates both clinical and liability considerations. Health systems must develop infrastructure to meaningfully integrate this data while managing risk and ensuring clinical workflow efficiency.

4

AI implementation offers administrative cost reduction at scale

Early adopters of health care AI can enjoy reductions in administrative overhead through automated documentation, coding, and revenue cycle management. This technology represents a significant opportunity to improve margins without compromising care quality.

5

Health data interoperability: strategic investment or disadvantage?

Enhanced data-sharing capabilities are becoming a key differentiator in value-based care success and strategic partnerships. Without this, health systems risk exclusion from profitable narrow networks and could struggle to demonstrate quality metrics to payers.

As technology reshapes health care's foundations, industry leaders must evolve or risk irrelevance.

The convergence of technology and health care in 2025 extends far beyond digital transformation, signaling a fundamental shift toward intelligent health systems. While established organizations have historically competed on reputation, scale, and location, new entrants are leveraging edge computing, advanced APIs, and seamless integration layers to rewrite the rules of care delivery.

This shifting competitive landscape is particularly evident in primary care and chronic disease management, where traditional providers face mounting pressure from Big Tech. Cloud-native architectures and intelligent automation are reshaping care delivery, from Apple's transformation of AirPods into FDA-cleared hearing aids, to Amazon's API-first Clinic platform and One Medical acquisition. In pharmaceutical distribution, Mark Cuban's Cost Plus Drugs has leveraged blockchain and smart contracts, forcing established players to modernize their technology stacks and patient engagement platforms.

The proliferation of Internet of Things medical devices and edge-enabled care platforms is democratizing access to medical expertise. Rural health care facilities are evolving into hybrid care hubs, using 5G networks and edge computing to combine local emergency services with low-latency remote specialty consultation. Best Buy Health is deploying smart home technology and ambient sensors for aging-in-place solutions, while Walmart's retail clinics integrate IoT diagnostics and cloud-based electronic health records (EHRs). Meanwhile, real-time analytics and predictive modeling are revolutionizing value-based care delivery, supported by advances in distributed sensors and edge-processed biometric data.

The technology stack for treatment modalities is equally advancing, with augmented reality/virtual reality therapeutics leveraging spatial computing and haptic feedback. Meta's investment in VR-based mental health treatments utilizes advanced biometric tracking and neural networks, while AppliedVR's FDA-cleared pain management platform demonstrates the maturation of immersive therapeutics. These developments parallel breakthroughs in quantum computing for molecular modeling and 3D bioprinting with smart materials, accelerating both drug discovery and personalized medicine. However, this rapid evolution introduces new challenges in edge security, distributed systems resilience, and regulatory compliance—technical hurdles that demand sophisticated architectural solutions from industry stakeholders.

From brain implants to nanobots, 2024 pushed medical boundaries into new territory.

JANUARY 2024

Neuralink's Human Trials Begin

The neurotech company successfully implants its first brain-machine interface in a human.

MAY 2024

Cyberattack Impacts Health Services

A cyberattack at Ascension, a nonprofit health system with 140 hospitals, disrupts emergency care.

JULY 2024

FDA Approves Alzheimer's Drug

The US regulatory agency OKs Donanemab for use at the early stage of the disease.

AUGUST 2024

AdventHealth Commits to Renewable

The company signs a virtual power purchase agreement, aiming to achieve 100% renewable energy by 2026.

SEPTEMBER 2024

Nanobots for Brain Aneurysms

Researchers successfully use nanobots to treat brain aneurysms in animal models.

« PAST

From AI to biotech, 2025 will set new rules for health care innovation.

FUTURE »

EARLY 2025

Medicare Expansion for Weight Loss

The Biden administration proposed expanding coverage to anti-obesity medications; approval will be up to the Trump administration.

MID 2025

FDA Guidance on AI/ML in Medical Devices

The agency will issue new guidelines on how AI is used and marketed when developing medical devices.

MID 2025

Launch of Oracle Health EHR

Oracle is launching a new AI-powered EHR that will automate administrative processes.

FALL 2025

Apple Watch Series 11

The newest Apple Watch will likely have even more optimized health insights.

MID TO LATE 2025

Passage of the BIOSECURE Act

The US House-approved bill limiting foreign adversary funding for biotechnology will likely go to the Senate floor in 2025.

Traditional health care business models are facing disruption on all sides.

The Real Returns of Health Care Analytics

While AI and analytics promise transformative insights, health care organizations face significant challenges and costs converting data into actionable value. Rather than delivering clear competitive advantages, data capabilities are increasingly table stakes—the real differentiation comes from an organization's ability to execute on insights while balancing the investment against practical considerations like workflow integration and staff adoption.

Virtual Care's Market Disruption Challenge

Virtual care platforms enable geographic expansion yet erode market barriers. Local health systems now compete with national telehealth providers and retail health players—all targeting their primary care base. Success in remote care demands fundamental changes to operational models, provider compensation, and patient engagement—adjustments that require time and attention.

Preventive Care Tech Reshapes Revenue Models

The rise of diagnostic technologies like biosensors presents a complex strategic challenge: the need to diversify revenue streams to rely less on expensive acute care episodes and specialty interventions. Offsetting the revenue impact requires consideration of new business models, whether through high-volume wellness services, or value-based care arrangements with payers.

Balancing Tech Innovation With Strategy

While cutting-edge technologies like AI attract attention, companies need to focus on making strategic investments that enhance existing service lines and support scalable care delivery models. Organizations must balance innovation against implementation costs, staff readiness, and clear paths to ROI, particularly as patients increasingly prioritize access and affordability.

Hidden Costs of Big Tech Health Care Alliances

Potential partnerships with tech giants offer a lot of promise, but they also come with caveats. These collaborations often require data sharing and investment that creates long-term dependencies. Big Tech could eventually evolve to a competitor. Organizations must compare short-term benefits to the risk of becoming commoditized in tech-controlled health care ecosystems.

Wearables Create New Provider Responsibilities

Health care providers face growing pressure to integrate real-time patient data from wearable devices. This data influx creates new obligations for provider response and intervention, requiring investment in data management infrastructure and the creation of clear protocols. As data availability grows, providers must manage patient expectations and legal responsibilities.

These individuals are at the forefront of transformation in pharmaceuticals, medical devices, and health care technology.

- **Emil Fristed, CEO at Novoic,** for her leadership in developing AI-powered speech analysis tools that detect early signs of neurological diseases like Parkinson's and Alzheimer's.

- **David Liu, professor at Broad Institute,** for his innovations in base editing—a more precise form of CRISPR—that has successfully corrected genetic mutations related to diseases like progeria.

- **Dimple Parmar, CEO at ZenOnco.io,** for creating a platform that integrates conventional and complementary cancer care services, opening up personalized treatment solutions across India.

- **Dr. Miriam Merad, director of Mount Sinai's Precision Immunology Institute,** for her contributions to leveraging immunotherapies to treat solid tumors.

- **Kristian Ranta, CEO at Meru Health,** for integrating professional therapy and mindfulness practices into an app to address global mental health challenges.

- **Sarah Tishkoff, professor at University of Pennsylvania,** for her research in population genomics, particularly related to the genetic basis of diseases prevalent in African populations.

- **Dr. Toshio Suda, director at International Research Center for Medical Sciences,** for his discoveries on the role of metabolism in stem cell maintenance and aging.

- **Dr. Fiona Watt, director of the European Molecular Biology Laboratory,** for her advancements in stem cell research, particularly her work on tissue regeneration.

- **Eirini Rapti, CEO at Inne,** for developing hormone-tracking biosensors that enable women to manage their reproductive health more effectively.

- **Dr. Sarah-Jane Dawson, a group leader at Peter MacCallum Cancer Centre,** for her research in liquid biopsies and circulating tumor DNA.

- **Michael Hayden, CEO at Prilenia Therapeutics,** for his work in developing treatments for neurodegenerative diseases, particularly Huntington's disease.

- **Dr. Shobi Ahmed, CEO of Sama Therapeutics,** for creating an AI-based platform that provides tailored brain health evaluations to speed up the development of safer and more effective treatments for complex patients.

New technologies enable better care and stronger margins...

...but threaten traditional revenue streams and provider relationships.

OPPORTUNITIES

New Care Models

Early intervention technologies and enhanced monitoring capabilities are enabling health systems to develop new value-based care models and risk-sharing arrangements that could significantly improve margins on population health management.

Broader Geographic Footprint

The rise of virtual care and remote monitoring creates opportunities for geographic expansion and new revenue streams without the traditional capital investments in physical infrastructure.

Expense Reduction

Artificial intelligence and automation technologies offer the potential to dramatically reduce administrative overhead while improving revenue cycle efficiency through enhanced clinical documentation and coding.

Improved Data Inputs

Health care organizations can monetize their growing data assets through research partnerships, value-based care contracting, and the development of new analytics-driven services.

THREATS

Biosecurity Breach Risk

Advances in molecular diagnostics and biosensors may increase the likelihood of biosecurity breaches, such as the misuse of these tools for bioterrorism or the accidental release of biological data, posing significant global risks.

New Competitors

Big Tech companies could evolve from enablers to competitors, potentially disintermediating health care providers from their patients. This could relegate traditional organizations, especially in primary and preventive care, to commoditized service providers.

Disrupted Revenue

The shift toward preventive care and virtual services is disrupting traditional revenue models and is particularly threatening to high-margin acute care services and facility-based revenue streams.

Increased IT CapEx

The growing cost of maintaining competitive technology infrastructure, including cybersecurity, data management, and analytics capabilities, threatens to outpace revenue growth and strain capital budgets.

Health care ROI demands targeted transformation, not total overhaul.

Develop a technology evaluation framework that separates commodity IT investments from strategic differentiators. This will put a focus of premium investment on patient engagement platforms and clinical workflow automation that can drive market share in an increasingly competitive landscape.

Map current revenue streams against emerging technologies to identify existential threats, particularly from diagnostic and preventive innovations that could reduce dependence on traditional acute care services. Develop mitigation strategies for each vulnerable service line.

Rather than building comprehensive data infrastructure, identify three specific service lines where improved data integration could protect market share from digital-first competitors, and focus investments there while monitoring clear ROI metrics for each initiative.

Create an innovation partnership model that maintains control of patient relationships and data while leveraging external technology capabilities, explicitly defining which capabilities should be built versus bought, with clear governance structures for data sharing and usage rights.

Establish rapid prototyping capabilities to test new care delivery models with existing technology. Focus on areas where virtual and physical care integration could create barriers to entry for digital-only competitors, while maintaining flexibility to scale successful pilots quickly.

Instead of following industry trends, design a five-year technology roadmap that prioritizes investments based on their ability to either defend core services from disruption or capture new revenue streams, with clear metrics for measuring success at each stage of implementation.

Technology Deployment
Capital Expenditure
Talent Development
Regulatory Influence

Important terms to know before reading.

BIOFACTURING
The process of producing biological products and materials, such as tissues, enzymes, or drugs, using living organisms or cells. In 2025, biofacturing is being scaled up for sustainable production of everything from lab-grown meats to biomaterials for construction, offering a low-carbon alternative to traditional manufacturing.

BIOMALWARE
Malicious technology or software engineered to attack, alter, or exploit biological systems, including human DNA and other living organisms. As biotechnologies like CRISPR and gene-editing tools become more accessible, biomalware presents a new cybersecurity threat, potentially targeting genetic data and health care infrastructure, or even modifying biological processes for nefarious purposes.

CYBER-PHYSICAL HEALTH SYSTEMS
The convergence of physical health care infrastructure with cyber technologies, such as IoT devices, AI diagnostics, and real-time monitoring systems. Cyber-physical health systems are enabling seamless data exchange between patients and health care providers, offering predictive health insights and remote care management that improve preventive medicine.

ELECTRONIC HEALTH RECORD (EHR)
A comprehensive digital system that stores a patient's entire medical history, including treatment plans, test results, and other health data. EHRs are increasingly interoperable, powered by AI to predict health risks, automate administrative tasks, and optimize personalized care across health care systems, enhancing both efficiency and patient outcomes.

EXOSKELETON
A wearable, external framework designed to enhance human physical capabilities. Exoskeletons have evolved beyond rehabilitation tools, becoming integral to industries like logistics, construction, and the military, where they improve worker endurance, reduce injuries, and augment physical performance through real-time AI feedback and adaptive control systems.

GENETIC PRIVACY
The right of individuals to control access to and use of their genetic information. This concept has become central to debates around data ownership, as genetic data is increasingly used for everything from health optimization to law enforcement, necessitating new frameworks for privacy protection in the face of rapid biotechnological advances.

HOLOBIONT
An integrated ecological unit composed of a host organism and its associated microbiome, including bacteria, viruses, fungi, and other microorganisms. Increasingly, the study of holobionts plays a critical role in personalized medicine, recognizing the microbiome's influence on health, disease, and even behavior, transforming our understanding of human biology as interconnected systems.

MICROBIOME
The unique community of microorganisms (bacteria, viruses, fungi) that inhabit the human body and play critical roles in processes like digestion and immune response. Advances in microbiome research are leading to the development of microbiome-targeted therapies and precision probiotics that tailor treatment to individual microbial profiles, revolutionizing fields like gut health and chronic disease management.

NANOBOTS
These microscopic robots, often at the scale of nanometers, are designed to perform specific tasks at a cellular or molecular level. Nanobots are increasingly used in medical applications such as targeted drug delivery, cancer treatment, and cellular repair, operating

autonomously within the human body, often in combination with AI-driven diagnostics for highly precise interventions.

NOOTROPICS
Often referred to as "smart drugs" or cognitive enhancers, these substances are intended to improve cognitive function in healthy individuals. They are increasingly bioengineered and personalized, with enhanced formulations that leverage genomics and AI for targeted cognitive enhancements, sparking both ethical debates and potential regulatory challenges.

PERSONALIZED MEDICINE
This type of health care model tailors medical treatments and preventive measures to an individual's specific characteristics, including genetics, lifestyle, and environment. With the increased involvement by big data, AI, and bioinformatics, precision medicine enables more precise interventions for everything from cancer treatments to chronic disease prevention. This often incorporates real-time health data from wearable tech.

PIEZOELECTRICITY
Piezoelectricity refers to the ability of certain materials (such as crystals and biological tissues) to generate an electrical charge in response to mechanical stress. Piezoelectric materials are being used in innovative applications, such as wearable energy-harvesting devices, ultra-sensitive sensors, and even in biomedical implants that convert movement into electrical signals to power medical devices.

PRECISION MEDICINE
A medical approach that uses detailed genetic, molecular, and environmental information to tailor treatment plans to individual patients. Precision medicine is integrated into routine health care, with AI-enhanced genetic testing providing real-time data to guide personalized therapies for conditions ranging from cancer to rare genetic disorders.

QUANTUM HEALTH CARE ALGORITHMS
These algorithms utilize the principles of quantum computing to process complex biological data at unprecedented speeds. They are being explored in genomics, drug discovery, and complex systems modeling, with the potential to revolutionize personalized medicine by accelerating the development of individualized treatment plans based on vast genetic datasets.

SYNTHETIC BIOLOGY PLATFORMS
These technological ecosystems enable the engineering of new biological entities or the redesign of existing organisms. The platforms, often powered by AI and automation, are accelerating innovation in fields like biofuels, agriculture, and pharmaceuticals, raising ethical considerations around the manipulation of life-forms.

XENOBOTS
Programmable living robots built from biological cells, often using stem cells from animals like frogs. These biological robots are evolving in their ability to perform complex tasks such as targeted drug delivery, environmental remediation, or tissue repair, offering new possibilities in regenerative medicine and sustainable technologies.

XENOTRANSPLANTS
The transplantation of organs, tissues, or cells between different species, primarily from animals (like pigs) to humans. Advancements in gene editing and immunosuppressive therapies are pushing xenotransplantation closer to widespread clinical application, aiming to alleviate the global organ shortage while addressing cross-species compatibility and ethical concerns.

HEALTH CARE & MEDICINE TRENDS

THE BUSINESS OF HEALTH CARE

7TH YEAR ON THE LIST

BIG TECH DISRUPTS HEALTH CARE

WHAT IT IS

Big Tech's push into health care is reshaping the industry through AI, cloud infrastructure, and consumer-driven innovations but faces substantial barriers from regulatory challenges and incumbent partnerships. Success will rely on collaboration rather than full disruption.

HOW IT WORKS

Big Tech is entering health care through artificial intelligence, cloud computing, wearables, and direct-to-consumer services, aiming to streamline medical practices, enhance patient care, and integrate digital health. Google, Microsoft, Amazon, Nvidia, and Apple are leading the charge. Google's AI advancements are focused on improving clinical workflows and diagnostics through tools like Vertex AI, which assists in medical records management. Its life sciences branches, Verily and Calico, explore longevity and genomics, furthering research in health data analytics and personalized care. Microsoft's strategy revolves around cloud-based enterprise solutions, enhanced by the acquisition of Nuance, whose AI-driven speech-to-text capabilities reduce physician burnout. Amazon focuses on telehealth and pharmacy services, using acquisitions like One Medical and innovations such as HealthScribe to integrate AI in patient care documentation. Nvidia's GPU technology powers AI-driven health care devices, such as AI-enhanced robotic surgery systems. Apple brings health data straight to consumers with its wearables, integrating health-monitoring technologies like heart rate and oxygen tracking. These technologies aim to make health care more efficient and accessible while addressing physician shortages, cybersecurity, and consumer trust.

WHY IT MATTERS

Big Tech's involvement in health care has the potential to transform the industry, but displacing health care incumbents, deeply rooted in regulation and infrastructure, is a major challenge. Instead of direct disruption, the near future will likely see more collaboration between technology companies and health care providers. Google and Microsoft are partnering with hospitals to integrate AI and cloud services, enhancing clinical and administrative processes rather than replacing them. However, data privacy remains a critical concern. Scandals involving sensitive health data misuse by companies like Meta and Google could hinder consumer trust, particularly as regulations like HIPAA evolve to address new challenges in digital health. Generative AI is also emerging as a transformative tool, with companies like Microsoft and Amazon using it to assist in diagnostics, give treatment recommendations, and reduce administrative burdens. Ultimately, the success of tech companies in health care will depend on navigating regulatory landscapes, addressing privacy concerns, and fostering trust among patients and health care providers. The health care market represents an enormous growth opportunity, but Big Tech must balance innovation with ethical considerations and collaboration with established players to unlock its full potential.

5TH YEAR ON THE LIST

DTC HEALTH CARE MODELS

WHAT IT IS

Direct-to-consumer (DTC) health care models are reshaping patient expectations and experiences by offering more accessible, personalized, and tech-driven care solutions, challenging traditional health care providers.

HOW IT WORKS

The DTC health care model is transforming patient experiences by using technology to bypass traditional barriers. As dissatisfaction with conventional health care grows due to high costs, complex processes, and impersonal care, DTC models offer direct access to virtual consultations, at-home diagnostics, and personalized care.

Digital health platforms are attracting major pharmaceutical attention, as evidenced by Eli Lilly's new partnership with Ro, which strengthens DTC access to medications through integrated prescription services. LillyDirect streamlines medication delivery and chronic disease management through digital pharmacies. K Health's AI platform provides symptom analysis and virtual consultations, partnering with institutions like Cedars-Sinai to enhance care. Telehealth platforms like Teladoc Health have expanded to mental health and offer text-based and video therapy via services like BetterHelp.

Strategic partnerships are further enhancing DTC health care. In 2024, Sanofi partnered with DarioHealth to integrate digital therapeutics into chronic disease management, while GE HealthCare's collaboration with Mass General Brigham focuses on AI-driven solutions to optimize clinical operations and improve access to diagnostics. These alliances show how merging advanced tech with traditional care drives more efficient, patient-centered health care.

WHY IT MATTERS

DTC health care models are a game-changer, democratizing access to health care services by putting the consumer at the center. This shift toward consumer-driven care challenges the traditional health care paradigm, where patients had little control over their care experiences. But patient expectations have changed: 70% of consumers are willing to switch providers in search of better options. Health care is no longer confined to traditional settings but is accessible at the click of a button, whether through a smartphone app or an at-home diagnostic kit.

This trend is driven by several factors, including rising health care costs, technological advancements, and an increasing consumer desire for convenience and control. As the US at-home diagnostics market is projected to reach $5.23 billion by 2033, the financial potential of DTC models is clear. However, this growth also brings challenges, including ensuring continuity of care, addressing data privacy concerns, and managing the risks associated with self-diagnosis and treatment without professional oversight.

Health care providers must adapt by integrating digital tools, enhancing patient engagement, and forming strategic partnerships to remain competitive. Failing to do so may result in losing patients to more innovative and consumer-centric competitors. The DTC model represents not just an evolution but a potential revolution in health care, one that could redefine patient care in the decades to come.

5TH YEAR ON THE LIST

HEALTH AT THE WORKPLACE

WHAT IT IS

Employers are enhancing workplace mental health programs. This reflects a growing demand for comprehensive health benefits that address both mental well-being and rising health care costs, alongside evolving treatments like ketamine-assisted therapy.

HOW IT WORKS

Companies are reevaluating traditional health programs like stress management workshops and fitness classes, with research showing little measurable impact on well-being. But as 91% of employers increase their investment in mental health benefits, AI chatbots are becoming critical tools. Ollie Health offers 24/7 AI-powered mental health support with constant access to live therapists, making it a robust solution for employee well-being in large, dispersed workforces. Wysa and Woebot Health both leverage cognitive behavioral therapy to help employees manage stress and depression through personalized interventions. These tools are particularly effective in remote and hybrid work environments, where employees increasingly prefer engaging with AI for mental health support rather than their manager. There's a cost incentive, too. These lower-cost options are attractive, especially as employees are increasingly filing lawsuits over mismanagement of health care expenses, as seen in cases against Wells Fargo and Johnson & Johnson, where workers accused their employers of overpaying for prescription drugs, leading to inflated premiums and out-of-pocket costs. These lawsuits have forced companies to face federal mandates requiring them to prove responsible use of employee contributions.

Employers are also adding alternative therapies to their health plans. Despite the FDA's recent rejection of MDMA for PTSD, ketamine is gaining traction for treatment-resistant depression, and these therapies are increasingly an option for some employees.

WHY IT MATTERS

Employers are shifting their approach to workplace mental health as stress, anxiety, and depression increasingly impact productivity. Traditional wellness programs are being replaced by solutions addressing deeper issues like heavy workloads, inflexible schedules, and low compensation. By focusing on these core organizational changes, companies can better support employee well-being, leading to lasting improvements for both workers and business outcomes.

At the same time, digital tools like telemedicine, mental health apps, and AI-powered chatbots are becoming essential in workplace wellness strategies, making it easier to scale services in remote and hybrid work settings. These AI-driven tools reflect a broader trend toward tech-based, accessible mental health care that meets diverse employee needs.

While psychedelic-assisted therapy remains a niche offering, treatments like ketamine are gaining traction for severe mental health conditions like treatment-resistant depression. Despite societal and legal barriers, these therapies could become a more significant part of workplace health benefits. By integrating digital tools, flexible health options, and systemic organizational improvements, employers can better support their workforce's mental health while managing health care costs and legal risks.

3RD YEAR ON THE LIST

CONSIDERING HEALTH EQUITY

WHAT IT IS

Efforts to improve health equity focus on closing gaps in care for vulnerable populations, such as people with disabilities, children, and communities of color, by enhancing access to data, policy reforms, and care resources.

HOW IT WORKS

Often, integrating data is one way to reduce inequities. In Worcester, Massachusetts, the Worcester Integrated Health Data Exchange combines data from the University of Massachusetts Chan Medical School, city officials, and local health organizations. Initially targeting opioid use disorders, the platform now focuses on communities of color disproportionately affected by opioid use and employs the Observational Medical Outcomes Partnership model to monitor prescriptions and risk factors, aiming to prevent patients from obtaining opioids from multiple sources. Success could lead to applications for other conditions like diabetes and hypertension.

Data collection is also vital in addressing the greater barriers to health care that 1.3 billion people with disabilities encounter around the world. However, nearly a third of countries lack datasets on disability challenges. Tools like New Zealand's National Child Health Information Platform (NCHIP), which tracks a child's health milestones, illustrate how data sharing can enhance health equity: Immunization rates and general practitioner enrollment increased for children on the platform.

Social determinants like education, income, and access to services account for 80%-90% of health outcomes. In Bogotá, initiatives like Care Blocks support caregivers by bringing services directly to them. And the AI4HealthyCities initiative by the Novartis Foundation combines data across sectors to identify health risks, influencing urban policies.

WHY IT MATTERS

Achieving health equity requires comprehensive data and collaboration across sectors. Initiatives like the data exchange in Worcester show data sharing's potential to tackle disparities in opioid use and other health conditions. Similarly, digital platforms like NCHIP and AI-driven tools offer scalable solutions to track health outcomes and address gaps in vulnerable populations, from children to people with disabilities.

As health care inequities continue to grow, improving data collection standards and leveraging technology will be critical to ensuring that every individual, regardless of race, gender, or disability, has access to high-quality care. Policymakers, health care providers, and communities must work together to integrate these tools and approaches, fostering an environment where health equity can be achieved on a larger scale.

2ND YEAR ON THE LIST

HEALTH CARE'S ENVIRONMENTAL IMPACTS

WHAT IT IS

Health care is increasingly adopting sustainable practices such as renewable energy, waste reduction, and green certifications. Despite high operational demands, collaborative initiatives and policy advocacy are helping hospitals reduce their ecological footprint.

HOW IT WORKS

The health care sector contributes more than 4% of global carbon dioxide emissions, more than aviation or shipping, with hospitals emitting 2.5 times more greenhouse gases than commercial buildings. To address this, hospitals are adopting renewable energy, improving the energy efficiency of medical equipment, and promoting sustainable behavior. For example, Mass General Brigham targets the environmental impact of metered-dose inhalers, which contain hydrofluorocarbon gases with high global warming potential, by promoting alternatives like dry powder and soft mist inhalers.

Collaborative efforts, like those led by the Institute for Healthcare Improvement, support hospitals in implementing sustainability projects, such as decommissioning nitrous oxide systems and eliminating the anesthetic desflurane in operating rooms. These initiatives not only reduce emissions but also save money, encouraging the creation of dedicated sustainability roles.

Hospitals are also investing in renewable energy projects like the Mutkalampi wind farm in Finland, which supplies clean energy directly to health care facilities, reducing reliance on fossil fuels and lowering carbon emissions. Beyond energy sourcing, hospitals are integrating digital health technologies and AI to optimize operations. AI-driven systems improve energy management by predicting peak usage times and adjusting heating, cooling, and lighting to reduce waste.

WHY IT MATTERS

The health care sector's environmental impact extends beyond its direct emissions, affecting both public health and global sustainability efforts. Reducing the carbon footprint of hospitals is critical, as they are major contributors to greenhouse gas emissions and environmental degradation. Sustainable health care practices not only help mitigate climate change but also align with the growing demand from clinicians and patients for environmentally responsible care.

But driving meaningful change toward sustainable health care requires leadership commitment and cross-sector collaboration. By setting clear standards and rules, governments can create a level playing field that incentivizes decarbonization efforts. This is both an environmental imperative and a public health priority, as sustainable health care systems can contribute to overall planetary health and resilience.

Hospitals adopting sustainable practices, such as green operating rooms, reusable medical devices, and eco-friendly inhalers, are leading the way in reducing their industry's environmental impact. By integrating sustainability into their operations, health care providers can improve efficiency, reduce costs, and enhance patient outcomes, setting a precedent for other high-impact industries to follow.

HEALTH CARE ADMINISTRATION

7TH YEAR ON THE LIST

HEALTH DATA INFRASTRUCTURE

WHAT IT IS

The future of health care hinges on robust health data infrastructure, focusing on enhancing electronic health record (EHR) systems with usability, security, and interoperability. Integration of AI, cloud solutions, and data governance is crucial for this transformation.

HOW IT WORKS

Health data infrastructure encompasses systems used to collect, manage, and use health information, with EHRs at its core. Historically, EHRs faced challenges such as poor usability, lack of interoperability, and data security concerns, hindering efficient data exchange and increasing administrative burdens.

Innovations are now addressing these issues. At Emory Healthcare, Epic Hyperspace works on Apple operating systems to streamline workflows and reduce documentation time, allowing clinicians to focus more on patient care. Wellsheet uses interoperability solutions powered by Fast Healthcare Interoperability Resources APIs, which enable seamless data sharing across different EHR platforms, ensuring comprehensive patient histories.

Cloud-based EHR systems, such as Cerner Millennium, offer real-time data access, simplified updates, and enhanced security features like encryption and multifactor authentication. Providence's Praia Health platform has leveraged cloud infrastructure to scale its new patient-facing features from 2-3 per year to more than 40. AI integration, such as Wellsheet's AI-enabled clinical workflows, supports predictive analytics and automates tasks like pre-filling forms, reducing clinician burnout.

But with increasing cyberthreats, enhanced security protocols—including encryption and multifactor authentication—are critical for protecting valuable health care data.

WHY IT MATTERS

By making EHR systems more user-friendly and interoperable, health care providers can reduce administrative burdens and focus more on patient care. Interoperability enhances the continuity of care, ensuring that all health care professionals involved in a patient's treatment have access to comprehensive and accurate information. This not only improves patient outcomes but also reduces the risk of medical errors.

AI and machine learning hold transformative potential for health care. Predictive analytics can identify at-risk patients, prevent adverse events, and personalize treatments. As AI becomes more integrated into health care systems, the potential for improved clinical decision-making and operational efficiency grows.

Among these EHR innovations, cloud-based solutions provide scalability and flexibility, allowing health systems to adapt quickly to changing needs, such as in the case of a pandemic or other public health emergency. We recently saw the importance of having flexible and secure digital systems capable of managing surges in patient data and facilitating remote care during the early years of the COVID-19 pandemic.

However, the widespread adoption of these technologies is not without challenges. Interoperability remains a significant hurdle, with different EHR systems often using incompatible formats.

3RD YEAR ON THE LIST

DEFINING PATIENT ACCESS TO MEDICAL DATA

WHAT IT IS

As data protection laws evolve in Europe, the UK, and the US, patient access to medical data is increasingly shaped by both opportunities and challenges, with new regulations demanding a balance between transparency, privacy, and cross-border data sharing.

HOW IT WORKS

Significant shifts in data protection laws across countries are redefining how patients access and control their personal medical data. In the European Union, the European Health Data Space (EHDS) is set to evolve patient data access. By 2030, all EU citizens will have access to their electronic health data through MyHealth@EU, a cross-border digital infrastructure that connects national health systems and will facilitate data sharing across EU countries. This decentralization ensures patient privacy while promoting secondary data use for research.

In the UK, the Data Protection and Digital Information (No. 2) Bill reflected post-Brexit divergence from the EU's GDPR. It introduced adjustments to patient data-sharing rules, impacting cross-border access for providers, but ultimately fell through because of the Parliament's May 2024 prorogation before its general election. Meanwhile, Switzerland's updated Federal Act on Data Protection (FADP) aligns more closely with GDPR, ensuring stricter sanctions for data misuse.

The US faces a fragmented landscape. While no federal-level law exists, states such as California and Washington have implemented rights-based data protection frameworks, leaving patients to navigate a patchwork of regulations. New laws, such as Nevada's consumer health privacy regulations, emphasize consumer access and deletion rights, complicating nationwide data management for organizations collecting patient data.

WHY IT MATTERS

The global shift toward more stringent, rights-based data protection laws, places patient data access at the forefront of health care transparency. The EHDS offers a template for enhanced patient control, enabling cross-border data sharing while ensuring privacy. This will improve care continuity for patients moving between countries and foster research by making anonymized health data more accessible under secure conditions.

However, the complexity of regulations in the US and UK presents challenges. The lack of a unified federal framework in the US means health care providers must adapt to varying state regulations, which can complicate patient access to data, especially when dealing with cross-border or multistate medical histories. In the UK, post-Brexit data regulation changes may limit the ease of international research collaboration, requiring new data-sharing agreements.

The rise of health data breaches, with a 239% increase in hacking-related incidents from 2018 to 2023, adds another layer of urgency to this trend. Health care institutions must not only focus on regulatory compliance but also implement robust cybersecurity measures to protect patient data from breaches and unauthorized access. The shift toward digital health infrastructure, as seen with the growing role of private companies like Klinik Healthcare Solutions and Palantir Technologies in the UK's National Health Service, raises concerns about transparency and the commercialization of patient data.

2ND YEAR ON THE LIST

INTEROPERABILITY OF DATA INFRASTRUCTURE

WHAT IT IS

The rapid growth of health data in fragmented silos is driving the urgent need for global interoperability standards. To enable seamless data exchange, international bodies are coordinating to focus on harmonizing data formats and terminologies.

HOW IT WORKS

The vast expansion of health data presents both an opportunity and a challenge for the health care ecosystem. This data is often stored in decentralized and disparate systems, lacking unified standards that would enable smooth data sharing. The current landscape consists of unstructured health data, housed in different formats across various databases, which creates significant obstacles for researchers, health care providers, and policymakers.

To address this, the system needs syntactic and semantic interoperability standards. Syntactic standards define the structure and format of data exchange (e.g., XML or JSON), while semantic standards set agreed-upon terms and definitions to ensure that data concepts are consistently understood. The use of standards like Fast Healthcare Interoperability Resources (FHIR) aims to solve the challenge by making it easier for systems to exchange data through a common framework.

Initiatives such as Germany's National Research Data Infrastructure for Personal Health Data (NFDI4Health) have been developing tailored metadata schemas that map to global standards like FHIR, ensuring both syntactic and semantic interoperability. By categorizing standards and mapping them to data exchange protocols, these efforts enable efficient data sharing across national and international systems. Global bodies, like the Joint Initiative Council for Global Health Informatics Standardization and the Global Alliance for Genomics and Health, are working to expand these frameworks.

WHY IT MATTERS

Interoperability in data infrastructure is critical for improving patient care, streamlining research, and enabling large-scale public health initiatives. Harmonized data formats allow health care systems to collaborate, reducing diagnosis delays, and enhancing clinical decision-making. Without global interoperability, health data remains trapped in silos, limiting its potential for driving medical breakthroughs. For example, retrospective data from clinical trials or patient histories often cannot be fully utilized due to incompatibilities in data formats and terminologies. Bridging these gaps can lead to faster development of treatments and more accurate predictive models in areas like genomics and personalized medicine.

Efforts like the HTI-1 rule, which enhances data sharing by enforcing interoperability and transparency in health IT systems, and the CDC's Data Modernization Initiative, aimed at improving public health data infrastructure, show that interoperability is a public health necessity. The COVID-19 pandemic exposed the risks of siloed data, and as AI becomes more integral, unified data sharing frameworks are increasingly essential.

By building a unified data infrastructure, health care institutions can improve everything from early disease detection to large-scale epidemiological studies. Investment in international standards, including the alignment of metadata schemas and AI-driven data curation, will ensure that health data can be used more effectively everywhere.

6TH YEAR ON THE LIST

AUTOMATION OF PROCESSES

WHAT IT IS

Automation, particularly through robotic process automation (RPA), is streamlining administrative and clinical workflows in health care. The results are reduced costs, increased efficiency, and staff members who can focus on higher–value tasks like patient care.

HOW IT WORKS

The health care industry, known for its complex and burdensome administrative systems, has long struggled with inefficiencies, particularly in revenue cycle management (RCM) and billing. Hospitals and physician practices spend billions annually on billing costs, with administrative inefficiencies often leading to significant revenue loss. For example, hospitals can lose up to $62,000 per bed annually due to billing issues.

RPA is addressing this by automating repetitive tasks such as insurance verification, claims processing, and prior authorization. Health care companies can integrate the technology across various systems—from scheduling to checking the status of claims—and the automation can handle up to 70% of manual tasks, cutting operational costs by 20%-35% and reducing the potential for human error. Perhaps more importantly, it frees up health care staff to focus on critical patient care rather than time-consuming administrative tasks.

Beyond billing, automation technologies like AI are enhancing clinical documentation and patient engagement. For instance, AI-powered platforms like Greenway Clinical Assist are helping health care providers save clinicians time by automating routine documentation tasks. The use of AI extends into more complex areas, like analyzing vast medical datasets in real time to enable faster clinical decision-making, a field that Nvidia is pushing forward with its advanced AI microservices and its powerful Blackwell B200 GPU.

WHY IT MATTERS

Inefficient RCM systems and manual billing processes are responsible for billions of dollars in lost revenue each year, creating a substantial drain on health care systems. Automating these processes can help alleviate this financial strain, as well as reduce the administrative burden for employees and increase operational efficiency.

RPA and AI are also crucial in addressing the industry's labor shortages, particularly in the wake of the pandemic, which has led to widespread burnout among health care professionals. Automation lets these providers do more with fewer resources, reallocating human labor to focus on complex, patient-centered tasks that require human judgment and empathy. It's also a stepping stone to more advanced AI applications, which can further reduce administrative burden, optimize clinical decision-making, and improve patient outcomes.

In addition, automation can help health care organizations maintain regulatory compliance and manage ethical concerns related to data privacy and security. As automation becomes more widespread, it will be crucial to maintain human oversight, develop governance frameworks, and ensure that these technologies are used responsibly, particularly in highly regulated health care environments.

2ND YEAR ON THE LIST

INCREASED CYBERSECURITY THREATS

WHAT IT IS

Emerging biotechnologies and critical infrastructure systems are increasingly vulnerable to cyberattacks. As cybercriminals evolve their tactics, the need for robust, interdisciplinary cybersecurity measures is more critical than ever.

HOW IT WORKS

Cybersecurity threats continue to evolve, with emerging dangers in bio-cyber hacking and attacks on critical infrastructure. One growing risk: the manipulation of synthetic DNA to insert malicious payloads. For instance, synthetic DNA can be used to infiltrate DNA sequencing pipelines, activating Trojan malware once processed. Researchers are combating this by applying deep learning techniques, like 1D convolutional neural networks, to detect such attacks with high accuracy. However, the increasing complexity of bioinformatics systems makes them a prime target for hackers.

Beyond biohacking, ransomware groups such as Ransomhub are increasingly targeting critical infrastructure like Industrial Control Systems and Supervisory Control and Data Acquisition (SCADA) systems. Recent attacks, including one on a Spanish bioenergy plant where hackers manipulated the building systems, highlight the risks. These groups use languages like Golang and C++ and buy stolen credentials on dark web forums, amplifying their reach.

Geopolitical factors have intensified these attacks. Nation-state actors, including Chinese government-backed groups, are increasingly targeting US critical infrastructure. In 2024, the FBI disrupted Chinese hackers attempting to upend the US energy grid, water treatment plants, and communication networks, marking a significant escalation in cyberwarfare tactics.

WHY IT MATTERS

As genetic sequencing and biotechnological systems become integral to health care, bio-cybersecurity threats are on the rise. Cybercriminals can exploit vulnerabilities in these systems, leading to data theft or manipulation of biological materials, raising concerns about biowarfare.

Health care data breaches have surged by 239% over the past five years, primarily from hacking and unauthorized access. Ransomware groups target health care systems, causing significant financial and operational damage. These attacks can delay patient care and disrupt medical procedures, putting lives at risk.

Health care providers also face threats to their infrastructure, particularly SCADA systems, which control essential hospital operations like energy management and life-support systems. A cyberattack on SCADA could cripple hospital functions and endanger patient safety. With health care providers relying on interconnected networks and often outdated cybersecurity measures, they are at heightened risk of both data breaches and operational sabotage.

To address these threats, health care organizations must implement robust cybersecurity strategies. This includes investing in advanced detection systems, training staff, and fostering international collaboration. Balancing technological innovation with security is essential to protect sensitive data and critical infrastructure in a rapidly evolving health care landscape.

REMOTE CARE

10TH YEAR ON THE LIST

IN-HOME CONSUMER HEALTH TECHNOLOGY

WHAT IT IS

Innovations in home health technology are empowering individuals to take control of their health with noninvasive, easy-to-use devices, particularly for those managing chronic conditions. These tools enhance self-care, real-time monitoring, and remote patient management.

HOW IT WORKS

Recent advancements in home consumer health technology are transforming how individuals manage chronic conditions at home. Devices like Accurate Meditech's cuffless Accurate 24 BPM monitor allow seamless tracking of blood pressure, oxygen levels, and core body temperature without traditional cuffs. Alerje's Omniject integrates an epinephrine auto-injector with a smartphone case: It automatically alerts health care professionals when activated, enhancing emergency preparedness.

The xKidney portable hemodialysis unit gives dialysis patients a more convenient alternative to conventional dialysis machines by using an advanced piston-balancing pump that eliminates daily cleaning. Similarly, the GyroGlove, designed for individuals with essential tremors, uses gyroscopic technology to stabilize hand movements, offering a noninvasive, drug-free solution that enhances mobility.

Healthcare Vision's noninvasive glucose monitors provide diabetes patients with real-time blood sugar readings without the need for finger sticks. Innovations like Infuzamed's wearable infusion pump allow remote monitoring of vital signs to enable proactive care, while Vivoo's at-home UTI diagnostic kit uses smartphone apps and deep learning for quick analysis, empowering users to share results with health care providers for timely intervention. These technologies reflect the broader trend toward decentralized, personalized health care, reducing reliance on traditional clinical settings.

WHY IT MATTERS

The shift toward home-based health care technology offers significant benefits for patients managing chronic conditions like hypertension, diabetes, and kidney disease. These innovations allow for more frequent monitoring, giving both patients and health care providers better data to track health trends and intervene when necessary.

Wearable health technology offers critical support for those needing continuous care, while minimizing physical discomfort. These devices also reduce the need for frequent clinical visits, which can be costly and time-consuming. By providing patients with real-time, actionable health data, the technology enables them to take more responsibility for their health and make informed decisions with their health care providers.

And as remote patient monitoring becomes more advanced, the potential for timely medical interventions grows. These solutions improve patient outcomes by reducing delays in care, while also easing the strain on health care systems by allowing more patients to be monitored from home. The integration of AI further highlights the role of technology in transforming health care delivery, providing rapid diagnostics and enhancing communication between patients and physicians.

5TH YEAR ON THE LIST

SCALING OF TELEMEDICINE

WHAT IT IS

Telemedicine is rapidly expanding, transforming health care delivery by increasing access to care, integrating innovative technologies, and reducing barriers for underserved populations.

HOW IT WORKS

The telemedicine market is projected to grow more than eightfold by 2031—from $87.2 billion in 2023 to $728.5 billion—driven by demand for tele-consultations and remote monitoring. Telehealth's ability to manage chronic conditions and provide virtual consultations is essential for hospitals and clinics, with some facilities already experiencing success with applications of the technology, like Phoenix Children's Hospital's integration of Amazon Alexa devices allowing family members and support staff to join remotely. Johns Hopkins uses eConsults, a tool for primary care providers to consult with specialists electronically, improving access to expert advice without in-person referrals. This streamlines diagnoses and treatment, enhancing care coordination and reducing unnecessary specialist visits.

Telemedicine is also expanding in specialized care. Well-Sync's partnership with The Vitamin Shoppe launched a testosterone replacement therapy program, expanding men's health services and building on its successful weight loss initiatives. Mental health care has seen significant telehealth adoption, with reduced no-show rates and better access for underserved populations. Institutions like MD Anderson Cancer Center have fully integrated telehealth into everyday clinical operations, highlighting the growing importance of virtual care in comprehensive health care delivery.

WHY IT MATTERS

Telemedicine's rapid expansion is reshaping how health care is delivered, by offering scalable, cost-effective solutions for chronic disease management, preventive care, and even acute care. The growing acceptance of remote monitoring and virtual consultations lets health care systems reach more patients, especially those in underserved or rural areas who often face barriers to accessing traditional care. This shift to digital health care is essential for enhancing access, reducing wait times, and personalizing care—whether through eConsults that facilitate quicker specialist input, remote monitoring of chronic conditions, or specialized telehealth clinics offering focused care like mental health or chronic disease management.

As telemedicine technologies become more sophisticated, the need for strategic integration into health care systems grows. Solutions like Alexa-enabled hybrid visits and remote consultations highlight telemedicine's potential to reduce costs, streamline workflows, and improve care coordination. However, significant challenges remain, including ensuring digital health equity, providing sufficient workforce training, and addressing technical limitations such as broadband access in rural regions. The future success of telemedicine will depend on how well these technologies are seamlessly incorporated into clinical practice, while overcoming these barriers to make health care more accessible, efficient, and patient-centered for everyone.

5TH YEAR ON THE LIST

REMOTE PATIENT MONITORING (RPM)

WHAT IT IS

Remote patient monitoring is revolutionizing health care by enabling patients to receive hospital-level care at home. This technology has the potential to improve patient outcomes, reduce costs, and expand access, especially for those with chronic conditions.

HOW IT WORKS

Increasingly, health care systems are adopting RPM to offer high-quality care outside traditional medical settings. One example is Mass General Brigham's work to transition 10% of its medical patients to home care—a move supported by CMS's Acute Hospital Care at Home initiative, which allows hospitals to deliver inpatient-level care in the patient's home. Studies reveal that the hospital-at-home (H@H) model reduces readmissions, shortens hospital stays, lowers costs, and prevents infections.

The rise of RPM technology has also led to programs like Island Health's Virtual Palliative Supportive Care (VPSC), where patients receive end-of-life care remotely through virtual visits and RPM devices. VPSC's free services include tablets for virtual check-ins, offering patients and families continuous support without frequent hospital visits.

RPM is also gaining traction in intensive care units, with the tele-ICU market valued at $3.5 billion in 2023 and expected to reach $11.8 billion by 2032. Critical care specialists use RPM tools like physiological monitors to remotely monitor and manage ICU patients, improving outcomes and optimizing resources.

In these efforts, key players like Cleveland Clinic are leading the way by integrating RPM tools with AI-based algorithms to enhance patient monitoring. This combination of RPM and AI is proving especially effective in managing chronic diseases like heart failure.

WHY IT MATTERS

RPM is not just improving patient care—it's transforming how health care systems operate, making them more agile and capable of handling higher patient volumes without expanding physical infrastructure. As health care faces increasing pressures from aging populations and rising chronic diseases, RPM offers a scalable solution that delivers high-quality care at a lower cost. By enabling patients to remain at home, RPM significantly reduces hospital overcrowding, a critical advantage during crises like the COVID-19 pandemic. By keeping patients out of the hospital, it also lowers the risk of hospital-acquired infections, which is particularly important for vulnerable populations such as the elderly and immunocompromised.

The expansion of RPM also addresses health care access disparities, particularly in rural or underserved areas where specialist care is limited. Through tele-ICUs and home care programs, RPM extends expert medical support to regions that would otherwise face shortages in critical care. This allows for continuous, real-time monitoring, ensuring that patients receive timely interventions and reducing the likelihood of costly readmissions. As AI continues to enhance the predictive capabilities of RPM systems, health care providers can deliver more proactive care, improving patient outcomes while further optimizing resource use. The continued growth and success of RPM hinges on overcoming challenges such as digital equity and creating sustainable reimbursement models, but its potential to reshape health care delivery is undeniable.

EMERGING DIAGNOSTICS

3RD YEAR ON THE LIST

SMART MATERIALS

WHAT IT IS

The smart textile market is projected to grow at a compound annual growth rate of 25.3%, driven by technologies for health monitoring, aging populations, and rising chronic disease. Europe and Asia are seeing rapid expansion due to R&D and rising health care costs.

HOW IT WORKS

Medical smart textiles combine fabrics with advanced sensors to monitor health in real time. These textiles enhance health care by embedding sensors into clothing, wound dressings, or bedding to track vital signs like heart rate, temperature, and glucose levels.

Active smart textiles integrate sensors to track vital health data such as heart rate and respiratory patterns. Hexoskin's shirts transmit data to smartphones for real-time analysis, helping manage chronic conditions like cardiovascular diseases, while AliveCor's devices monitor heart activity to detect arrhythmias. These innovations enable continuous health monitoring, allowing for early detection of issues and timely interventions, making them increasingly valuable in both home and hospital settings.

Passive smart textiles are also gaining popularity for their antimicrobial and moisture-wicking properties, which improve patient comfort and hygiene. Outlast's temperature-regulating materials, for example, help patients maintain optimal body temperature while reducing infection risks, particularly in long-term care settings. Pecotex, a conductive cotton thread, keeps sensors seamlessly integrated in clothing so they monitor vital signs like heart and respiratory rates. Researchers are exploring materials like MXene and graphene to create textiles that harvest energy from body heat or solar power and companies like Adidas and Jabil are integrating these textiles into sportswear and medical garments.

WHY IT MATTERS

The demand for medical smart textiles is rising sharply due to the increasing prevalence of chronic diseases, an aging population, and the growing focus on home health care. These textiles provide a convenient and noninvasive way to monitor long-term health conditions, significantly reducing hospital visits and enabling personalized care. And that's not all: With health care costs surging globally, these technologies are cost-effective, improve patient outcomes, enhance patient comfort, and reduce the strain on health care systems. They can also help in early diagnosis, crucial for conditions like cardiovascular diseases or sleep apnea, where timely intervention can save lives.

The expansion of the smart textile market is not limited to the West; government initiatives in Europe and Asia-Pacific are pushing research and development, making this technology more accessible worldwide. With leading companies like Adidas, Hexoskin, and DowDupont innovating in this space, the future of medical smart textiles looks promising, particularly as they become more integrated with AI and other digital health platforms.

2ND YEAR ON THE LIST

BIOSENSOR AND CHIP-BASED DIAGNOSTICS

WHAT IT IS

Biosensors provide real-time, continuous monitoring of physiological conditions. Whether embedded in the body or worn externally, these sensors track biomarkers like glucose, proteins, and DNA, enabling early detection of diseases like diabetes, heart disease, and cancer.

HOW IT WORKS

Abbott's Lingo system and Dexcom's G7 offer continuous glucose monitoring, providing real-time insights that help manage diet and lifestyle, even for nondiabetics. By tracking these markers, biosensors enable personalized interventions, making health care more precise and proactive.

Biosensors detect biological signals—like chemical changes or electrical impulses—and transmit data to external processors. These processors analyze the information and send it to devices like smartphones or medical dashboards, where health care providers can instantly interpret the results. For example, cardiovascular biosensors that monitor heart function can detect early signs of disease, allowing for rapid intervention. Technologies like nano-electronics and microfluidics further enable minimally invasive molecular diagnostics, enhancing accuracy and patient comfort. Carterra's high-throughput biosensors, for instance, analyze thousands of molecular interactions in a fraction of the time, speeding up diagnostics and drug discovery.

Advanced biosensors are also being developed for specific applications. BioIntelliSense's multi-parameter biosensors track respiratory and cardiac health continuously, while liquid biopsy biosensors detect cancer biomarkers in blood and saliva, offering a noninvasive alternative to traditional biopsies. Even consumer wearables like the WHOOP 4.0 strap and Apple Watch integrate biosensors to track metrics such as heart rate and oxygen levels, providing continuous data for preventive care and lifestyle adjustments.

WHY IT MATTERS

Unlike traditional methods that require biopsies or surgical interventions, biosensors enable the early detection of diseases, often before symptoms appear, significantly improving treatment outcomes. This shift reduces the need for invasive procedures and allows for proactive, precise care. The ability of biosensors to provide localized, real-time monitoring is especially impactful in reducing misdiagnosis. For example, a biosensor placed near a tumor can track growth and treatment responses, allowing health care providers to adjust strategies dynamically. Devices like BioIntelliSense's multiparameter biosensors continuously monitor vital signs for conditions like respiratory or cardiac disease, while liquid biopsy sensors detect cancer biomarkers in blood and saliva, offering noninvasive alternatives to traditional diagnostics.

Biosensors are also driving the expansion of remote health care. Patients in rural or underserved areas can receive the same level of care as those in urban centers, reducing hospital visits and enabling long-term disease management. Continuous, remote monitoring ensures that any complications are detected early, prompting timely medical intervention. This capability supports a more sustainable health care system by reducing the need for repeated tests and hospital stays.

While challenges like data privacy and sensor reliability remain, the benefits of biosensors—more accurate, timely, and patient-specific health care—are set to redefine medical diagnostics and care delivery.

3RD YEAR ON THE LIST

MOLECULAR DIAGNOSTICS

WHAT IT IS

Molecular diagnostics refers to the process of analyzing biological markers in the genome and proteome to diagnose and monitor disease. It enables early detection of various conditions through blood-based biomarkers, offering noninvasive, accurate, and early diagnosis.

HOW IT WORKS

One recent breakthrough in this field, led by researchers at the German Center for Neurodegenerative Diseases, involves the identification of four key blood proteins—GFAP, NEFL, GDF15, and LTBP2—that can predict the onset of conditions like Alzheimer's and vascular dementia up to 15 years before clinical diagnosis. These protein biomarkers, when combined with other risk factors like age, sex, and genetic susceptibility, offer up to 90% accuracy in predicting dementia.

Galleri, a liquid biopsy test by GRAIL, can detect more than 50 types of cancer in their early stages by identifying circulating tumor DNA and patterns in blood samples, letting patients begin treatment much sooner. Sherlock Biosciences has introduced the Inspectr platform, a CRISPR-based diagnostic tool that enables the rapid identification of viral infections such as COVID-19. The platform can detect viral RNA in under 30 minutes using a portable device, offering fast and accurate diagnostics during outbreaks. This innovation is critical for controlling the spread of infectious diseases. Oxford Nanopore Technologies' MinION is a portable, real-time DNA and RNA sequencer that uses nanopore technology to analyze long strands of genetic material, providing highly detailed, immediate results. Unlike traditional sequencing methods, the MinION is compact and can be used outside of laboratories, making it a flexible tool for field research, clinical diagnostics, and rapid pathogen detection.

WHY IT MATTERS

Molecular diagnostics holds transformative potential across a wide range of diseases, especially through early detection. In cancer, early-stage diagnosis using liquid biopsies or protein biomarkers significantly improves survival rates by catching the disease before it spreads. Similarly, in infectious diseases, rapid molecular tests like CRISPR-based diagnostics can identify pathogens quickly, reducing transmission and saving lives. In resource-limited areas, portable diagnostics enable real-time, point-of-care testing for diseases such as HIV and tuberculosis, making health care more accessible.

Personalized medicine is also benefiting from molecular diagnostics, allowing treatments to be tailored to a patient's genetic or molecular profile. This is particularly important for chronic conditions like diabetes and neurodegenerative diseases, where diagnostics can help refine treatments. In Alzheimer's, for example, identifying distinct biomarkers can lead to targeted therapies, improving patient outcomes.

The global molecular diagnostics market, projected to reach $26.27 billion by 2032, is fueled by rising demand for early detection and personalized care. This growth lowers long-term health care costs by preventing late-stage disease management. Molecular diagnostics is accelerating drug discovery and clinical trials, identifying target populations and tracking responses more efficiently, especially in oncology and immunotherapy.

5TH YEAR ON THE LIST

POINT-OF-CARE DIAGNOSTICS CAPABILITIES

WHAT IT IS

Point-of-care (POC) diagnostics are rapidly evolving, with advances like home-based cardiovascular risk tests showing comparable accuracy to clinical tests, empowering individuals to manage their health and driving broader adoption of decentralized health care solutions.

HOW IT WORKS

Swedish researchers have developed a home questionnaire that identifies individuals at high risk for heart attacks, and it's just as accurate as blood tests and blood pressure measurements. This POC test consists of 14 simple questions and detects 65% of individuals most at risk for cardiovascular disease. This noninvasive, accessible method exemplifies how POC diagnostics can empower patients to take charge of their health without the need for complex medical procedures. POC tools are increasingly used for conditions like infectious diseases and sexually transmitted infections. Binx Health's Binx io platform provides rapid diagnosis for chlamydia and gonorrhea in about 30 minutes, allowing treatment to be delivered effectively in clinical settings like urgent care and emergency rooms. These innovations reduce time-to-result, promote early intervention, and help prevent further transmission of diseases. En Carta Diagnostics is working on a rapid Lyme disease test that can provide results within minutes, addressing a growing need for early detection in vector-borne diseases. These tests can be deployed in both clinical and home settings.

VedaBio's CRISPR Cascade detects nucleic acids in under a minute with sensitivity on par with PCR tests, making it a game changer for real-time, on-site diagnostics in industrial and clinical applications. By eliminating the need for complex laboratory equipment and lengthy amplification processes, this technology enables faster, more accessible testing in diverse settings.

WHY IT MATTERS

The rise of POC diagnostics represents a big shift in health care delivery, offering numerous advantages in terms of accessibility, convenience, and cost-effectiveness. By decentralizing diagnostic services, POC tools empower patients to manage their health proactively and enable faster medical interventions, and can significantly reduce the time between diagnosis and treatment, improving patient outcomes and reducing the spread of infections. These advancements are also shaping the future of health care in underserved and remote regions. With POC diagnostics, medical professionals can easily bring testing to rural areas or low-resource settings where access to laboratory facilities is limited. POC testing is also expected to accelerate in emerging economies where governments are decentralizing health care systems.

There will be a growing need to integrate POC diagnostic data with existing health care systems, particularly through electronic health records and telemedicine platforms. This integration will allow health care providers to track patient data more efficiently, monitor trends in public health, and respond to outbreaks faster.

As more diagnostic capabilities move to the home, there could be shifts in health care spending, with a reduction in hospital-based diagnostics and an increased focus on preventive care. Policymakers will also need to address regulations and reimbursement to ensure equitable access to these innovations, particularly for underserved populations.

5TH YEAR ON THE LIST

XR IN DIAGNOSTICS

WHAT IT IS

Extended reality (XR) combined with artificial intelligence is enabling more accurate, faster, and accessible medical assessments, from pulmonary disease detection to cancer diagnostics, improving patient care and monitoring in various health care settings.

HOW IT WORKS

AI can analyze lung ultrasound images to detect COVID-19 with precision similar to facial recognition. AI models like TRUDLMIA have demonstrated improved diagnostic accuracy for COVID-19, pneumonia, and melanoma by using supervised learning to analyze medical images, offering health care providers faster and more accurate diagnoses.

GE Healthcare is developing wearable technology that monitors lung conditions, such as detecting fluid buildup, and provides real-time alerts for medication adjustments. These wearable ultrasound AI-powered patches let patients manage conditions like heart failure or chronic respiratory diseases from home, reducing the need for frequent clinical visits and offering continuous health monitoring. Lucerno Dynamics' electron waveshaping technology has greatly improved X-ray intensity and precision, delivering beams 1,000 times more intense than conventional X-rays. This enhances image clarity, aiding in early detection of diseases like cancer and potentially lowering radiation exposure for patients, improving both safety and diagnostic accuracy.

Additionally, X-ray fluorescence imaging, which traces immune cell movement and drug delivery in tumors, is becoming more accessible. Together, Siemens Healthineers and Universität Hamburg are developing lab-based systems to make this technology more widely available. This could offer new insights into immune responses and the effectiveness of therapies, especially in cancer and infectious diseases.

WHY IT MATTERS

The integration of XR technologies in diagnostics presents a transformative shift in health care, offering a wide array of implications beyond traditional diagnostic methods. By combining virtual and augmented reality with advanced imaging and AI, XR diagnostics can improve accuracy, reduce diagnostic time, and enhance the visualization of complex medical data. This allows health care professionals to interact with patient data in immersive, 3D environments, leading to more informed and precise decision-making.

XR diagnostics can significantly reduce health care costs by minimizing the need for in-person consultations and unnecessary imaging tests. Patients can be monitored remotely using XR systems, decreasing hospital visits and optimizing the use of resources. This is particularly important for managing chronic diseases, where continuous monitoring is crucial, but frequent clinic visits are impractical.

In medical education, XR can enhance the training of health care professionals by allowing them to interact with lifelike simulations of diagnostic processes. This immersive learning experience can improve understanding of complex conditions and prepare clinicians for real-world scenarios with greater confidence and expertise.

3RD YEAR ON THE LIST

MEDICAL DEEPFAKES

WHAT IT IS

Medical deepfakes involve the creation of highly realistic, yet entirely fabricated images, videos, or audio clips, generated by AI. These deepfakes can be used to mislead patients, manipulate health care professionals, and enable malicious activities.

HOW IT WORKS

As AI capabilities advance, deepfakes are becoming more convincing and harder to detect, creating significant challenges for the health care industry. One significant risk is false endorsements of medical products or treatments. During the COVID-19 pandemic, several misinformation campaigns leveraged deepfakes and AI-generated content to spread false information about vaccines, treatments, and public health measures. While these campaigns did not always involve well-known doctors or officials, they successfully manipulated public opinion, leading to confusion and distrust in legitimate health information. In extreme cases, these campaigns contributed to vaccine hesitancy, endangering public health on a global scale.

Another rising concern is the use of deepfake technology to manipulate medical records or imaging data. Researchers have demonstrated how AI could be used to manipulate medical images, such as MRI and CT scans, to create fake but realistic tumors. These manipulated images were used to deceive radiologists into diagnosing cancer where none existed.

AI-generated voice clones are also a growing threat in health care, where scammers can mimic the voices of doctors or health care providers to defraud patients. While in the past these deepfakes have impersonated family members, they could convincingly impersonate trusted professionals, tricking patients into providing sensitive information or making payments to fraudulent accounts.

WHY IT MATTERS

The health care industry relies heavily on trust between patients, health care providers, and institutions. Deepfakes undermine this trust by blurring the line between real and fake medical information, leaving patients vulnerable to misinformation. When false videos of doctors endorsing unproven treatments circulate, patients may follow dangerous advice, abandon legitimate therapies, or fall victim to fraudulent schemes.

The implications extend beyond misinformation. Deepfakes could severely disrupt health care operations, particularly if they are used to alter patient records or medical imaging data. These disruptions can delay critical treatments, cause medical errors, and expose health care providers to legal and financial liabilities. Furthermore, cybersecurity risks are magnified by deepfake technology, as cybercriminals use these tools to perpetrate more sophisticated attacks, such as ransomware or phishing schemes targeting sensitive patient data.

The ongoing issue of medical fraud is another area where deepfakes pose a serious risk. As voice and video deepfakes become more sophisticated, fraudsters can exploit these technologies to impersonate doctors, insurance representatives, or even patients, leading to significant financial losses for health care institutions and patients alike.

SCENARIO YEAR 2050

A DAY IN THE LIFE

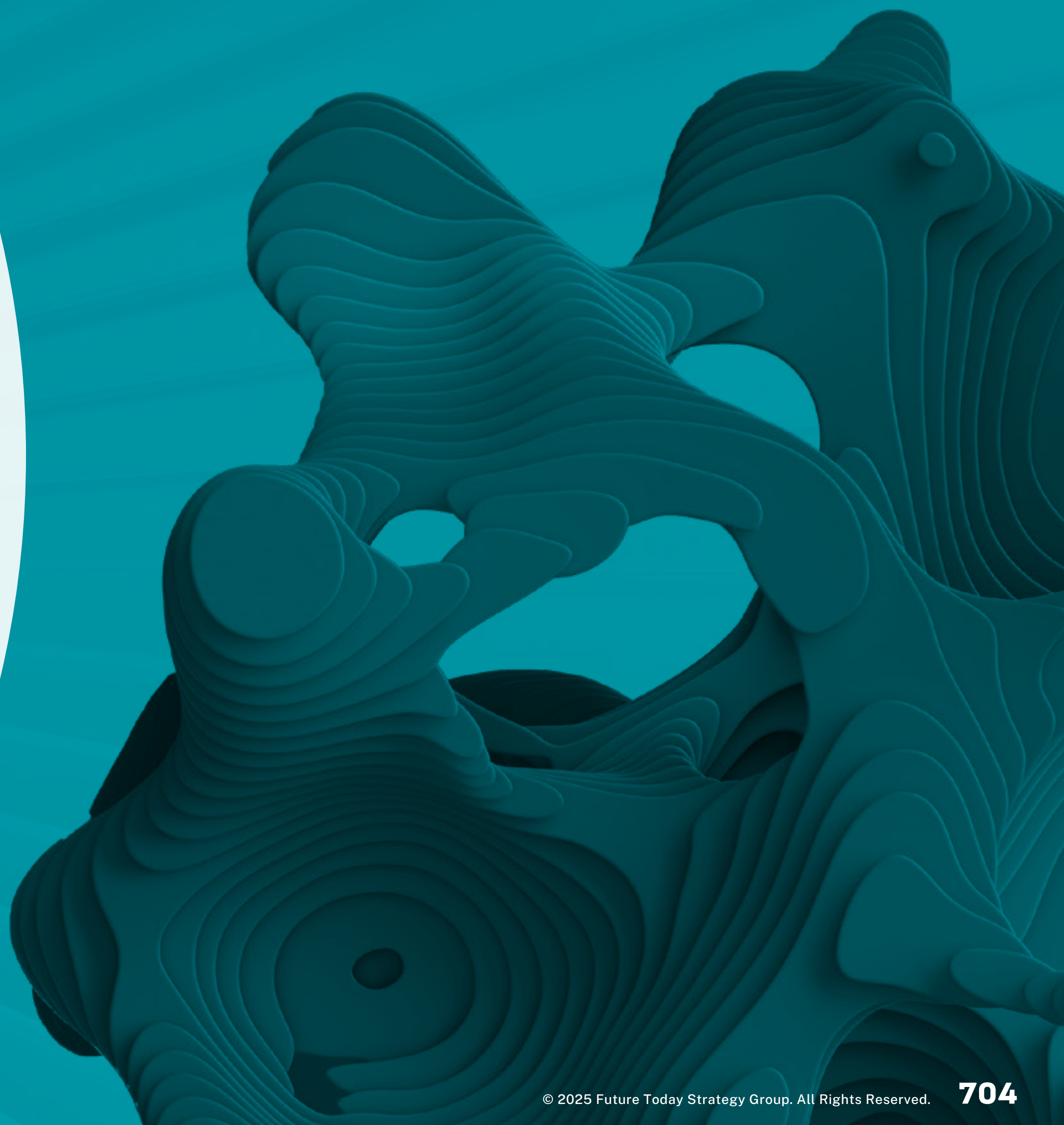
The year is 2050 and health data, diagnostics and personalized care are baked into our days, no matter where you are.

The convergence of personalized medicine, quantum computing, alternative materials and advanced biotech means cutting-edge technology is constantly improving the health of even those living in rural areas, far away from a brick-and-mortar medical center. It starts from the moment you wake up: through the night, a nanotech-powered biosensor embedded in your clothing and bedsheets has been continuously monitoring vitals like blood pressure, glucose and even stress markers. These biosensors, made from nanoscale materials and seamlessly integrated into everyday fabrics, are capable of detecting and measuring biological data at the molecular level.

When the day starts, the sensors compile your data and transmit it to the AI-driven health assistant through your home's neural hub, an advanced interface that connects all your wearable devices, AI systems, and home sensors. Before breakfast is done, the AI health assistant has already suggested some dietary tweaks based on real-time metabolic analysis. It syncs with the personalized nanobot that's been implanted into your thigh, and tells it to adjust the microdoses of vitamins and medications it's releasing directly into your bloodstream. If there's something amiss, no need to worry: the AI will go ahead and schedule a virtual checkup with a global care network specialist without even being prompted.

In the afternoon, it's time for a routine scan at the local CommPrev, a fully autonomous diagnostic station equipped with AI-guided medical scanners and gene-editing capabilities for early disease prevention. The pod performs a full-body scan using terahertz imaging, a revolutionary technique that deploys non-ionizing radiation to penetrate tissues and provide detailed internal images without harmful X-rays. Terahertz waves offer highly precise imaging, revealing abnormalities in skin, tissues, and even cell-level changes. Additionally, the pod conducts a blood analysis through a noninvasive spectrometry interface. It cross-references your results with a blockchain-secured global health database, recommending personalized health trends and optimizing preventive care protocols. If something more is needed, a built-in 3D bioprinter stands ready to create personalized medication or tissue grafts.

This decentralized health care ecosystem, powered by quantum-secure cloud systems, is now the norm. This precision-level health care, far surpassing what was previously available in even the best hospitals, is now seamlessly integrated with our daily routines.



EMERGING TREATMENTS

3RD YEAR ON THE LIST

NANOBOTS

WHAT IT IS

Nanobots, microscopic machines typically measured in nanometers, are designed to perform highly specific tasks at the cellular or molecular level. Recently, their design has gotten more sophisticated, inspired by biological mechanisms, such as those found in bacteria.

HOW IT WORKS

Researchers at ETH Zurich developed a nanobot featuring a clutch mechanism similar to the bacterium *Bacillus subtilis*, enabling precise movement control. This innovation is crucial for delicate tasks inside the human body, such as targeted cell manipulation and tissue repair. Similarly, scientists at the Harbin Institute of Technology created tPA-anchored nanobots to treat blood clots, guided by magnetic fields to deliver a clot-dissolving enzyme more efficiently, reducing the necessary dosage by 42 times and improving treatment outcomes.

At University of California, San Diego, enzyme-powered nanobots have been designed to deliver cancer drugs directly to bladder tumors, minimizing exposure to healthy tissues. Early trials have shown tumor shrinkage, and this technology may be adapted to treat other solid tumors, offering a less toxic alternative to chemotherapy. Additionally, DNA Nanobots, a company using gene-editing technology licensed from University of California, Berkeley, has developed nanobots that deliver genetic material with precision using CRISPR-Cas systems. These bots reduce the risk of immune responses and off-target effects, opening new possibilities for treating genetic disorders and cancers.

In another promising development, researchers at the University of Barcelona created radioactive nanobots to treat bladder cancer. These bots propel themselves toward tumors and release radioactive iodine, reducing tumors by up to 90% in a single dose.

WHY IT MATTERS

The development of nanobots has opened new frontiers in medicine. Their ability to operate at the cellular and molecular levels allows for unprecedented precision in treatments, reducing the need for invasive procedures and improving the efficacy of therapies. For example, cancer therapies often cause significant side effects due to the systemic delivery of drugs. Nanobots offer a solution by targeting only the affected cells, sparing healthy tissues and reducing overall toxicity.

Additionally, the use of nanobots in cardiovascular health, such as the tPA-anchored nanobots for thrombolysis, represents a breakthrough in minimally invasive therapies. The precise targeting of blood clots with significantly reduced drug doses minimizes the risk of hemorrhage, a common side effect of conventional clot-busting drugs. The retrieval capability of these nanobots further reduces the risk of complications.

Nanobots are also showing promise in treating conditions like inflammatory bowel disease by delivering therapeutic agents directly to inflamed tissues, reducing symptoms and promoting healing without the use of systemic medications. This localized approach could transform how chronic diseases are managed, reducing long-term reliance on medications with broad systemic effects.

For a detailed analysis, see the Biotechnology section of our trend report.

5TH YEAR ON THE LIST

AR/VR THERAPEUTICS

WHAT IT IS

Augmented and virtual reality therapeutic technologies immerse patients in realistic, computer-generated environments where they can practice coping mechanisms and learn new behaviors in a safe, controlled space.

HOW IT WORKS

A key feature of VR therapy is its interactive component, used in conjunction with a therapist who guides patients through the scenarios. The content and design of these experiences are crucial; poor execution could lead to ineffectiveness, making rigorous clinical testing a necessity. Solutions like GameChange, a VR therapy designed for people with psychosis, have already gained traction in health care systems such as the UK's National Health Service. This system provides cognitive therapy through simulated situations that help patients reengage with real-world activities they may avoid.

Similarly, AR-based tools like Reality DTx allow patients to undergo exposure therapy for PTSD. These systems make use of devices like the Microsoft HoloLens to offer progressive therapeutic exercises that can be tailored to the individual's condition and treatment goals. In the case of physical rehabilitation, AR systems can assist in gait and balance training for disorders like Parkinson's disease, improving physical mobility.

AR/VR therapeutic systems are not standalone treatments but are designed to be integrated into a broader therapeutic plan, with the technology serving as a medium through which patients can practice and refine the skills they need for real-world application. This emerging field is bolstered by increased funding and technological development, with AR-enhanced PTSD therapy projects like Wayne State University's, backed by the US Department of Defense.

WHY IT MATTERS

A critical advantage of AR/VR therapeutics is the ability to tailor experiences to the individual's progress and needs, which is particularly beneficial for chronic or complex conditions that require long-term management. The technology's scalability also makes it a viable solution for the mental health professional shortage. VR-based systems that offer standalone treatments or digital therapeutic avatars can expand access to care, especially in underserved populations. AR systems can also mimic real-world therapy at less cost than traditional treatments.

The integration of AR/VR technology into therapy can be more fulfilling for patients, too. By offering a more interactive and immersive experience, these therapies can keep patients more motivated and invested in their treatment plans, and this increased engagement can lead to better adherence to therapy sessions. It lets providers measure emotional and cognitive responses in real time, offering therapists richer data to adjust treatment plans more effectively.

AR/VR therapeutics also have the potential to transform training for health care providers. Universities and medical schools could integrate AR/VR into their curricula, ensuring the next generation of health care professionals is equipped to leverage these emerging technologies from the outset.

3RD YEAR ON THE LIST

IN-WOMB TREATMENTS

WHAT IT IS

In-womb treatments represent a transformative approach to addressing genetic and neurological disorders before birth, aiming to prevent the onset of debilitating conditions.

HOW IT WORKS

Around the world, researchers are working on in-womb therapies to treat a variety of conditions. At the University of California, Davis, the CuRe Trial uses placental stem cells to treat spina bifida, a severe spinal defect. Early successes in treatment highlight the potential to intervene before birth, reducing the need for invasive surgery postnatally.

University of California, San Francisco (UCSF) is pioneering in-utero enzyme replacement therapy to address Pompe disease. By administering enzymes in utero, this method allows for early intervention without triggering the immune response. The university is also testing a new way to treat Angelman syndrome, a genetic disorder, before a baby is even born. Special molecules called antisense oligonucleotides are placed in the amniotic fluid surrounding the fetus. These molecules help “turn on” a gene that doesn’t work properly in children with the disease. By starting the treatment before birth, they could prevent brain damage that usually happens later.

Researchers at the University of London have developed a technique using fetal cells from amniotic fluid to create organoids that mimic fetal tissue. This approach helps doctors assess the severity of lung malformations and optimize treatment before birth. Finally, Dr. Tippi MacKenzie, also at UCSF, is advancing the use of CRISPR for fetal genome surgery. Her work, though still in the research phase, highlights the potential to treat genetic conditions like spinal muscular atrophy before irreversible damage occurs.

WHY IT MATTERS

The rapid development of in-womb treatments has the potential to improve prenatal care, offering hope to families facing devastating diagnoses during pregnancy. For conditions that currently have no cure or require lifelong management, in-womb therapies could provide an opportunity for a healthier future, reducing the physical and financial burden on families and health care systems.

One major advantage is the ability to prevent irreversible damage before birth. Conditions like Angelman syndrome or spinal muscular atrophy can cause severe neurological and physical impairments. By intervening early, these therapies can potentially halt the progression of the disease, giving children a chance at normal development. This shift from managing symptoms to addressing root causes could dramatically improve quality of life for patients and families.

Another critical implication is the potential for these therapies to reduce health care costs over a patient’s lifetime. Current treatments for genetic disorders, such as enzyme replacement therapies or surgeries, are often costly and must be repeated throughout the patient’s life. By addressing the issue before birth, in-womb therapies could eliminate the need for ongoing treatments, saving health care systems billions of dollars while also resulting in healthier patients.

5TH YEAR ON THE LIST

COGNITIVE AND NEURAL OPTIMIZATION

WHAT IT IS

Cognitive and neural optimization leverages substances and technologies designed to enhance brain function, improving areas such as memory, focus, and mental clarity. Nootropics, also known as “smart drugs” or “brain boosters,” are central to this trend.

HOW IT WORKS

These substances—natural or synthetic—claim to boost cognitive abilities by improving nerve signal transmission, maintaining neuron health, or increasing energy production in the brain. Adaptogens like ashwagandha are gaining traction for their ability to improve cognitive flexibility, executive function, and visual memory, particularly in people with mild cognitive impairment. Similarly, creatine, widely known as a supplement for physical performance, has shown cognitive benefits in older adults. Emerging studies on paraxanthine, a metabolite of caffeine, suggest that it may offer cognitive benefits with fewer side effects, including improved memory and longer-lasting wakefulness.

Cognitive optimization is increasingly supported by neural technologies. Companies like Cymbiotika are innovating with nootropic creamers that blend cognitive-enhancing compounds like L-theanine, Alpha GPC, and L-tyrosine, designed to enhance focus and brain health. Adaptogenic blends, like those offered by London Nootropics, incorporate natural ingredients like Lion’s Mane, Cordyceps, and Rhodiola rosea to combat stress and improve mental clarity through everyday products like coffee.

Paradigm Sports’ partnership with Ten Percent Club brings certified nootropics to pro athletes, offering products that enhance focus, reaction time, and mental clarity. These rigorously tested supplements are designed to support athletes’ cognitive performance alongside physical training, promoting peak performance in high-pressure scenarios.

WHY IT MATTERS

The rising interest in cognitive and neural optimization is fueled by a broader societal push toward enhancing human performance and managing mental health. The global nootropics market, expected to grow to $4.4 billion by 2032, reflects this surge in demand for natural, safe cognitive enhancers. As people around the world face increasing stress, burnout, and cognitive decline due to aging, there is a growing need for accessible solutions that improve mental performance and resilience.

Despite the rising popularity of nootropics for cognitive enhancement, there is a substantial lack of rigorous scientific research to confirm their efficacy, particularly for long-term use. While substances like caffeine and creatine are well-studied and show some short-term cognitive benefits, many other nootropics lack robust clinical trials. Studies on compounds such as Ginkgo biloba and Bacopa monnieri, for example, offer mixed results, with some showing limited improvements in specific cognitive functions, but overall, evidence remains inconsistent.

While some nootropics have been proven safe, their actual effectiveness in improving long-term cognitive performance remains uncertain. Many claims are based on anecdotal evidence or short-term studies, making it difficult to draw conclusive results on their impact over time. Longitudinal research is needed to better understand their effects, and whether they can truly prevent cognitive decline or significantly enhance brain function.

8TH YEAR ON THE LIST

BRAIN-COMPUTER INTERFACES AND NEUROPROSTHETICS

WHAT IT IS

Brain-computer interfaces (BCIs) and neuroprosthetics are enabling seamless communication between the brain and external devices. This is paving the way for innovations in mobility, communication, and neurological health.

HOW IT WORKS

BCIs and neuroprosthetics are developing new ways for our brains to control the world outside the body. At MIT and the University of Pittsburgh, scientists have developed neuroprosthetics that use neural signals to enable intuitive movement. By directly linking the prosthetic to the nervous system, users experience improved coordination and mobility, including the ability to walk faster and climb stairs more naturally compared to traditional prosthetics.

In 2024, Elon Musk's Neuralink implanted its BCI in a second patient after its initial human trial. This implant, part of the ongoing clinical trials, enables individuals with spinal cord injuries to control devices using their thoughts. The Swiss Federal Institute of Technology in Lausanne has developed a miniaturized brain-machine interface that translates neural signals into text, helping individuals with severe motor impairments communicate through thought-controlled text systems. BCIs are also being explored for cognitive enhancement. A Harvard University study revealed that manipulating neural circuits involved in curiosity could lead to more personalized BCIs that respond to a user's mental state. Chinese researchers have developed gene-powered BCIs that enhance the health of neurons around implanted electrodes, improving the longevity and performance of these systems. This genetically engineered approach shows promise for long-term applications, from restoring movement in paralyzed patients to enabling more complex neuroprosthetic control.

WHY IT MATTERS

BCIs and neuroprosthetics provide new solutions for people with disabilities, neurodegenerative conditions, or severe injuries. For individuals with paralysis, BCIs offer a pathway to regaining autonomy, enabling movement and communication that would otherwise be impossible. This technology could dramatically improve quality of life for people with conditions like ALS or spinal cord injuries, as it allows them to control external devices using only their brain activity.

The implications extend beyond health care. BCIs also present opportunities in gaming, virtual reality, and smart home control. As the technology evolves, it may enable users to interact with digital environments and devices in more immersive ways, enhancing experiences in entertainment and daily life. And as seen in Neuralink's early trials, the future of BCIs could include broader applications, such as enhancing cognitive functions like language learning, memory, and focus.

But as BCIs advance, there are ethical considerations that must be addressed. Issues such as privacy, data security, and cognitive autonomy are critical when developing systems that decode neural signals. Ensuring that BCI technology is accessible and safe for all users is essential as it becomes integrated into more aspects of daily life, from health care to consumer technology.

For a detailed analysis, see the Biotechnology section of our trend report.

2ND YEAR ON THE LIST

PRECISION MEDICINE

WHAT IT IS

Precision medicine is transforming health care by tailoring treatments to individual genetic, molecular, and environmental profiles. This approach allows for more effective therapies and better patient outcomes.

HOW IT WORKS

Precision medicine leverages advancements in genetic profiling, molecular biology, and AI technologies to develop personalized treatments based on an individual's unique genetic makeup. AlphaFold 3, developed by Google DeepMind and Isomorphic Labs, revolutionizes drug development by predicting 3D molecular structures, accelerating the discovery of tailored therapies. Similarly, personalized cancer vaccines using mRNA technology—such as those developed for melanoma—train a patient's immune system to target specific tumor cells, representing a significant leap in individualized cancer treatment. Additionally, the recent development of in vivo CAR-T therapies by Interius BioTherapeutics creates targeted immune responses in the patient's body, bypassing complex manufacturing processes and making cancer treatments more accessible and precise.

The approach extends beyond cancer. Researchers at various organizations, including CRISPR Therapeutics and Editas Medicine, are using CRISPR-Cas9 technologies to target genetic diseases like sickle cell anemia and hereditary blindness. By editing the specific DNA sequences responsible for these conditions, they are tailoring therapies that promise long-term solutions. In the field of metabolic diseases, studies have shown that individuals have varying insulin responses to proteins, fats, and carbohydrates, leading to personalized dietary interventions for managing conditions like diabetes. These efforts exemplify how precision medicine is expanding the potential for highly personalized health care across various medical domains.

WHY IT MATTERS

Precision medicine marks a fundamental shift from one-size-fits-all treatments to approaches tailored specifically to each individual's biology—a move that is particularly transformative for diseases like cancer, genetic disorders, and chronic conditions that previously relied on broad-spectrum treatments. By understanding the genetic and molecular underpinnings of diseases, clinicians can provide more effective, targeted interventions with fewer side effects.

This approach can significantly reduce health care costs by eliminating ineffective treatments and improving long-term patient outcomes. As therapies become more targeted, patient recovery times decrease, reducing hospital stays and the need for further interventions. For conditions like cancer or diabetes, where disease management is often ongoing and complex, precision treatments offer the possibility of more sustainable, long-term care strategies.

Beyond individualized treatment, precision medicine also opens new avenues for drug development. AI systems like AlphaFold 3 enable faster, more accurate drug discoveries, cutting years off traditional development timelines. This is particularly important for rare and neglected diseases, where traditional research methods are slow and expensive. Precision medicine also allows for the application of emerging technologies like CRISPR to correct genetic disorders at the source, offering potential cures rather than symptom management.

4TH YEAR ON THE LIST

EXPANDING MEDICAL MIS- AND DISINFORMATION

WHAT IT IS

The rapid spread of health misinformation on social media, exacerbated by AI advancements and influencer content, is eroding trust in legitimate health information. Platforms like YouTube are introducing measures to verify credible sources, but challenges persist.

HOW IT WORKS

The spread of health misinformation on social media remains a significant issue. A recent study on TikTok's content about sinusitis revealed that a large percentage of these videos, created by nonmedical influencers, contained false information, leading to misinformed health decisions. YouTube has expanded its YouTube Health initiative, which was launched to verify health professionals and prioritize their content. YouTube has also partnered with trusted organizations like the World Health Organization and the National Academy of Medicine to ensure that verified creators provide accurate information. These verified channels are becoming vital sources of reliable medical advice, especially in regions where access to health care is limited.

Another growing area of misinformation relates to cancer treatments. Some misleading claims suggest that herbal remedies or unverified dietary supplements can cure cancer. These falsehoods have led some patients to delay or avoid conventional treatments, with serious health consequences. Social media platforms and fringe websites are major vectors for these harmful narratives.

Misrepresentation of gene-editing technologies like CRISPR has fueled disinformation around precision medicine. Some claims exaggerate the dangers or ethical concerns, while others spread false hopes about curing complex diseases immediately. Such distortions not only confuse patients but also complicate the public's understanding of emerging medical technologies.

WHY IT MATTERS

Misinformation and disinformation, especially when spread by influencers or deepfake technology, contribute to a growing mistrust of health care institutions and professionals. This erosion of trust undermines public health initiatives and can lead to a decline in individuals seeking preventive care, following medical advice, or adhering to treatment regimens. As trust weakens, misinformation can foster skepticism toward vaccines, medications, and even the competence of medical practitioners, making it harder to manage public health crises and leading to poorer health outcomes on a larger scale. Misinformation also deepens health care disparities, especially in marginalized communities with medical mistrust.

Misinformation can lead to the adoption of ineffective or harmful treatments, or the avoidance of effective ones, which can result in preventable hospitalizations, complications, and deaths. This not only harms individuals but also places a significant burden on health care systems, increasing the costs associated with treating conditions that arise from following false medical advice.

While platforms like YouTube have taken steps to verify credible health professionals and flag false content, the speed at which misinformation spreads remains a major obstacle. Addressing this challenge requires coordinated efforts between governments, tech companies, and health care organizations to strengthen digital media regulation and improve public health education.

SCENARIO YEAR 2040

THE BIOTECH REBELLION

The allure of genetic enhancement and personalized biotech has established a dark undercurrent in global health care. Driven by the promise of engineered perfection—enhanced intelligence, strength, and immunity—individuals are seeking unregulated genetic modifications as mainstream biotech companies struggle to keep up with demand. Rogue biohacking communities, once niche groups experimenting in garages, have expanded into an underground industry, offering back-alley CRISPR modifications and black-market implants. The appeal is undeniable: Why wait for government-approved procedures when you can fast-track your evolution? Yet, the consequences of these DIY procedures are unpredictable and catastrophic.

In unmonitored labs and secret clinics, genetic experiments go awry. Early adopters of unregulated biotech soon face devastating repercussions—mutations spread across cellular structures, causing organ failure, accelerated aging, and aggressive cancers. Augmentations intended to enhance intelligence lead to severe neurological conditions. The impact ripples through society as hospitals, overwhelmed by biohacking injuries, are unequipped to treat novel, genetically modified diseases. Communities fracture as those with failed augmentations demand restitution and treatment while governments, caught off guard, are slow to respond. The health care system—already burdened by aging populations and chronic disease—collapses under the weight of the biotech rebellion.

As chaos mounts, regulatory bodies scramble to contain the crisis. Attempts to shut down rogue labs and enforce stricter biotech laws lead to protests, and biohackers claim their right to self-determination. Some regions, unable to enforce regulations, become biotech wastelands where genetic experimentation continues unchecked. Trust in mainstream health care plummets, and legitimate biotech research grinds to a halt as public fear of genetic modification escalates. What was once seen as the next frontier of human progress is now a battlefield—one where the consequences of unchecked ambition threaten the very fabric of society.

IMPLANTS, PROSTHETICS, AND WEARABLES

3RD YEAR ON THE LIST

EMERGING IMPLANTS

WHAT IT IS

Innovations in implant technology, powered by advanced materials and energy harvesting, are enabling smaller, more efficient, and biocompatible medical devices. These emerging implants are transforming health care by offering adaptive and minimally invasive solutions.

HOW IT WORKS

Researchers at Penn State University have developed a wireless charging device that harnesses both magnetic fields and ultrasound, generating 300% more power than current technologies. This allows the miniaturization of implants, such as bioelectronic devices, eliminating the need for bulky batteries and external components. By combining safe, low-frequency energy sources, this technology could improve the power supply for tiny medical devices, offering more comfort and convenience to patients.

The university has also developed new electrospinning techniques that are enabling the creation of nano/microrobots and implantable biosensors, addressing long-standing material compatibility issues. These biosensors can monitor conditions at the cellular level, offering precise, personalized treatments. 4D Medicine's resorbable material, 4Degra, is being used to develop bioresorbable orthopedic implants. The material, compatible with 3D printing, naturally degrades without harmful by-products, making it ideal for temporary implants.

Bioresorbable opto-electronic systems are emerging in neurology, allowing for both neural stimulation and real-time activity recording. These biodegradable implants reduce the risk of long-term complications and could transform the treatment of neurological disorders. North Carolina–based Restor3d is advancing 3D-printed orthopedic implants that are custom-designed for each patient, reducing recovery times and the need for follow-up surgeries.

WHY IT MATTERS

The rise of advanced implant technologies is transforming health care by shifting from reactive to proactive care. These devices allow for continuous monitoring and early intervention, reducing the need for invasive procedures and improving overall health outcomes. By enabling personalized, real-time treatments, implants have the potential to lower health care costs and improve management of chronic conditions like heart disease and diabetes. As these technologies become more accessible, they could also help close gaps in underserved regions, bringing high-quality health care to patients in remote areas.

As these implants become more integrated into everyday medical practice, they will likely reshape the health care infrastructure itself. From a regulatory perspective, there will be a need for updated guidelines and standards for safety, data security, and patient privacy, especially as more data is continuously collected and transmitted through these devices. From a workforce perspective, health care providers will need specialized training to manage and implement these advanced systems. This could lead to the development of new medical specialties and job opportunities focused on the maintenance, interpretation, and application of implant technology, further modernizing the health care ecosystem.

3RD YEAR ON THE LIST

ADVANCED PROSTHETICS

WHAT IT IS

Advances in prosthetics are transforming the capabilities of artificial limbs by incorporating artificial intelligence, biomimetic designs, and enhanced sensory feedback systems. These make prosthetics more functional, adaptable, and personalized.

HOW IT WORKS

MIT's Agonist-Antagonist Myoneural Interface (AMI) uses the patient's own nervous system to control bionic limbs. This allows for natural movements by reconnecting residual muscles in the amputated limb, providing proprioceptive feedback and enabling users to walk, climb, and navigate obstacles with ease. Patients with AMI implants reported feeling their prosthetic as a natural part of their body, showing improved mobility compared to traditional prosthetics.

STMicroelectronics and DuPont Liveo Healthcare collaborated to create an intelligent electronic skin patch for monitoring cardiac events. This skin patch is designed to provide continuous heart monitoring, combining smart sensing technology with AI to deliver real-time data to health care providers. Heriot-Watt University's accelerator program supported Infinity DPM in developing prosthetics with softer, human-like materials, enhancing comfort and reducing irritation caused by traditional designs.

Emerging materials and technologies are also making prosthetics more durable and user-friendly. 3D printing is revolutionizing prosthetics with customized, patient-specific designs, such as the Hero Gauntlet, a prosthetic that enhances grip strength and functionality using advanced materials like Nylon 12. At Esper Bionics, researchers are leveraging AI to create bionic hands that adapt to user behaviors, allowing for more natural, independent finger movements, which is helping Ukrainian veterans regain functionality after limb loss.

WHY IT MATTERS

The development of advanced prosthetic technologies marks a significant leap in health care, offering life-changing benefits for individuals who rely on artificial limbs. As prosthetics become more integrated with the body's own nervous system, they not only restore physical abilities but also enhance the user's sense of embodiment, leading to greater confidence and independence. This shift from mechanical to biomimetic prosthetics represents a move toward solutions that feel more natural and are better aligned with the user's lifestyle and needs.

The integration of AI in prosthetics is creating devices that can learn from the user's movements and adjust over time, offering a more personalized experience. The use of intelligent materials and 3D-printing techniques allows for faster, more cost-effective production of prosthetics that are tailored to fit each individual's anatomy. This accessibility and customization are vital for improving the functionality and comfort of prosthetics, enabling users to engage in a wider range of activities and reducing the long-term physical strain associated with traditional designs.

As prosthetics become more advanced and better integrated with the user's body, they not only restore physical abilities but also help reduce feelings of alienation or loss that often accompany limb amputations. The ability to regain a sense of normalcy through natural movements and enhanced sensory feedback can improve self-esteem and emotional health.

13TH YEAR ON THE LIST

EMERGING WEARABLES

WHAT IT IS

Emerging wearable technologies are revolutionizing health monitoring, with devices like continuous glucose monitors, smartwatches, and sensor-embedded smart fabrics offering real-time insights into personal health metrics.

HOW IT WORKS

The BeamO by Withings is a 4-in-1 health monitoring tool, combining an electrocardiogram (ECG), oximeter, digital stethoscope, and thermometer in a handheld unit. Designed for both personal use and remote medical consultations, it can detect serious conditions like atrial fibrillation, lung wheezing, and desaturation, which makes it one of the most comprehensive consumer health devices on the market. Its ability to capture heart and lung sounds for medical diagnosis sets it apart from standard wearables, which typically focus on more general metrics like heart rate or steps.

The GyroGlove assists individuals with Parkinson's disease by stabilizing tremors. This wearable glove empowers users to regain control over everyday tasks like eating and writing, offering a significant improvement in quality of life.

Microfluidic patches are another development in this space, analyzing biomarkers like glucose and cortisol directly from sweat or skin without invasive tests. Startups like LifeLeaf are pioneering noninvasive glucose monitoring, offering patients real-time insights crucial for managing chronic conditions such as diabetes. Additionally, AI-enhanced wearable ECG devices, such as those developed by STMicroelectronics, are transforming cardiac care, enabling remote monitoring of heart activity to detect early signs of stroke and other cardiac issues. These wearables are increasingly integrating with electronic health records, allowing health care providers to access continuous health data for more informed decision-making.

WHY IT MATTERS

The growing adoption of wearables is reshaping health care by promoting proactive health management and reducing the need for frequent clinic visits. With real-time monitoring, patients can receive timely interventions, which is especially valuable for managing chronic conditions like diabetes and cardiovascular diseases. The continuous collection of health data also enables more personalized treatment plans, improving patient outcomes and lowering health care costs. As these devices become more accessible, they hold the potential to address disparities in care, particularly in underserved and rural areas, where regular access to health care providers can be challenging.

The integration of AI into wearable technologies enhances their ability to process large amounts of biometric data quickly and accurately, allowing for both predictive and preventive care. By providing users and health care providers with near real-time insights into health status, AI-driven wearables can detect early signs of illness, reduce the burden on hospitals, and support long-term wellness management. As these technologies evolve, they will likely continue to play a critical role in transforming health care by fostering a more data-driven, patient-centered approach.

13TH YEAR ON THE LIST

MATURE WEARABLES

WHAT IT IS

Wearable technology has evolved from fitness tracking to become a crucial tool for personal health monitoring. With innovations in sleep, heart, and hearing health, wearables offer real-time health insights and make proactive care more accessible.

HOW IT WORKS

Apple is enhancing its Apple Watch and AirPods Pro with features designed to monitor critical health conditions like sleep apnea and hearing loss. Using the new "Breathing Disturbances" metric, the Apple Watch can detect sleep apnea signs, a condition affecting more than one billion people globally. By tracking breathing irregularities, users can share this data with their health care providers, improving diagnosis and treatment accuracy. Similarly, the AirPods Pro now feature tools aimed at hearing health, including a hearing test and basic hearing aid functions. This marks a significant shift, especially following the FDA's ruling that allows over-the-counter hearing aids in the US, democratizing access to hearing care.

Samsung is advancing its Galaxy wearables lineup, notably the Galaxy Ring and Watch7, which provide continuous health monitoring and sleep apnea detection. These devices integrate Samsung's advanced sensor technologies with AI to offer personalized health insights. The Galaxy Watch Ultra, Samsung's most durable option, caters to athletes by offering triathlon tracking and enhanced heart health metrics. With Wear OS 5, these devices deliver faster performance and power efficiency.

These wearables leverage AI to process vast amounts of biometric data, and they are seamlessly integrated into broader ecosystems. As a result, users can collect, track, and share health data across multiple devices, allowing for a comprehensive understanding of their well-being.

WHY IT MATTERS

The integration of advanced health monitoring features in wearables signals a profound shift in personal health care. This level of accessibility to health insights is critical as it addresses public health issues affecting millions globally, such as hearing impairment, which has been linked to cognitive decline and emotional well-being.

These advancements contribute to a growing trend where tech companies are positioning themselves within the health care space. By offering medical-grade monitoring and analysis, wearables are becoming more central in preventive health care strategies. This shift is particularly relevant as health care systems become strained and consumers demand more autonomy over their health.

Users can now monitor their biological age and metabolic health, offering proactive management of lifestyle diseases such as diabetes. This aligns with broader trends in digital health, where continuous monitoring and personalized data are empowering users to take control of their health before more severe interventions are necessary.

As more companies enter the wearables market, the focus on health monitoring is expected to deepen, potentially leading to early detection of more complex conditions such as cardiovascular diseases or even mental health disorders. These wearables are not a substitute for professional health care but serve as essential tools in preventive care and early intervention.

SCENARIO YEAR 2032

THE HEALTH CAPSULE

The overwhelming influx of data from wearables and AI-powered health platforms has reached a critical point, leaving both patients and health care providers buried in endless streams of information. With continuous tracking of everything from heart rates to stress levels, patients are anxious, unsure how to interpret fluctuating metrics. Doctors, too, struggle to prioritize relevant data, leading to burnout and delayed care. The sheer volume of health information—meant to improve outcomes—has instead created confusion, inefficiency, and mistrust in health technologies.

Enter the Health Capsule. This small, e-ink device distills the flood of data into a personalized, minimalist format that both patients and providers can easily understand. Rather than tracking every minor fluctuation, the Health Capsule gives patients simple daily summaries—like “low energy” or “good sleep”—while its AI filters out irrelevant data from wearables, identifying only the most important patterns. It provides a clear, concise health snapshot each day, displayed on its calming e-ink screen, offering natural language insights such as “Hydration needed” or “Steady improvement in energy.”

For health care providers, the Health Capsule solves a major issue: how to manage the growing deluge of patient data without sacrificing care quality. Doctors can sync the Capsule during appointments, retrieving concise insights without being overwhelmed by raw metrics. By simplifying health data into actionable summaries, the Health Capsule restores balance, making health care manageable again for both patients and providers.

RESEARCH

3RD YEAR ON THE LIST

SYNTHETIC HEALTH DATA

WHAT IT IS

Synthetic health data offers a privacy-preserving alternative to real-world patient data, enabling AI model training, clinical research, and health care innovations without compromising confidentiality. However, its accuracy and application require careful validation.

HOW IT WORKS

Synthetic health data refers to artificially generated datasets designed to replicate the statistical properties of real-world patient data without including identifiable information. These datasets are created using algorithms, such as generative adversarial networks (GANs) or diffusion models, which learn the relationships between variables in the original data. They then produce new, statistically similar records that can be used in place of actual patient data.

Several organizations are leading in this space, such as MDClone, which provides health care institutions with a platform to generate synthetic data for research and clinical trials. Nvidia's Nemotron-4 models offer developers synthetic data to train large language models (LLMs), which can be leveraged in health contexts. Academic institutions like King's College London have created synthetic 3D images of human organs, such as the brain, to study neurological diseases without relying on real patient scans.

One of the primary advantages of synthetic data is its ability to bypass privacy concerns under regulations like HIPAA or GDPR, which has enabled entities like the FDA and Veterans Affairs to use synthetic datasets for research to avoid exposing sensitive patient information. In these cases, synthetic data mimics real-world data so closely that it can be used for hypothesis testing, algorithm training, or generating "precision cohorts" for clinical research.

WHY IT MATTERS

Synthetic data holds immense potential for transforming health care. Traditional reliance on real-world patient data poses numerous challenges, from privacy risks to logistical hurdles in data access. With synthetic data, health care organizations can overcome these barriers, unlocking new avenues for AI model training, policy simulation, and clinical research.

In the age of AI, access to vast datasets is crucial for developing accurate diagnostic tools, predictive models, and personalized treatment plans. Synthetic data plays a key role in addressing data scarcity, particularly in underrepresented medical conditions or minority populations, where real-world data is limited. For example, diffusion models have been used to generate synthetic chest X-rays, significantly improving AI-based diagnostic accuracy for underrepresented groups. This not only helps to generalize health care models but also ensures that new innovations are more inclusive.

Despite these advantages, synthetic data must be rigorously validated to ensure it is representative and free from systemic biases. Flaws in the synthetic data generation process can lead to incorrect insights or model collapse, especially if the data is used to train AI systems for high-stakes decision-making. And transparency is paramount: Pulling back the curtain on how synthetic datasets are generated and maintained is vital to building trust among health care providers, researchers, and patients.

2ND YEAR ON THE LIST

NEW TRIAL METHODS

WHAT IT IS

In silico, virtual reality (VR), and remote clinical trials are transforming medical research, reducing costs, enhancing trial design, and making trials more accessible, while providing reliable regulatory evidence for drug and medical device development.

HOW IT WORKS

In silico trials use computational models and simulations to mimic human responses to drugs and medical devices without needing human or animal participants. One example is the FDA's VICTRE project, which compared breast imaging techniques using 3,000 synthetic breast phantoms. The results demonstrated that in silico models could produce reliable regulatory evidence.

VR allows researchers to simulate real-world environments in which patients can interact with medical devices or treatments. They are being used to test rehabilitation devices and mental health therapies, providing immersive environments that replicate real-life conditions. Dassault Systèmes' "Emma Twin," a digital twin avatar, has been used to simulate patient outcomes in VR environments, enabling researchers to study the efficacy of treatments for various conditions in a highly controlled, yet realistic, setting.

Remote trials, which rely on decentralized clinical trial platforms, enhance patient accessibility and engagement. They allow patients to participate from their homes, significantly reducing the need for in-person visits and increasing the diversity of trial participants. AI-driven tools like TrialGPT and Criteria2Query help match patients to trials, improving recruitment efforts and patient retention. These platforms often incorporate wearable devices and mobile health apps to collect real-time data, streamlining patient monitoring and enhancing data accuracy.

WHY IT MATTERS

In silico trials are especially beneficial for rare diseases, where gathering enough participants for traditional trials can be a challenge. They also reduce the risk of late-stage failures by allowing researchers to refine trial designs and dosing regimens early in the development process. By providing a controlled yet flexible environment, VR trials offer deeper insights into how patients interact with new treatments. Remote trials have democratized clinical research.

In addition to the cost and time savings, these new methods are also environmentally friendly, as they reduce the need for travel, on-site staff, and physical infrastructure. For pharmaceutical companies, the reduced trial costs mean lower financial risks and faster time-to-market for new treatments. According to GlobalData, the market for in silico clinical trials is projected to reach $5.1 billion by 2030.

However, challenges remain in gaining full regulatory acceptance for these new trial methods. While in the US the FDA has approved several in silico trials, including for a pacemaker designed to be safe in MRI scans, European regulators are still developing frameworks to incorporate these models into their approval processes.

4TH YEAR ON THE LIST

LAB-ON-A-CHIP (LOC)

WHAT IT IS

Lab-on-a-chip devices are revolutionizing diagnostics by integrating complex laboratory functions onto a single, miniaturized platform, enabling faster, cost-effective, and portable testing across health care, biotechnology, and environmental fields.

HOW IT WORKS

LoC devices are compact, integrated systems that replicate the functionality of entire laboratories on microchips. These devices use microfluidic technology to manipulate tiny volumes of liquids through networks of channels etched onto a chip. This allows for multiple simultaneous tests, such as chemical analysis, molecular diagnostics, and biological assays, on a single platform.

One device already doing this is LoCKAmp, developed by researchers at the University of Bath; it's capable of providing lab-quality viral detection within minutes using a highly sensitive and specific molecular technique used to detect RNA sequences. By integrating AI to figure out how to most effectively monitor and control the microfluidic processes, researchers are able to develop intelligent microfluidics that self-regulate based on real-time data, making LoC systems more autonomous and adaptable. At the University of Pittsburgh, researchers developed a self-powered, millifluidic LoC device that uses blood flow to generate electricity via a triboelectric nanogenerator. This system is being explored as a way to diagnose metabolic disorders like diabetes by measuring blood conductivity, offering portable and real-time health monitoring.

Researchers at the University of Bath have developed 3D-printed chips that function without needing an external power source. These devices, which can be produced in less than an hour, hold great promise for rapid diagnostics at a low cost.

WHY IT MATTERS

Lab-on-a-chip technologies are reshaping diagnostics and research by offering rapid, cost-effective, and portable alternatives to traditional laboratory setups. In health care, LoC systems provide immediate, on-the-spot testing, which is particularly beneficial in rural or resource-limited areas.

Sustainability is another critical factor driving the development of LoC systems. Traditional lab tests often require large amounts of single-use plastics and other non-recyclable materials, contributing to environmental waste. By miniaturizing processes and reducing the materials needed for each test, lab-on-a-chip technologies offer a more sustainable alternative. Efforts to incorporate biodegradable materials and reduce the carbon footprint of manufacturing processes align with the growing need for eco-friendly medical technologies.

These lab-on-a-chip systems are also democratizing science and health care by making advanced diagnostic tools available to a broader range of users. A notable example is the educational initiative in Bolivia, where students were introduced to programming and computational biology through internet-enabled lab-on-a-chip technologies. This initiative not only improved their technical skills but also increased their interest in pursuing careers in STEM fields, showing the potential of LoC systems to inspire the next generation of scientists and engineers.

2ND YEAR ON THE LIST

3D BIOPRINTING

WHAT IT IS

3D bioprinting is an advanced tissue engineering technique that constructs tissue by layering bioactive substances, such as living cells and biomaterials, into complex 3D structures. This addresses the demand for customized implants and reduces reliance on organ donors.

HOW IT WORKS

Mayo Clinic researchers are using bioprinting to create tissue models, such as skin replicas for studying inflammatory diseases like eczema. With bioinks—combinations of hydrogels, biomaterials, and cells—they can accurately print tissues that resemble human skin. The ultimate aim is to print fully functional organs like kidneys to address organ shortages.

Innovations in bioprinting materials are helping advance this technology. A research team at Hefei Institutes of Physical Science, part of the Chinese Academy of Sciences, mixed a special glass with biocompatible polymers to make a new material that works well for bone healing. This material helps the body form bone more easily and can be adjusted depending on the type of bone repair needed.

In space, 3D bioprinting is being tested in microgravity, allowing the development of tissues like cardiac muscle and meniscus without the need for scaffolds. On the International Space Station, the BioFabrication Facility is printing human tissues in three dimensions, advancing regenerative medicine in ways not possible on Earth. Vital3D is focusing on printing complex structures using laser light to harden bioinks. Its precision tools aim to enhance scalability for future organ bioprinting.

WHY IT MATTERS

3D bioprinting holds transformative potential across multiple areas of health care, particularly in addressing organ shortages and personalizing medical treatments. One of the most pressing applications is in organ transplantation. Millions of patients worldwide suffer from organ failure, and donor organs are limited. By enabling the printing of functional organs, 3D bioprinting could alleviate this shortage, reducing the need for donor organs and minimizing the risk of rejection by using patient-derived cells.

This technology also promises advancements in personalized medicine. By bioprinting tissues using a patient's cells, physicians can tailor treatments specifically to the individual. For example, bioprinted tissue models can simulate how a patient's body will react to drugs, allowing more precise testing of new therapies. This personalization could reduce drug side effects and increase treatment efficacy.

In regenerative medicine, bioprinting allows the development of tailored implants for bone and soft tissue repair, offering an alternative to traditional methods that often require invasive procedures. It has the potential to accelerate wound healing, particularly for patients with chronic conditions like diabetes.

2ND YEAR ON THE LIST

QUANTUM IMPROVES RESEARCH

WHAT IT IS

Quantum computing has the potential to transform scientific research across industries by enabling faster data processing, simulations, and problem-solving, especially in health care and drug discovery.

HOW IT WORKS

Quantum computing harnesses qubits, which differ from classical bits by being able to exist in multiple states simultaneously. This property, known as superposition, allows quantum computers to process complex data much faster than traditional computers. The Quantum Technologies Group at Carnegie Mellon University is investigating how quantum computing can enhance health care diagnostics, such as using quantum-inspired support vector machines for predicting diseases like pneumonia more efficiently than classical AI methods.

The University of Colorado's Anschutz Medical Campus and Atom Computing are also exploring quantum computing's potential through their collaboration with the Elevate Quantum consortium. Their focus includes improving access to health care in rural areas, detecting rare diseases, and advancing drug discovery. Another application is quantum's ability to create more accurate molecular simulations, which holds promise for personalized medicine and drug development.

Cleveland Clinic is collaborating with IBM and the Novo Nordisk Foundation to integrate quantum computing and AI into personalized medicine and drug discovery. By combining quantum computing with machine learning, these partnerships aim to customize health care solutions at an individual level, optimizing treatment plans based on genetic profiles.

WHY IT MATTERS

Quantum computing holds transformative potential for industries, particularly health care and drug discovery. Traditional computational tools struggle with the complexity of molecular interactions and large datasets, leading to limitations in research speed and accuracy. Quantum computing breaks through these barriers, enabling faster drug discovery and more precise diagnostics. For instance, quantum simulations could tailor treatments to a patient's unique genetic makeup, a major goal in personalized medicine.

Additionally, quantum computing could drastically reduce drug development times and costs by enabling simulations that replace costly laboratory experiments. This democratizes research, making high-powered computational tools available to smaller biotech firms, fostering competition, and potentially lowering drug costs. Quantum computing can also protect sensitive patient data through quantum-enhanced cryptography, a growing concern as health care becomes more digitized.

Despite these advancements, quantum computing remains in its early stages, with much of its potential yet to be realized. Key challenges, including the development of fault-tolerant quantum systems and scalability, must be overcome. However, collaborations between universities, health care institutions, and tech companies are laying the groundwork for quantum's integration into research and clinical settings, ushering in a new era of innovation.

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As founder and CEO of the Future Today Strategy Group (FTSG), Amy pioneered a unique quantitative modeling approach and data-driven foresight methodology that identifies signals of change and emerging patterns very early. Using that information, Amy and her colleagues identify white spaces, opportunities, and threats early enough for action. They develop predictive scenarios, along with executable strategy, for businesses worldwide. In addition, Amy is regularly asked to advise policymakers in the White House, Congress, U.S. regulatory agencies, the European Union and United Nations. In 2023, Amy was recognized as the #4 most influential management thinker in the world by Thinkers50, a biannual ranking of global business thinkers. With research specializations in both AI and biotechnology, Amy is the author of four books which have been translated into 23 languages. She developed and teaches the Strategic Foresight Course at NYU Stern School of Business.

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2025 TECH TRENDS REPORT • 18TH EDITION

FINANCIAL SERVICES & INSURANCE

FTSG

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Nick Bartlett
Financial Services and Insurance Lead

Transformation efforts need to happen now—before it's too late.

The next decade will be make-or-break for companies in the financial services and insurance industry based on their ability to harness the immense amount of data available to improve efficiency, personalization, and speed. While headlines focus on the latest artificial intelligence breakthroughs, a more fundamental challenge looms larger: the capacity to build and maintain the data and computing infrastructure necessary to support these advancements at an unprecedented scale. While many companies have made strides in modernization, they're moving too slowly compared to the rapid pace of technological change. Current efforts, though commendable, risk falling short of the rapid advancements in the tech sector. By 2030, this industry will face significant disruption from nontraditional competitors that are already integrating sophisticated financial and insurance capabilities into their offerings. To maintain industry leadership, companies must accelerate digital transformation efforts and embrace cutting-edge technologies more comprehensively.

The transformation needed in financial institutions isn't just about upgrading systems; it demands a fundamental reimagining of operational models that will determine their relevance in the evolving financial landscape. The industry faces significant challenges—from the substantial computational demands of AI workloads to the widening skills gap in specialized infrastructure management and growing data privacy concerns—yet these hurdles also present unprecedented opportunities. Companies that successfully modernize their platforms with a focus on business strategy rather than technology alone stand to gain improved customer experiences, enhanced data analytics capabilities, and greater regulatory agility. Building robust, scalable, and secure computing infrastructures will help companies maintain a competitive advantage and control of their own destiny in an increasingly digital financial world. The institutions that rise to the occasion will lead in AI adoption and actively shape the future of finance, securing their place at the forefront of the industry's next evolution.

Forward-thinking institutions that embrace comprehensive digital transformation now will be best positioned to lead as the industry becomes evermore technology-driven. The future of financial services is being written today, and it will be defined by those who take decisive, strategic action to modernize their operations and capabilities.

Regulatory adaptation and scrutiny will underscore transformative efforts over the next year.

1

AI Governance Is a Strategic Imperative

The NAIC's AI model bulletin, adopted by 21 states, signals intensifying regulatory scrutiny of AI in financial services and calls for robust governance frameworks.

2

Quantum Computing Will Revolutionize Future Risk Modeling

Banks like Citi are already experimenting with quantum computing for portfolio optimization and fraud detection, heralding a new era in financial management.

3

Digital Identity Is the New Battleground for Data Security

With digital wallets projected to reach 5.2 billion users by 2026, securing digital identities becomes crucial in preventing fraud and protecting sensitive financial data.

4

Climate Change Is Redefining Risk Management

Swiss Re estimates that climate risks could reduce global GDP by 11%–14% by 2050, forcing insurers and banks to radically rethink their risk assessment models.

5

Instant Payments Are Accelerating Disruption of Legacy Systems

The EU's mandate for instant payments and the success of Brazil's Pix system are driving global adoption of real-time payment infrastructure.

A perfect storm of forces are rapidly reshaping financial services and insurance.

The financial services industry is undergoing a profound transformation, marked by forces that create both extraordinary opportunities and systemic risks. AI has evolved from theoretical applications to become foundational technology, now powering core operations, from underwriting and fraud detection to customer service and risk modeling. However, its rapid deployment across the industry requires robust governance frameworks to prevent bias and ensure equitable outcomes.

Real-time interactions have become the baseline expectation across financial services. Instant payments, driven by regulatory mandates and consumer demand, are positioned to replace legacy systems. This shift creates a hyperefficient transactional landscape while introducing new vulnerabilities that call for sophisticated security measures. Similarly, digital identity has evolved beyond basic authentication into a complex ecosystem of personal data and financial credentials, magnifying the importance of data privacy and cybersecurity.

The insurance sector faces mounting challenges as climate-related disasters increase in frequency and severity, necessitating new risk models and coverage strategies to address escalating losses and maintain long-term solvency. Simultaneously, widespread digitalization exposes institutions to increasingly sophisticated cyberthreats, and they'll need to shift from reactive security to proactive, intelligence-driven defense architectures.

The decisions made in this period of transformation will shape not only individual institutions but the stability and inclusivity of the entire financial ecosystem. This convergence of technological advancement, changing consumer expectations, and emerging risks defines the current state of financial services and sets the stage for its evolution.

Artificial intelligence is a top focus, prompting new product rollouts and several regulatory changes.

MAY 2024

Key Players Form AI Readiness Working Group

The Fintech Open Source Foundation's new task force is developing a governance framework for safe AI implementation.

JULY 2024

NY Dept of Financial Services Issues AI Circular

The guidance regulates NY-based companies in their use of artificial intelligence in insurance underwriting and pricing.

SEPTEMBER 2024

JPMorgan Chase Launches AI Assistant

Chase introduces the AI assistant LLM Suite to more than 140,000 employees, just one piece of a broader AI strategy.

OCTOBER 2024

AXA XL Launches AI Coverage

The new endorsement to AXA XL's cyber policies covers data poisoning, usage rights infringement, and regulatory violations.

DECEMBER 2024

States Adopt NAIC's AI Guidance

By the end of 2024, 21 states had adopted the NAIC's Model Bulletin on the Use of AI Systems by Insurers.

« PAST

Decreasing US regulation and oversight could reshape the industry.

FUTURE »

Q1—Q2 2025

Capital One Moves Cards to Discover Rails

Following a successful acquisition, Capital One plans to move its cardholders over to the Discover network.

Q2 2025

Basel III Endgame in Question

With Donald Trump in and Michael Barr out, the Fed's Basel III regulations are in limbo, potentially easing banks' capital requirements.

Q2—Q3 2025

Bank M&A to Become Easier and Faster

The Trump administration has promised deregulation, and the industry is gearing up for streamlined deal approvals.

Q2—Q4 2025

Insurer Response to Climate Crisis

As insurers reel from wildfire losses earlier in the year, watch for policy and coverage changes.

Q4 2025—Q1 2026

Truth.Fi's Disruptive Fintech Offerings

Trump's fintech venture Truth.Fi recently announced plans to offer customized ETFs and cryptocurrency products in the future.

AI and decentralization are transforming the future of financial services.

Hyper-Personalized Risk Ecosystems

AI-driven data modeling will transform risk assessment by creating dynamic, individualized financial profiles that transcend traditional credit scoring, enabling institutions to make nuanced decisions based on holistic, real-time behavioral insights and alternative data streams.

Programmable Value Networks

Cryptocurrency and open banking could plausibly converge to create fluid, borderless financial ecosystems where value transfer becomes instantaneous, programmable, and decentralized, fundamentally reimagining how capital moves across global economic landscapes.

Autonomous Compliance Engines

Advanced AI and blockchain technologies will create self-regulating compliance mechanisms that dynamically adapt to evolving regulatory landscapes, reducing human error and transforming risk management from a reactive to a predictive discipline.

Parametric Risk Intelligence

AI-powered parametric insurance models will revolutionize risk transfer by enabling instantaneous, algorithmically triggered protection mechanisms that respond to predefined environmental, technological, and economic parameters with unprecedented precision.

Frictionless Identity Economics

Digital identity technologies will emerge as the foundational infrastructure for a new economic paradigm, where authentication becomes seamless, privacy-preserving, and cryptographically secure across financial, governmental, and commercial interactions.

Cyber Resilience Architectures

Emerging cyber risk mitigation strategies will transform from defensive postures to proactive, intelligence-driven ecosystems that anticipate, neutralize, and learn from potential threats through advanced machine learning and predictive analytics.

These individuals are at the forefront of development and transformation in the financial services & insurance industry.

- **Andrew Mais, Connecticut's insurance commissioner,** for his work on the potential of AI and the importance of regulatory compliance.

- **Brian Collins, executive director of the Earth Fire Alliance,** for his organization's work to build a satellite constellation focused specifically on fire, ushering in a new era of fire monitoring.

- **Dave Jones, director of the Climate Risk Initiative at University of California, Berkeley,** for his founding of the Sustainable Insurance Forum and forward-thinking work on climate impacts to insurance.

- **Günther Thallinger, board member of Allianz SE and chair of the UN Net-Zero Asset Owner Alliance,** for his work leading sustainable finance initiatives and aligning global investment portfolios with net-zero goals.

- **Dr. Henna Karna, Harvard fellow and formerly from Google,** AXA, AIG, and Verisk, for her work on the impact of AI on the insurance workforce, including the need for AI literacy and talent development.

- **Dr. Marco Pistoia, head of Global Technology Applied Research at JPMorgan Chase,** for his research in the application of quantum, blockchain, and other technologies in the field of financial services.

- **Rafael Forte Araújo Cavalcanti, SVP data, analytics and AI at Bradesco,** for his work developing generative AI use cases for banking in the Bradesco Artificial Intelligence Lab.

- **Dr. Robert Hartwig, director, Risk and Uncertainty Management Center, and clinical associate professor at University of South Carolina,** for his ongoing thought leadership and research on the insurance market.

- **Rose Goslinga, co-founder and CEO of Pula,** for her work pioneering climate insurance and risk management solutions for smallholder farmers in emerging markets.

- **Ryan Bank, founder and global managing director of the Geospatial Insurance Consortium,** for his work broadening aerial imagery for the insurance sector.

- **Serge Beck, CEO and founder of Omniwire,** for his work to develop more secure financial systems for consumers.

- **Sopnendu Mohanty, chief fintech officer of the Monetary Authority of Singapore,** for his work driving fintech innovation and regulatory frameworks that foster digital finance and insurtech.

Advancing technology will drive increased revenues and decreased expenses...

...but firms must navigate rapidly evolving digital and compliance risks.

OPPORTUNITIES

Ecosystem Orchestration

Open banking can help institutions integrate diverse services and create value-added ecosystems. Through cross-sector partnerships, banks can enhance engagement and generate new revenue.

Behavioral Economics Integration

AI-driven insights will enable firms to nudge customers toward better decisions. By analyzing patterns in spending, saving, and investing, institutions can design personalized offerings that improve financial health while fostering stronger customer relationships.

Embedded Finance Proliferation

Financial services are seamlessly integrating into nonfinancial platforms. These strategic partnerships allow firms to offer new products to new customers, securing relevance in an increasingly platform-driven economy.

Regulatory Technology (RegTech) Leadership

Firms pioneering AI-driven compliance solutions will gain a competitive advantage. By developing sophisticated RegTech capabilities, they can automate compliance processes, predict regulatory changes, and proactively manage risk.

THREATS

Data Sovereignty Challenges

The proliferation of localized data laws may complicate cross-border services and data management strategies. Institutions must steer through a complex web of regulations that potentially require duplicative infrastructure and increasing operational costs.

Quantum Computing Encryption

Quantum advancements could render current cryptographic methods obsolete, necessitating rapid and costly security overhauls. Institutions face the task of quantum-proofing their entire digital infrastructure to prevent unprecedented security risks and maintain customer trust.

Digital Identity Monopolies

Tech giants may dominate digital identity verification, marginalizing traditional financial institutions in customer relationships. As these platforms become primary gatekeepers of identity, banks and insurers risk losing direct customer engagement and valuable insights.

Climate Liability Exposure

Insurers face potential litigation for underestimating climate risks that could lead to unforeseen liabilities and reputational damage. As climate-related events intensify, insurers may be held accountable, resulting in financial losses, regulatory scrutiny, and erosion of public trust.

The right strategies will guide financial leaders through the emerging landscape.

Implement solutions, such as blockchain-based capabilities, for smart contracts, instant payments, and secure digital identity verification. This will streamline operations, reduce fraud, and enable new business models in areas such as parametric insurance and decentralized finance.

Establish comprehensive digital literacy programs and data science training initiatives for existing staff, while also recruiting specialists in emerging fields like climate risk modeling and behavioral economics to ensure the workforce can leverage new technologies effectively.

Proactively engage with regulators to shape policies around open banking, data privacy, and digital currencies. By participating in regulatory sandboxes and industry working groups, companies can help create a balanced regulatory environment that fosters innovation while protecting consumers.

Allocate significant resources to develop a robust cybersecurity infrastructure, including advanced encryption capabilities. This investment will safeguard against evolving cyberthreats, protect sensitive customer data, and maintain trust in an increasingly digital financial ecosystem.

Develop integrated platforms that leverage open banking APIs and alternative data sources for enhanced credit scoring and risk assessment. This will enable more accurate underwriting, personalized product offerings, and improved access to financial services for a broader market.

Invest in climate risk modeling tools and sustainable finance initiatives. This will help insurers better assess and price climate-related risks, while enabling financial institutions to develop innovative green financial products that align with global sustainability goals.

Technology Deployment | Capital Expenditure | Talent Development | Regulatory Influence

FINANCIAL SERVICES & INSURANCE TRENDS

BUILDING BLOCKS

12TH YEAR ON THE LIST

DIGITAL IDENTITY

WHAT IT IS

Digital identity is evolving rapidly, driven by increased digital interactions, regulations, and technological advancements. By 2026, a significant transformation in how individuals control and protect their digital identities will reshape security, privacy, and accessibility.

HOW IT WORKS

Digital identity is the unique representation of an individual, organization, or device in the digital space. It comprises identifiable attributes like usernames, passwords, biometric data, and other personal information for online interactions and transactions. The concept of digital identity has existed since the early days of the internet, but its significance has dramatically increased as our lives have become more digitally integrated.

Creating and managing digital identities involves complex systems that collect, verify, and store personal data. For example, when setting up a new online account, a user provides information such as an email address, password, and sometimes biometric data like fingerprints or facial recognition. The service provider then authenticates this data, to create a digital identity profile.

Increasingly, governments are also exploring digital identities. Last year, Australia's Parliament passed the Digital ID Bill 2024; it lays the groundwork for a nationwide digital identity system that allows financial institutions and service providers to integrate with the government's Digital ID platform, enhancing security and convenience for users. Similarly, the US Department of Commerce's National Institute of Standards and Technology is working to adapt digital identity guidelines to support public benefits programs.

WHY IT MATTERS

Adopting digital identity systems offers vital benefits, including fraud prevention and improved security for personal information. As seen with Australia's new law, the systems can be regulated to protect users by ensuring that only accredited service providers can handle digital identities, thereby reducing the risk of fraud and identity theft.

Another critical aspect is accessibility. Digital identity systems can provide official documentation to individuals who previously lacked it, such as refugees or people living in remote areas, improving their access to essential services. This is particularly evident in initiatives like those supported by the UN Refugee Agency, which integrates refugees into national identification systems across several African nations.

Digital identity also offers individuals greater control over their personal information. For instance, Japan's major banks are working on a digital identity solution that allows users to store their data on their mobile devices securely, giving them complete control over their information. But the widespread adoption of digital identities also presents challenges. As more personal information is stored online, the potential for breaches increases, necessitating robust security measures and requiring a delicate balance between convenience and privacy.

7TH YEAR ON THE LIST

SCALING CRYPTO-CURRENCIES

WHAT IT IS

Regulatory approval of cryptocurrency products like Bitcoin ETFs is transforming the market by bringing digital assets into the realm of traditional finance. This shift is fostering broader adoption, institutional engagement, and a more stable market environment.

HOW IT WORKS

In 2024, the cryptocurrency market underwent a significant transformation driven by regulatory advancements and institutional integration. One of the most impactful developments was the US Securities and Exchange Commission's approval of Bitcoin exchange-traded funds. These ETFs allow investors to purchase shares in a fund that holds Bitcoin and trades on regulated exchanges like Nasdaq, marking the first time cryptocurrencies have been brought under the same regulatory umbrella as other financial instruments. Soon after, the UK's Financial Conduct Authority approved crypto-backed exchange-traded notes for professional investors. The introduction of Bitcoin ETFs represents a broader trend toward the institutionalization of cryptocurrencies, but as of January, the US stopped short on full institutionalization after the incoming administration promptly banned a US CBDC (or digital dollar).

Major financial institutions and payment processors are increasingly offering cryptocurrency services, further embedding digital assets into the traditional financial system. For instance, Stripe, a leading fintech company, has reentered the cryptocurrency space by allowing merchants to accept payments in stablecoins like USDC on multiple blockchains. This is the first time Stripe has accepted cryptocurrencies since 2018. This move signifies a shift in the perception of digital currencies, recognizing them as viable means of everyday transactions rather than merely speculative assets.

WHY IT MATTERS

As regulatory frameworks solidify, the cryptocurrency market is becoming more accessible and less volatile, attracting a more diverse and risk-averse investor base. The approval of Bitcoin ETFs and the increasing integration of cryptocurrencies into traditional financial services mark the beginning of a new era for digital assets. These regulatory developments legitimize cryptocurrencies and pave the way for more institutional investment, which is crucial for the market's long-term stability and growth.

However, the move toward greater regulation also brings new challenges. As governments and regulatory bodies like the SEC continue to develop and enforce cryptocurrency regulations, the industry will need to adapt to new compliance standards. This could include stricter Know Your Customer and Anti-Money Laundering requirements, which may increase operational costs for crypto exchanges and other service providers. Another challenge will likely be a more fragmented and complex global regulatory environment as more countries follow US efforts to regulate digital assets.

For businesses, the implications are profound. Companies that can navigate this evolving regulatory landscape will be well-positioned to capitalize on the growing acceptance of cryptocurrencies. On the other hand, those that fail to comply with new regulations could face significant legal and financial repercussions.

3RD YEAR ON THE LIST

OPEN BANKING

WHAT IT IS

In 2024, US banks faced a turning point when the Consumer Financial Protection Bureau (CFPB) advanced its rule on "personal financial data rights," pushing them to adopt open banking or risk losing ground. The rapid integration of open banking APIs is now critical for staying competitive.

HOW IT WORKS

Open banking has been driven by mandates like the European Union's second Payment Services Directive (PSD2) and the UK's Open Banking Standard. The CFPB advanced similar regulations under its 2024 rule mandating the secure sharing of consumer financial data.

Key players continue to expand, enabling a new generation of services. Plaid connects with more than 11,000 financial institutions, allowing applications like Venmo, Robinhood, and Coinbase to securely access and use financial data to offer seamless digital financial services. Stripe also launched a new open banking–powered payment method, "Pay by Bank," in the UK so that businesses can accept bank-to-bank payments without the need for credit cards, as a more secure and cost-effective payment option. Similarly, Klarna, a Swedish payments fintech company, has introduced open banking–powered settlement services in Europe for users to make direct payments from their bank accounts rather than use traditional payment cards.

For small and medium-size enterprises, open banking enables better cash flow management through real-time access to financial data and integration with accounting software. This streamlining allows businesses to make informed financial decisions, optimize working capital, and reduce the cost of financial operations.

WHY IT MATTERS

The competitive landscape is rapidly shifting as fintech companies and new market entrants leverage open banking to introduce innovative financial solutions that directly challenge traditional players. For example, Revolut and Monzo, two digital-only banks, have capitalized on open banking to offer services like budgeting tools, real-time spending notifications, and no-fee foreign transactions. Traditional banks and insurance companies must adapt by forming partnerships with these agile fintechs or developing their own competitive offerings. By integrating open banking solutions, they can expand their service portfolio, reach new customer segments, and capture a larger market share.

Operational efficiency and compliance are also crucial considerations. Open banking enables seamless integration across various financial platforms, reducing the need for manual processes and minimizing the risk of human error. This integration can lead to significant cost savings, particularly in areas like payment processing and customer onboarding.

As regulatory frameworks become more stringent, financial institutions that are proactive in adopting secure and compliant open banking practices will mitigate regulatory risks and avoid potential fines. Additionally, the enhanced data visibility provided by open banking can improve fraud detection capabilities, allowing institutions to better protect their customers and reduce the risk of financial loss.

2ND YEAR ON THE LIST

AI-ASSISTED DATA MODELING

WHAT IT IS

AI-assisted data modeling is transforming industries like finance and insurance by enhancing risk management, fraud detection, and decision-making. Major players like Visa and Lemonade are leveraging AI to improve operational efficiency, reduce fraud, and drive competitive advantage.

HOW IT WORKS

AI-assisted data modeling utilizes artificial intelligence to analyze vast amounts of data, uncover patterns, and make predictions that inform business decisions. This technology has significant applications in industries like finance and insurance, where companies deal with large volumes of complex data.

Visa integrated AI into its fraud detection systems, using a range of AI-powered tools to assess transaction risks in real time. These tools analyze data from multiple sources, apply machine learning models to detect anomalies, and assign risk scores to each transaction. Similarly, digital insurance company Lemonade has developed a suite of AI models, including a composite AI called LTV, which aggregates insights from 50 different machine learning models to predict the lifetime value of each customer. This allows Lemonade to make more informed decisions about customer acquisition and retention strategies, ultimately improving its loss ratio—a key measure of an insurance company's efficiency.

AI models in these contexts work by being trained on historical data, learning from past transactions, and continuously updating their algorithms as new data becomes available. These systems can then identify patterns that human analysts might miss, such as subtle shifts in customer behavior or emerging fraud tactics. The AI's ability to process and analyze data at scale enables businesses to make real-time decisions that improve efficiency and reduce risk.

WHY IT MATTERS

The integration of AI into data modeling represents a significant shift in how industries manage risk and make decisions. For financial services and insurance, where the ability to accurately assess risk is crucial, AI provides a competitive edge by enhancing the accuracy and speed of decision-making processes. For instance, AI models can predict the likelihood of fraud far more effectively than traditional methods, making companies more proactive in being able to prevent fraudulent transactions. This not only saves money but also enhances customer trust and satisfaction. These AI-assisted models can also improve customer segmentation and personalized marketing, helping companies to better target their services and improve customer retention.

The impact of AI-assisted data modeling is profound, especially as the technology continues to evolve. With AI, companies can harness vast amounts of data to drive more strategic decision-making, improve operational efficiency, and maintain a competitive advantage in an increasingly data-driven world. But the adoption of AI also brings challenges, such as the need for robust data governance and the potential for new forms of cyberthreats. As AI models become more sophisticated, the risk of adversarial attacks—where bad actors manipulate AI systems—also increases. Organizations must invest in securing their AI systems and ensuring that they are transparent and accountable.

SCENARIO YEAR 2040

SYNTHETIC OVERLOAD

By 2035, financial institutions and insurers have fully transitioned to digital-first operations. Physical branches are obsolete, replaced by AI-powered virtual service hubs that handle onboarding, claims, and transactions remotely. Biometric verification and video KYC (Know Your Customer) protocols are standard, offering convenience and efficiency. However, these advancements inadvertently create fertile ground for a new threat: hyper-realistic synthetic identities. Generative AI has evolved to produce “Super Synthetic Identities,” blending stolen personal data with AI-generated biometrics, deepfake videos, and fabricated behavioral patterns. These identities are indistinguishable from real individuals, bypassing even the most advanced verification systems. Fraudsters exploit this technology to secure loans, file insurance claims, and conduct financial transactions on a massive scale.

For several years, the financial system is thrown into chaos as synthetic identity fraud spirals out of control. Insurers face skyrocketing fraudulent claims supported by deepfake accident footage and fabricated medical records, driving up loss ratios and premiums. Banks are inundated with defaults on loans issued to nonexistent customers. Trust in the financial system erodes as legitimate customers bear the cost of rising fraud. Regulators step in, mandating the adoption of cryptographic identity systems tied to government-issued digital credentials.

In 2040, a global “Digital Trust Initiative” emerges, albeit fragmented by region, requiring all digital interactions to be verified through secure hardware-based cryptographic keys combined with live biometric authentication. While this restores some stability, it comes at the cost of increased surveillance and reduced privacy. The financial system survives, but society is left grappling with the trade-offs between security and freedom in an era dominated by synthetic deception.

SEAMLESS INTERACTIONS

6TH YEAR ON THE LIST

PROGRAMMABLE MONEY

WHAT IT IS

Programmable payments are transactions that execute automatically based on predefined conditions. Central banks and financial institutions are accelerating their adoption of programmable money, enabling rule-based transactions that enhance efficiency, security, and financial inclusion.

HOW IT WORKS

Unlike traditional money, which often requires manual intervention or third-party oversight, programmable money enforces rules at the transaction level, ensuring funds are used as intended without intermediaries.

India's e-rupee, a blockchain-based central bank digital currency (CBDC), is set to expand cross-border transactions and programmable money applications in 2025. The Reserve Bank of India (RBI) is working to integrate the e-rupee with the Unified Payments Interface, potentially driving mass adoption by linking it to India's well-established digital payment ecosystem. To enhance public understanding and trust, the RBI held in-person CBDC training sessions in New Delhi in February 2025. Globally, other nations are also advancing programmable money initiatives. The Bank of Thailand has introduced an enhanced regulatory sandbox, focusing first on programmable payments. This lets financial institutions and fintech companies test automated transactions under regulatory oversight. In the private sector, the Digital Cash SDK 2.6 incorporates programmable money features like targeted subsidies, real-time settlements, and compliance automation. This builds on existing systems such as India's direct benefit transfer program, which could use programmable money to ensure subsidies—like food or fuel assistance—are spent only on designated goods or services.

WHY IT MATTERS

Programmable money could transform the industry by reducing reliance on traditional banking systems while enhancing speed, transparency, and security. Automated payments governed by smart contracts ensure transactions occur only when conditions are met. Governments and businesses can use this for conditional payments like rent, triggered by salary deposits, to ultimately cut errors and delays while boosting efficiency.

This technology could also improve cross-border payments. Programmable money enables instant settlements, benefiting global commerce and remittances. Central banks experimenting with CBDCs could link digital currencies internationally to send money across borders seamlessly.

Programmable money would also advance regulatory compliance and fraud prevention. government assistance funds could be programmed to ensure intended use, while automated anti-money laundering checks enhance trust in digital systems. For businesses, including solo entrepreneurs, programmable money unlocks new models like dynamic pricing based on demand or inventory levels and viable microtransactions due to lower costs.

In decentralized finance (DeFi), programmable money could spur innovation by enabling tokenized assets and new investment mechanisms. Real-world assets like real estate could be tokenized for easier transfers across borders. Financial institutions must adapt as smart contracts increasingly handle loans and payments with minimal human intervention.

4TH YEAR ON THE LIST

FRICTIONLESS PAYMENTS

WHAT IT IS

Frictionless payments remove obstacles in the checkout process, making transactions seamless and nearly invisible. From biometric authentication to embedded payments, these innovations enhance security and improve customer experience.

HOW IT WORKS

Frictionless payments eliminate manual steps, reduce wait times, and create seamless transactions. These payments rely on advanced authentication, automation, and data-driven personalization to function in the background.

Some of these systems rely on biometrics, authenticating users through physical characteristics such as fingerprints and facial recognition. Amazon One enables customers to pay by scanning their palm, linking the biometric data to a stored payment method. J.P. Morgan Payments piloted biometric authentication at the Miami Grand Prix, where it processed transactions in under a second, demonstrating how this technology can streamline high-traffic events.

Other systems use embedded payments; these integrate payment processing directly into an application or service, so customers can make purchases without a separate checkout step. Uber pioneered this model, where riders complete transactions effortlessly without pulling out a card or cash. Skipify and Synchrony recently introduced an embedded payment system that autofills payment details, recognizes cardholders, and enables instant access to rewards. US Bank provides merchants with embedded payment software, making the purchasing process frictionless.

AI-driven fraud detection, tokenization, and biometric security measures ensure these payments remain secure. As frictionless payments become more widespread, financial institutions and retailers must balance convenience with privacy and cybersecurity.

WHY IT MATTERS

Frictionless payments are reshaping customer expectations, leading consumers to increasingly demand effortless transactions. Traditional banks face mounting pressure from fintechs and tech giants offering mobile wallets, contactless payments, and embedded finance. Businesses failing to deliver seamless payment experiences risk losing loyalty in competitive markets, where speed and ease are key differentiators.

But the benefits of frictionless payments go beyond retaining customers: They also generate valuable data to inform risk assessments, personalize offerings, and enhance marketing. For example, insurers can use payment data to refine underwriting or develop tailored policies. These innovations boost efficiency by automating recurring transactions like loan repayments or insurance premiums, reducing costs and errors. Instant digital payouts for claims or loans improve cash flow and customer satisfaction.

Security is critical, and many frictionless payments integrate advanced methods like biometrics and AI-driven fraud detection to mitigate risks while maintaining seamless experiences. Real-time, cross-border transactions further disrupt traditional models, with open banking enabling faster transfers at lower costs. An institution adopting frictionless payments signals innovation and security, building trust, optimizing operations, and positioning the company for growth in an evolving financial landscape.

4TH YEAR ON THE LIST

INSTANT PAYMENTS

WHAT IT IS

Instant payments are becoming a regulatory requirement and competitive necessity worldwide. While adoption grows, challenges around legacy infrastructure, interoperability, and compliance remain. The next five years will define winners and laggards in real-time payments.

HOW IT WORKS

Instant payments allow funds to be transferred between accounts in real time, making them available immediately, 24/7. Unlike traditional bank transfers, which can take hours or even days to clear, instant payments are processed within seconds. These transactions typically rely on real-time payment rails—such as the EU's SEPA Instant Credit Transfer, the US's FedNow and RTP networks, or Brazil's Pix. However, interoperability challenges persist, with no standardized verification system.

In Europe, the Instant Payments Regulation (IPR) mandates that by 2025, all EU payment service providers (PSPs) must be able to send and receive instant payments, with staggered deadlines for non-EU and nonbank PSPs through 2027. Compliance requires banks to process transactions at scale, verify payee details, and conduct real-time sanction screening. In the US, there's a rapid growth in demand for instant payments, with the amount of money transferred this way expected to surpass $58 trillion by 2028. Yet, adoption is slow—only a fraction of US banks are onboard with RTP or FedNow, and less than 1% use both. Other global markets offer valuable lessons. Brazil's Pix, launched in 2020, now processes more than 36 billion transactions annually, demonstrating the potential for mass adoption. Canada's Real-Time Rail (RTR) system is set to launch by 2026, positioning the country to learn from earlier adopters and implement a modernized, scalable solution.

WHY IT MATTERS

As real-time payments become the norm, businesses and banks will need to adapt to faster transaction speeds, new compliance requirements, and shifting revenue models. For banks, this is both an opportunity and a challenge. On one hand, instant payments provide a competitive edge, reducing settlement risks and improving customer satisfaction. On the other, legacy infrastructure, processing speed limitations, and regulatory compliance create significant barriers. Of the banks currently capable of instant payments, only 10% can process more than 300 transactions per second. This may not be enough once corporations start using instant payments for mass disbursements like payroll and pensions.

Regulation is pushing banks to accelerate adoption. The EU's IPR mandates instant payments, forcing PSPs to enhance their systems despite interoperability concerns. Meanwhile, in the US, growing demand could eventually pressure more banks to join RTP or FedNow. However, there is a long road ahead: Out of more than 4,500 institutions, only 570 banks are on RTP and 700 are on FedNow.

Fintechs and digital banks have a major opportunity to gain market share. Without the constraints of legacy systems, they can move faster than traditional banks in offering seamless instant payment solutions. The rapid adoption of Pix in Brazil and the forthcoming RTR in Canada suggest that instant payments will soon be the global standard. Those that fail to adapt will risk losing customers and relevance in the financial ecosystem.

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The shift towards instant and faster payments has been gathering pace... I believe that 2024 will be the year when instant payments... truly enter the mainstream consciousness across Europe.

Lena Hackelöer, CEO & Founder of Brite Payments

3RD YEAR ON THE LIST

DIGITAL WALLETS

WHAT IT IS

Digital wallets are evolving beyond payments, integrating identity verification, biometric authentication, and flexible spending options. Innovations from Visa, Apple, and the EU are expanding digital wallet functionality, making them central to personal finance.

HOW IT WORKS

Over the past year, digital wallets have advanced beyond simple payment tools to multifunctional platforms. Visa's Flexible Credential gives users control over their transactions, allowing them to switch between debit; credit; Buy Now, Pay Later (BNPL); or rewards points within a single card. Meanwhile, its Tap to Everything is expanding NFC-based interactions, enabling seamless peer-to-peer payments, secure authentication, and faster onboarding of new cards.

Security and fraud prevention are also becoming more sophisticated. The Visa Payment Passkey Service, built on Fast Identity Online (FIDO) standards, replaces passwords and one-time codes with biometric authentication for a more secure and frictionless payment experience. Apple's iOS 18 Wallet update introduces new Apple Pay features, including reward redemption, installment payments, and Tap to Cash, which enables instant money transfers between iPhones. Additionally, Apple Wallet is expanding digital ID support across multiple US states.

On a broader scale, governments are integrating digital wallets into public infrastructure. The European Digital Identity Wallet, now in development, will hold a variety of personal documents—including payment methods, travel credentials, and medical records—allowing EU citizens to securely store and share their verified identity across the bloc.

WHY IT MATTERS

As digital wallets integrate more functions, they are becoming the de facto financial hub for consumers, offering unparalleled convenience. This shift has significant implications for financial service providers. Banks and payment processors must adapt to consumer demand for seamless, multi-modal transactions, as evidenced by Visa's Flexible Credential. BNPL services, loyalty programs, and even traditional credit models may need to adjust their offerings to remain competitive within digital wallets.

Security concerns are paramount, and the rapid adoption of digital IDs and biometric authentication creates new vulnerabilities. A single compromised wallet could expose financial, medical, and personal identity data at once. Financial institutions will need to balance enhanced security measures with ease of use, ensuring consumers trust these new systems. Additionally, as governments and private companies take different approaches to digital identity, interoperability will become critical—particularly in cross-border transactions and regulatory compliance.

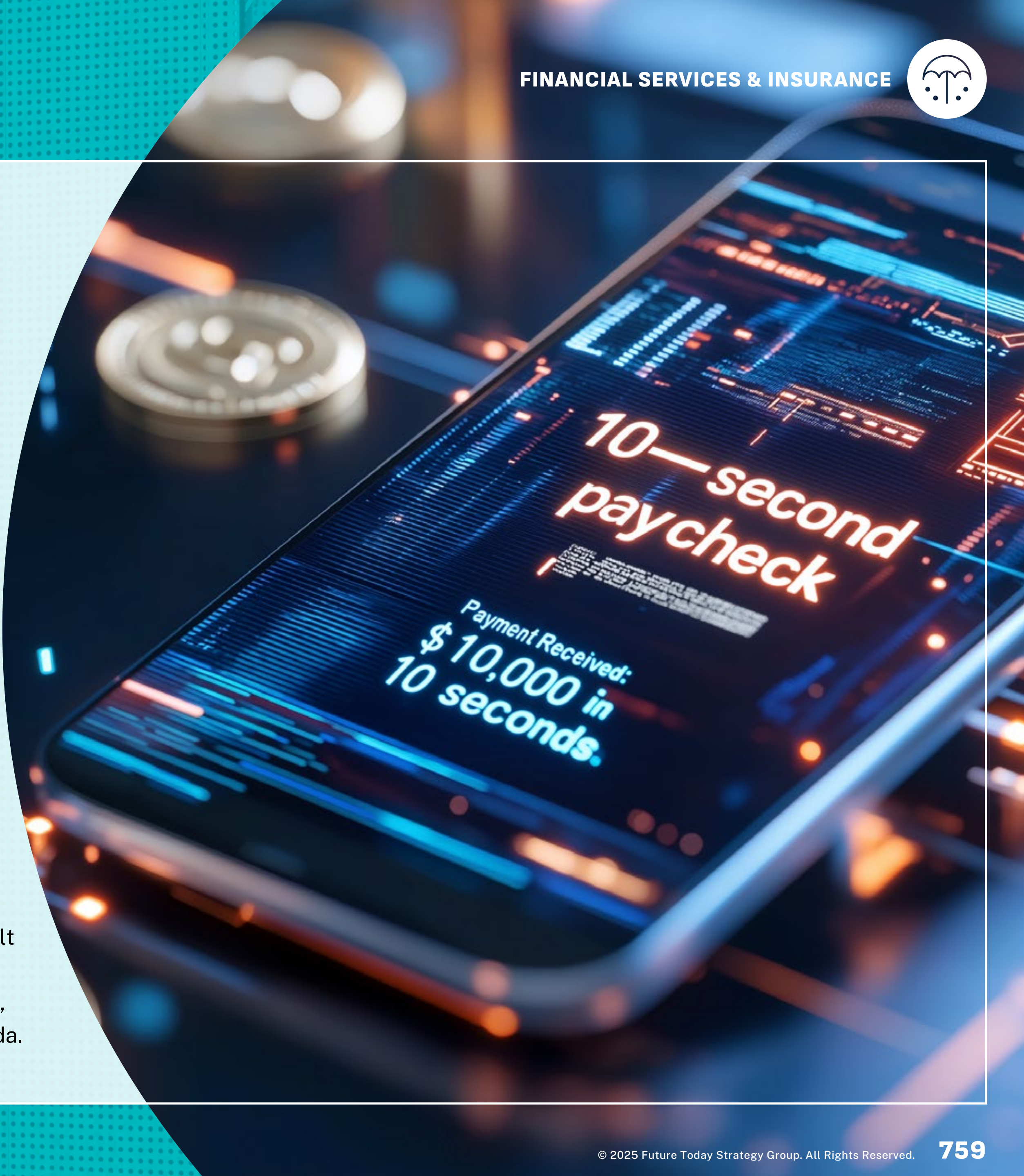
As digital wallets continue to expand, the question is no longer whether they will replace physical wallets but rather how deeply they will integrate into everyday life. Financial services providers must prepare for a future where digital wallets serve as both a financial tool and a primary identity credential.

SCENARIO YEAR 2029

THE 10-SECOND PAYCHECK

By 2029, the widespread adoption of instant payment systems like FedNow and RTP has transformed payroll processing in the US, enabling 90% of salaries to land in workers' accounts within seconds of completing a shift. Gig economy platforms such as Uber and DoorDash leverage this infrastructure to disburse earnings immediately after drivers or delivery personnel finish tasks, eliminating the traditional 1–3 day payment delays. This shift is further enhanced by programmable money frameworks, inspired by India's e-rupee model, which give employees a choice of embedding rules directly into digital currencies—for example, they can automatically divert 30% of earnings to rent payments when their daily income exceeds $500. Digital wallets like Apple's Tap to Cash and Visa's Flexible Credential enable workers to split funds instantly across savings, debit, or BNPL accounts, while AI-driven compliance systems (similar to J.P. Morgan's biometric authentication) screen transactions in real time to prevent fraud.

Legacy banks face existential threats as fintechs offering "smart accounts" with automated budgeting tools capture market share, while payday lenders collapse under reduced demand for cash advances. The IRS capitalizes on blockchain-based transparency to increase audits by 40%, scrutinizing previously opaque gig economy income streams. Though financial stress drops 35% due to instant liquidity access, critics highlight algorithmic biases in programmable rules—lower-income users face disproportionate compliance flags, sparking debates about fairness in automated financial systems. Policymakers respond by proposing universal basic income pilots built on FedNow's infrastructure, testing how real-time disbursements could reshape social safety nets. Meanwhile, the EU's Instant Payments Regulation pressures global banks to adopt similar systems, creating a ripple effect that accelerates real-time payroll adoption in markets like Brazil and Canada.



GOVERNANCE

12TH YEAR ON THE LIST

ALTERNATIVE CREDIT SCORING

WHAT IT IS

AI-driven alternative credit scoring models analyze nontraditional data to assess creditworthiness, improving financial inclusion. While these models enhance accuracy and fairness, there are still concerns about bias, privacy, and regulatory compliance. Standardization and transparency will be critical.

HOW IT WORKS

Traditional credit scoring relies on a limited set of financial data—mainly credit history, outstanding debt, and repayment behavior. Alternative credit scoring expands this approach, leveraging AI and machine learning to take diverse data sources into account, including rent and utility payments, bank transactions, employment history, social media activity, and online behavior.

Machine learning algorithms identify patterns in this data to predict a borrower's credit risk more precisely. Companies like Tala and Upstart analyze smartphone usage, transaction history, and employment records to score applicants who lack conventional credit histories. Hybrid models, such as those used by Zest AI and Kabbage, merge traditional scores with real-time financial data to improve accuracy. VantageScore's latest model integrates open banking data, offering a 10% predictive boost over previous versions.

These systems, while powerful, introduce complexity. AI models consider thousands of variables, making their decision-making processes difficult to interpret. Regulators and industry leaders must balance innovation with accountability, to ensure fair and transparent lending practices.

WHY IT MATTERS

Alternative credit scoring has the potential to expand financial access for millions who are underserved by traditional credit models. People without established credit histories—gig workers, recent immigrants, and younger consumers—can demonstrate creditworthiness through alternative data, potentially reducing systemic inequalities in lending.

However, the shift to AI-driven risk assessments raises serious concerns. Data privacy is a major issue, as these models require access to sensitive personal information. The use of nontraditional data also introduces new risks of bias—some behavioral indicators could disproportionately disadvantage specific demographics. Regulatory oversight remains fragmented, with existing consumer protection laws struggling to keep pace with AI-powered lending decisions. Transparency is another challenge. Consumers may not understand what factors influence their credit scores, making it difficult to dispute inaccuracies. Without industry-wide standardization, different lenders could arrive at vastly different credit decisions for the same applicant.

Financial institutions adopting alternative credit scoring must navigate regulatory complexities, integrate new data sources, and ensure their models are fair and explainable. While AI offers unprecedented insights into creditworthiness, responsible implementation will determine whether these innovations truly improve financial equity or reinforce existing barriers.

5TH YEAR ON THE LIST

RISING CYBER RISK

WHAT IT IS

Financial institutions face an unprecedented surge in cyberthreats, with attacks increasing by 75% in Q3 2024 compared to 2023. This trend is reshaping the industry's approach to cybersecurity, driving innovation in risk management and insurance strategies.

HOW IT WORKS

Increasing cyber risk has far-reaching implications for financial institutions. It's expensive, with the global average cost of a data breach reaching $4.88 million in 2024. According to the International Monetary Fund, the potential impact of extreme losses has risen as well, with an estimate that a cyber incident is expected to result in a $2.5 billion loss once every 10 years.

These cyber incidents can manifest through various channels and attack vectors. Ransomware remains a dominant threat, with sophisticated groups like BlackCat (ALPHV) causing significant disruptions, such as the February 2024 attack on Change Healthcare. Payment diversion fraud has emerged as a potent threat, affecting 58% of organizations in 2024, up from 34% the previous year. Cybercriminals are leveraging AI to create more sophisticated phishing attacks and automate hacking processes, adding a new dimension to the threat landscape.

The interconnectedness of digital systems has also introduced systemic vulnerabilities, such as the widespread disruptions caused by the CrowdStrike-Microsoft outage in July 2024. Despite these incidents, the cyber insurance landscape is evolving, with premium rates decreasing by 17% in 2023, though insurers are adjusting strategies and adding restrictions. Regulatory focus has intensified, with the US government working to quantify cyberattack impacts on critical infrastructure, including financial markets, potentially leading to new compliance requirements.

WHY IT MATTERS

Operational resilience has become paramount, as cyber incidents can lead to significant disruptions, necessitating robust risk management strategies and incident response plans. Increased regulatory scrutiny may result in new compliance requirements, potentially including federal insurance responses, impacting operational costs and risk management practices. The evolving cyber insurance market requires financial institutions to reassess their coverage and risk transfer strategies, potentially leading to increased self-insurance or alternative risk management approaches.

To combat sophisticated threats, companies will need to invest in advanced technologies like AI and machine learning for enhanced cybersecurity. Recent incidents have highlighted the need for robust vendor risk management and supply chain security, expanding the scope of cybersecurity efforts beyond internal systems. The cybersecurity talent shortage remains a critical challenge, with 26% of business leaders admitting to insufficient resources for managing cyber threats. Moreover, cyber incidents can significantly damage a financial institution's reputation, potentially leading to loss of customer trust and business opportunities.

As the digital financial ecosystem continues to expand, financial institutions must proactively adapt, balancing innovation with security, and developing agile risk management strategies to protect their assets, customers, and reputation.

3RD YEAR ON THE LIST

DATA MINIMIZATION

WHAT IT IS

States are increasingly stepping up to implement stringent data minimization standards. However, their efforts face significant resistance from powerful lobbying groups, making the passage of effective legislation a complex and contentious process.

HOW IT WORKS

Data minimization refers to the practice of limiting the collection and processing of personal data to only what is necessary for specific, clearly defined purposes. This concept is increasingly a cornerstone of state-level privacy regulations in the US as federal legislation lags in providing comprehensive data protection.

In a significant move, the California Privacy Protection Agency issued its first enforcement advisory, emphasizing the importance of data minimization under the California Consumer Privacy Act. Vermont's new data privacy law, passed in May 2024, is another example of a state-level initiative aimed at enforcing data minimization. It's notable for allowing individuals to sue companies for violating their privacy rights, a provision that sets a new standard in privacy protection and adds a significant enforcement mechanism to data minimization efforts. In Maine, lawmakers rejected two competing data privacy bills; both were the subject of intense tech industry lobbying, and underscore the challenges that state lawmakers face when trying to implement robust data protection measures.

At the federal level, the Federal Trade Commission is exploring new regulations to address the growing concerns around commercial surveillance and data security. This initiative aims to curb businesses' excessive collection and use of personal data, reflecting a broader shift toward recognizing the risks associated with data hoarding practices.

WHY IT MATTERS

The increasing focus on data minimization reflects a growing recognition of the risks associated with excessive data collection. As businesses gather vast amounts of personal information, the potential for misuse, data breaches, and privacy violations escalates. State-level actions on data minimization are critical because they set precedents that could influence broader national standards. With federal legislation still lacking, states are becoming the testing grounds for data protection strategies that could eventually shape nationwide policies.

The resistance from powerful lobbying groups indicates the high stakes. The outcomes of these legislative battles will determine the future of data privacy in the US and the balance of power between public interests and corporate influence. As more states push forward with their own data minimization laws, we could see a patchwork of regulations that vary significantly across the country, creating challenges for businesses operating in multiple jurisdictions.

In the long run, the trend toward data minimization could lead to a paradigm shift in how personal data is handled, moving away from the current model of data hoarding to one that prioritizes privacy and security. This shift could drive innovation in data processing technologies, encourage the development of new business models that do not rely on extensive data collection, and ultimately lead to a more privacy-conscious digital landscape.

1ST YEAR ON THE LIST

AI LIABILITY

WHAT IT IS

The increasing use of AI in decision-making processes is generating liability risks for businesses, particularly in sectors like health care and finance, creating new legal, financial, and reputational risks.

HOW IT WORKS

As AI systems take on more decision-making roles, the potential for liability grows. AI liability refers to the legal responsibility that companies might face when their AI systems cause harm or make decisions that are later deemed biased or incorrect. This issue is particularly acute in sectors where decisions have significant impacts on people's lives, such as health care and finance.

In one example, AI is being used by Medicare Advantage insurers to decide when to cut off care. These decisions, often made by algorithms like those created by NaviHealth, can result in premature denial of necessary care, impacting seniors who rely on these benefits. The algorithms can prioritize cost-efficiency over patient care, leading to appeals and disputes when care is denied without fully considering individual patient needs. In the financial sector, banks and insurers use AI for everything from underwriting to fraud detection. However, the risks associated with AI errors are significant. For instance, an AI model that makes a wrong trading decision or an underwriting algorithm that discriminates against certain demographics could lead to substantial financial losses and legal challenges. In a recent case, a federal judge allowed a lawsuit against Workday's AI screening software, which allegedly discriminated against job applicants based on race, age, and disability, to proceed. This highlights the growing scrutiny of AI tools in hiring and the potential for legal challenges when AI-driven decisions are perceived as biased.

WHY IT MATTERS

The complexity of AI systems makes error identification and rectification challenging, increasing liability. As AI becomes integral to business operations, comprehensive governance frameworks and accountability mechanisms are crucial. However, a survey found only 16% of health care organizations have system-wide AI governance policies, highlighting the gap between adoption and risk management.

Similarly, as AI integrates deeper into financial operations, regulatory scrutiny intensifies. Financial institutions must ensure AI systems comply with evolving standards, requiring investments in compliance, auditing, and robust governance frameworks. Many firms are unprepared, risking regulatory penalties and erosion of customer trust if AI decisions are perceived as unfair.

Despite risks, AI's prevalence in financial services presents a market opportunity: AI liability insurance. As companies recognize potential AI-related errors and financial fallout, demand for specialized insurance could surge, and insurers developing tailored AI risk policies could capture a lucrative market segment. This opportunity extends to innovative products addressing unique AI challenges, such as automated decision-making errors or AI misuse in critical financial processes.

SCENARIO YEAR 2026

FINANCEEATER

The Cyber Pandemic of 2026 began with a sophisticated ransomware attack on a major US health care provider in March, exploiting a previously unknown vulnerability in widely used financial software. The malware, dubbed "FinanceEater," was designed to specifically target interconnected financial systems. Its rapid spread was facilitated by several key factors, including a zero-day exploit in popular financial transaction processing software, AI-powered adaptation that made it difficult for traditional antivirus systems to detect, and a supply chain attack that infected multiple organizations simultaneously through software updates.

FinanceEater's ability to hop from one system to another was particularly devastating. It exploited APIs used for interbank communications, allowing it to spread across different financial institutions rapidly. Once inside a system, the malware stole authentication credentials to access connected systems and partner networks. It also compromised shared cloud services used by multiple financial entities, creating a web of infection across seemingly isolated systems. Additionally, FinanceEater specifically targeted high-frequency trading platforms, using their lightning-fast connections to propagate across global stock exchanges within minutes.

As the attack flourished, it paralyzed electronic trading systems, froze millions of bank accounts, and compromised sensitive financial data of countless individuals and businesses. By June 2026, more than 70% of major financial institutions worldwide had reported significant operational disruptions, leading to a temporary shutdown of stock exchanges and a global economic crisis. The cyber pandemic was finally contained in September 2026 through an unprecedented international collaboration of cybersecurity experts, government agencies, and tech giants. This collaborative effort led to the development of an AI-powered defense system capable of predicting and neutralizing FinanceEater's evolving attack vectors in real time, finally bringing the global financial crisis under control.

INSURANCE

The use of artificial intelligence by the insurance industry could make some people 'uninsurable'... We want safe and responsible use of AI to drive beneficial innovation, but also an open conversation about the risks and trade-offs.

Nikhil Rathi, Chief Executive of the UK's Financial Conduct Authority

1ST YEAR ON THE LIST

AI IN UNDERWRITING

WHAT IT IS

AI is revolutionizing underwriting through augmented and algorithmic approaches, blending human expertise with automated decision-making. While it enhances efficiency, the technology's infancy introduces challenges, requiring careful adoption and regulation.

HOW IT WORKS

In underwriting, AI is generally used in one of two ways: augmented underwriting, where AI processes the data but human underwriters apply their judgment to complex cases, or algorithmic underwriting, where AI analyzes data, assesses risks, and issues policy decisions.

State Farm has led the industry in AI-related patent filings. One is for a system that utilizes real-time vehicle data—driving behavior, vehicle conditions, and location-based risks—to generate dynamic insurance quotes. Another patent uses generative adversarial networks to fill gaps in 3D data, which could significantly improve the accuracy of damage assessments and claims processing.

As highlighted by the New York Department of Financial Services' AI Circular Letter, regulators are increasingly focused on ensuring AI underwriting models are transparent, nondiscriminatory, and actuarially sound. As of the end of 2024, the NAIC bulletin on AI use for insurers had been adopted by 21 states. (See map on next page.)

This shift toward AI-driven underwriting is not without its challenges. Underwriting has traditionally relied on deep, experiential knowledge, especially in specialized lines of insurance where subtle risk factors play a crucial role. In their current form, AI systems may not yet fully capture these complexities, potentially overlooking nuances experienced underwriters would consider.

WHY IT MATTERS

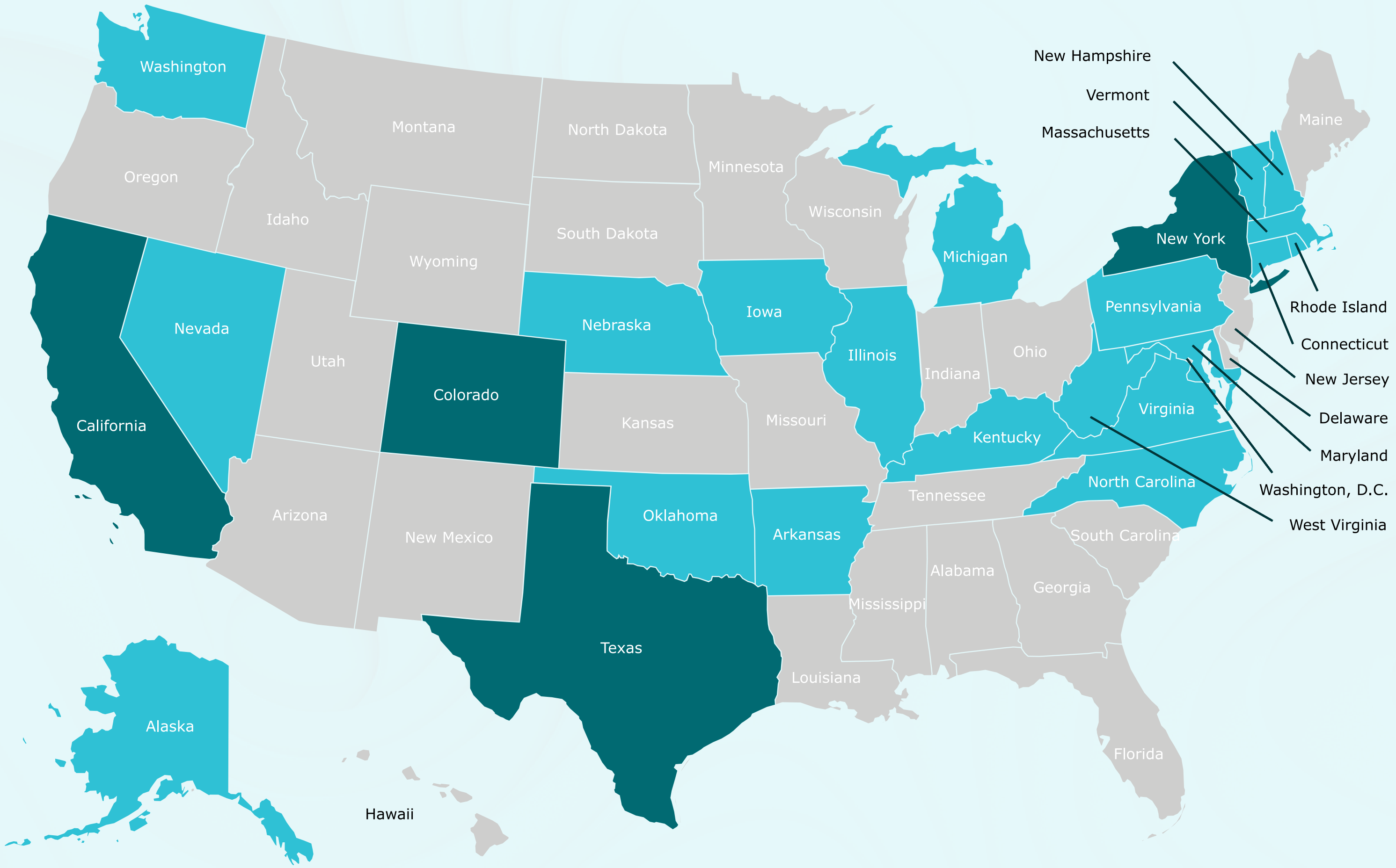
AI-driven processes can drastically reduce the time needed to assess risks and issue policies, improving customer satisfaction and enabling insurers to handle higher volumes of applications more efficiently. However, this also introduces heightened regulatory scrutiny. Compliance with evolving standards, such as those outlined by the NYDFS, will require insurers to invest in governance frameworks that ensure AI models are transparent, fair, and free from bias. Failure to meet these standards could lead to legal challenges, fines, and reputational damage.

The shift to AI-driven underwriting will also impact workforce dynamics. Traditional underwriting roles may evolve, requiring underwriters to develop new skills to work effectively with AI tools. Companies may need to invest in training programs to bridge the gap between traditional and data-centric skills. As more routine tasks are automated, the demand for entry-level underwriting positions may decline while the need for data scientists and AI specialists within insurance companies increases.

Competitive advantage in the insurance industry will increasingly depend on the successful integration of AI. Companies that can harness AI to offer more personalized, efficient services will gain an edge in a market that values speed and accuracy. However, this advantage comes with managing the risks associated with AI, including ensuring compliance with regulations and addressing potential biases within AI models.

Implementation of NAIC Model Bulletin: Use of Artificial Intelligence Systems by Insurers

Status as of February 1, 2025



Adopted
(21-Jurisdictions)

Insurance Specific Regulation/Guidance
(4-Jurisdictions)

Source: NAIC

1ST YEAR ON THE LIST

PARAMETRIC INSURANCE

WHAT IT IS

Parametric insurance, with its automatic payouts based on preestablished triggers, is positioned to transform risk management as advancements in sensor technology and climate volatility heighten the need for rapid, data-driven solutions.

HOW IT WORKS

Unlike traditional indemnity-based insurance that assesses actual damage post-event, parametric insurance relies on predefined triggers, such as specific weather conditions or seismic activities, to automatically activate payouts. For example, a parametric policy covering hurricane damage might stipulate that if a hurricane of Category 4 or higher passes within a 50-mile radius of the insured location, the company will issue a payout. The critical aspect here is the reliance on external, third-party data sources—such as meteorological agencies or Internet of Things–based sensors—that confirm the occurrence and intensity of the triggering event.

The technology behind parametric insurance has evolved significantly. Companies like Safehub are at the forefront, utilizing sophisticated sensors capable of capturing building-specific data such as Peak Ground Acceleration during an earthquake. These sensors provide granular data that goes beyond general regional measurements; this ensures that the response is tailored to the specific impact on the insured property, reducing the potential for disputes.

Increasingly, parametric insurance models are incorporating machine learning and predictive analytics—as well as historical data—to refine the accuracy of trigger definitions. This is particularly crucial as climate change continues to alter traditional risk models, making historical data less reliable for predicting future events.

WHY IT MATTERS

The growing unpredictability of natural disasters, driven by climate change, is rendering traditional insurance models less effective. These models are often slow, which can delay critical financial support. Parametric insurance addresses these shortcomings by offering near-instant payouts based on clear, predefined criteria, providing essential liquidity in the immediate aftermath of a disaster. Its ability to provide quick financial relief is especially vital for vulnerable sectors like agriculture: In one example, a farmer in the Philippines with a parametric policy was able to receive a payout immediately after a flooding event, enabling him to replant crops without delay. This outcome would have been impossible under a traditional policy.

As sensor technology continues to advance, the precision and reliability of parametric triggers will improve. The use of site-specific data from sensors like those deployed by Safehub not only enhances the accuracy of risk assessments but also opens up new possibilities for customizing insurance products to meet the unique needs of individual properties or businesses.

But widespread adoption of parametric insurance still faces challenges, primarily due to a lack of understanding among potential customers about how these products work. Insurers must invest in education and transparency—as well as ensure the robustness and reliability of the technologies underpinning parametric insurance to maintain trust and efficacy.

1ST YEAR ON THE LIST

CLIMATE IMPACT ON INSURERS

WHAT IT IS

Climate-related disasters are forcing insurers to adopt advanced predictive models and rethink risk management. Rising premiums and market exits are increasing as insurers grapple with unpredictable weather patterns and rising claims from natural disasters.

HOW IT WORKS

Severe weather is accelerating an insurance crisis. In 2024, natural catastrophes (nat cats) accounted for an estimated $320 billion in losses worldwide, but only slightly more than half of that was insured. Historically, hurricanes and earthquakes make up for a majority of those losses, but wildfires are giving other nat cats a run for their money. Experts currently estimate that losses resulting from the January Los Angeles wildfires alone will exceed $250 billion. For years, insurers have been raising premiums or exiting altogether; several insurers had halted new home insurance policies in California even before the recent wildfire blitz. The trend extends beyond California; insurers are also withdrawing from Colorado, Florida, and Louisiana. As private insurers retreat, state-backed “last-resort” plans are under pressure. The California FAIR Plan now carries $458 billion in property exposure—an increase of 61% from the previous year.

To counter these risks, insurers have adopted AI-driven climate modeling. Munich Re and Swiss Re are integrating real-time wildfire prediction models, using satellite imagery, drought indices, and wind pattern analysis to forecast wildfire spread. Allstate has expanded its machine-learning risk assessment system to better predict property damage from simultaneous climate events, such as windstorms combined with wildfires. Regulatory changes are also underway—California’s insurance commissioner is considering allowing insurers to factor long-term climate projections into their pricing models.

WHY IT MATTERS

Climate-driven loss frequency and severity will continue to increase over the next decade or two, both in the “usual suspect” regions and in less expected geographic areas, such as regions of the Northeast due to flooding and wind damage. In particular, flooding outside traditional floodplains is expected to increase property losses by 40%–50% over the next 20 years. These losses are driven by some non-climate specific factors as well—namely demographic growth in key geographic regions, and the impact of inflation on construction costs—but the losses that do occur stem from climate-specific events, which will continue to intensify.

The approach for property and casualty insurers has been to withdraw from high-risk markets. However, insurers will need to develop more sophisticated solutions to address the challenge in order to maintain their market penetration. Health insurers will also feel the effects. Research shows that extreme weather events, like heat waves and wildfires, are leading to a rise in hospitalizations. As these weather events become more common, health insurers will need to reassess their risk models, premiums, and coverage options.

The increase in climate-related events and losses over the last several years sets the stage for the new normal. Insurers in all sectors have survived up to now, but to succeed in the future, they’ll need to find new ways to thrive.

1ST YEAR ON THE LIST

FRAUD MITIGATION

WHAT IT IS

Fraud mitigation in insurance is evolving rapidly, with AI and machine learning at the forefront. New solutions leverage advanced analytics, behavioral data, and real-time processing to detect complex fraud patterns, reduce false positives, and enhance operational efficiency for insurers.

HOW IT WORKS

Insurers are increasingly adopting AI-powered fraud detection technologies to improve accuracy, reduce losses, and enhance customer experiences. RSA Insurance's partnership with Clearspeed exemplifies this trend: Clearspeed's technology uses AI-powered voice analytics to assess claim legitimacy and rapidly flag high-risk cases, allowing RSA to focus investigative efforts where needed while expediting low-risk claims.

Other industry leaders are also investing in AI-driven fraud detection. SAS Institute introduced an AI-powered solution that uses machine learning to reduce false positives, while FICO upgraded its fraud detection platform with advanced AI analytics to uncover complex fraud patterns. In Brazil, Solutis partnered with FICO to offer AI-powered risk assessment tools for midsize banks and insurers, improving fraud prevention and customer personalization.

New AI solutions also integrate behavioral data analytics. ForMotiv and FRISS joined forces to analyze thousands of digital behavioral data points during the application process, so insurers can detect inconsistencies and potential fraud in real time. Meanwhile, the Insurance Fraud Bureau (IFB) and Shift Technology launched IFB Exploration in the UK, leveraging AI analytics to detect organized fraud networks across insurers.

WHY IT MATTERS

Fraud costs the insurance industry billions annually, with opportunistic fraud and organized crime networks creating significant financial strain. AI-driven fraud detection is crucial for reducing these losses, increasing efficiency, and maintaining consumer trust. By leveraging AI, insurers can automate fraud detection processes to reduce human error and accelerate decision-making.

Beyond cost savings, AI-powered fraud detection also improves customer experiences. Faster claims processing for low-risk cases ensures that legitimate customers receive payouts more quickly, while fraudsters are identified with greater precision. The competitive landscape is evolving as insurers integrate AI into risk assessment strategies. Companies that fail to adopt AI-based fraud detection risk falling behind under higher losses and operational inefficiencies. Meanwhile, regulatory bodies and industry organizations are monitoring AI's role in fraud prevention, ensuring ethical considerations and bias mitigation remain priorities.

As AI fraud detection systems grow more sophisticated, the industry must balance automation with transparency. Understanding how AI models make decisions will be crucial for regulatory compliance and customer trust. Looking ahead, expect insurers to refine fraud detection models with even more granular data inputs that will lead to highly personalized and adaptive fraud prevention strategies.

1ST YEAR ON THE LIST

CLAIM ENHANCEMENTS

WHAT IT IS

Property and casualty (P&C) insurers are leveraging artificial intelligence to automate and accelerate claims processing. AI-powered underwriting, fraud detection, and real-time damage assessments are reducing costs and improving the customer experience.

HOW IT WORKS

AI-driven claims processing is transforming P&C insurance by automating key functions in underwriting, fraud detection, and claims estimation. Insurers such as Travelers, Zurich, CCC Intelligent Solutions, Clearcover, and Snapsheet are deploying AI models trained on years of claims data to enhance decision-making and improve efficiency.

At Travelers, the company has developed an AI large language model, trained specifically on Travelers documents and decisions, that ingests documents and analyzes lawsuit documents. Zurich is feeding six years of claims data into generative AI models to identify risk patterns, refine policy pricing, and reduce loss ratios.

AI is also reducing processing times by automating damage assessment and fraud detection. CCC Intelligent Solutions and Clearcover use AI-powered image recognition to assess accident damage from user-submitted photos, allowing insurers to provide near-instantaneous damage estimates. This eliminates the need for adjusters to manually inspect vehicles, cutting processing times from weeks to hours. Snapsheet extends AI-driven automation further by digitizing the full claims process, including fraud detection. By integrating AI with cloud-based claims management systems, Snapsheet's tools can identify false claims and process legitimate ones faster. These solutions, powered by computer vision, natural language processing, and predictive analytics, enable insurers to handle higher claim volumes with fewer resources.

WHY IT MATTERS

AI-driven claims processing requires significant investment in data infrastructure, machine learning models, and cloud-based automation. Insurers must integrate AI with legacy systems, train models on diverse claims data, and ensure regulatory compliance. Despite these costs, the long-term benefits are substantial. AI can reduce claims processing expenses by up to 30%, improve fraud detection accuracy, and accelerate settlements—leading to higher customer satisfaction and lower operational costs.

For carriers, measurable improvements include faster cycle times, reduced loss adjustment expenses, and enhanced underwriting precision. AI-powered claims automation enables insurers to process higher volumes without increasing headcount, improving scalability and profitability. Fraud detection algorithms help carriers mitigate billions in losses, strengthening overall financial performance.

Challenges remain. AI models must be continuously refined to prevent bias and maintain accuracy. Insurers must also navigate evolving regulations on AI decision-making in claims. Additionally, as claims processes become more digitized, cybersecurity threats targeting sensitive policyholder data will rise. To maximize AI's potential, insurers must invest not just in technology but also in governance, transparency, and security frameworks.

SCENARIO YEAR 2030

CASCADING LIABILITIES

In late 2028, a series of cyber incidents targeting logistics companies in Southeast Asia triggered a prolonged global economic challenge, exposing vulnerabilities in interconnected digital supply chains. Supply chain disruptions cascaded through industries, and business interruption and contingent business interruption claims surged, with 45% of companies reporting financial impacts from supply chain issues. The complexity of digital partnerships and blockchain-based smart contracts created scenarios of cascading liabilities that tested conventional underwriting models. Insurers struggled to adapt their policies to cover losses from unforeseen events, leading to increased litigation and reputational risks. The crisis highlighted the need for insurers to reassess risk assessment models, revise coverage terms, and develop new products to address emerging risks.

As the crisis unfolded, a clear divide emerged. Companies that had invested in advanced modeling techniques to anticipate interconnectedness in the global digital ecosystem were able to mitigate their losses. These insurers had developed sophisticated risk assessment tools that accounted for digital dependencies, allowing them to adjust their underwriting practices. In contrast, insurers who continued to rely on standard underwriting practices found themselves heavily impacted. Their traditional models failed to capture the accumulating nature of risks in the interconnected digital landscape, leaving them exposed to unexpected and substantial losses.

Now, in 2030, this disparity has reshaped the competitive landscape of the insurance industry. The crisis served as a powerful catalyst for innovation, pushing the entire sector toward more dynamic risk modeling and collaborative approaches to managing systemic vulnerabilities. The recent lessons learned have fundamentally transformed how insurance companies approach risk assessment and policy underwriting in the digital age.

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Nick Bartlett is a Director at Future Today Strategy Group and leads our Financial Services & Insurance and Transportation & Manufacturing practice areas.

Prior to FTSG, he held positions in corporate strategy and insights generation roles, serving as a partner to senior leadership at multiple Fortune 100 financial services companies. Throughout his career, he has specialized in framework design, corporate innovation, strategic management, and insurance.

Nick has an extensive background in developing strategic insights across a variety of industries (e.g., manufacturing, transportation, construction, energy) and subject matter areas (e.g., small business, mobility, robotics, platforms & ecosystems), in addition to the shifting nature of business and consumer preferences. He has deep experience in developing and implementing both trend sensing, as well as signal identification for large organizations. Nick has also led the design and establishment of internal foresight and scenario development capabilities across multiple institutions.

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Sam Jordan
Space Lead

The space industry is at an inflection point that deserves attention.

Even if you've never thought much about rockets, satellites, or the fact that we are dangling off a rock catapulting through an ever expanding vacuum, now is the perfect time to become a space enthusiast.

Space is shifting from government-driven to markets-driven. This is because of the convergence of several trends–falling launch costs, improved materials science, advanced AI, and accumulated expertise from decades of public investment. Private space activities are approaching profitability in multiple areas, which means it's time for the government to step back.

This transition from government to private enterprise is similar to what happened with the early internet; what was initially a government project later became a thriving commercial marketplace. However, this shift comes with a paradox: as commercial entities take over routine space operations, space itself has become more strategically important than ever. The new space race isn't just about exploration—it's about controlling crucial orbital assets and resources that will shape global power dynamics in the 21st century.

While these commercial and strategic developments are compelling on their own, space development offers something even more fundamental: optionality for humanity's future. Even if you're skeptical about space tourism or Mars colonies, the ability to operate beyond Earth gives us new ways to solve future challenges we can't yet anticipate. And we'll learn valuable lessons through the process of becoming a spacefaring civilization, too. The challenges of solving complex coordination problems and developing new institutional frameworks will force us to become better at governance and cooperation—skills that benefit humanity regardless of how space development proceeds. Even more fundamentally, space exploration expands our literal, physical reach, letting us go to new places and use new resources we couldn't access before.

Taken together, these trends matter because they represent humanity expanding its production possibility frontier. And that is worth paying attention to.

Private firms dominate space ops as nations race to the moon, and orbital tensions mirror Earth's geopolitical strife.

1

Control of the moon could define global power

Lunar control may define a country's influence over others, making the moon a new arena for space claims.

2

SpaceX sets new launch records in 2024

The aerospace company is on track for 148 launches in 2024, breaking previous Falcon records.

3

Concerns over Russian space weapons

Fears grow over Russia's potential orbit of nuclear anti-satellite weapons.

4

Government hands-off to commercial

Corporates now drive space exploration, from launches to satellite deployment.

5

The tragedy of the space commons

As Earth's orbit crowds, space sustainability and debris control become vital.

Private sector leadership is shaping the future of space exploration.

The transition from public- to private-sector leadership in space exploration marks a pivotal shift in human spaceflight. As governments delegate responsibilities to private companies, we're witnessing an unprecedented surge in mission frequency. This shift, coupled with reusable rocket technology, has led to a dramatic reduction in launch costs, ushering in a new era of accessible and dynamic space exploration.

For the space economy to flourish, it must evolve into a self-sustaining ecosystem while serving Earth's needs. Advancements in space manufacturing, Earth observation, and extraterrestrial mining are crucial for enabling long-term missions and enhancing sustainability on our planet. AI further accelerates this progress, enabling autonomous systems that optimize operations and decision-making in space's harsh environments.

Despite the space sector's enthusiasm, there's a pressing need to craft compelling narratives that resonate with other industries and the general public. Illustrating space exploration's relevance to sectors like pharmaceuticals and logistics is vital for garnering broader support and investment. By engaging diverse audiences and tailoring messages to different sectors, we can foster a deeper understanding of space's potential benefits and open the door to a more collaborative future that bridges the economies of space and Earth.

Private companies dominated 2024 space milestones, redefining exploration and flight.

FEBRUARY 2024

Private Lunar Landing

Odysseus, a private lander, is the first American craft to land on the moon since the final Apollo mission in 1972.

June 2024

Astronauts Stranded on ISS

Butch Wilmore and Suni Williams launched on Boeing's Starliner for an 8-10 day mission, but technical issues forced the capsule to return empty in September 2024.

JUNE 2024

China's Chang'e-6 Returns Lunar Samples

Chang'e-6 returns the first samples from the far side of the moon, marking a major feat.

SEPTEMBER 2024

Polaris Dawn's Commercial Spacewalk

Polaris Dawn sets new milestones in private spaceflight, completing the first-ever private spacewalk.

OCTOBER 2024

SpaceX Chopsticks

SpaceX's Super Heavy booster landed at Boca Chica, caught by robotic arms, during Starship's fifth test flight. The second successful catch was achieved in January 2025.

« PAST

AI, cybersecurity, biopharma, and lunar logistics redefine space innovation.

FUTURE »

AUGUST 2025

Commercial Space Station Launch

Vast Space plans to launch Haven-1 in 2025, aiming to establish the first commercial space station in orbit.

APRIL 2026

Artemis Delays

The Artemis II lunar flyby was delayed to April 2026, and Artemis III's south pole landing moved to mid-2027.

SEPTEMBER-NOVEMBER 2026

SpaceX Uncrewed Mars Missions to Mars

SpaceX aims to launch uncrewed Starship missions to Mars in 2026, followed by crewed flights in 2028.

LATE 2026

Gaganyaan-4 Launch

The Indian Space Research Organisation (ISRO) plans to launch the first Indian crewed spaceflight.

2026

Commercial Space Operations Double

The FAA expects commercial space launches to double by 2026, highlighting rapid growth in private spaceflight operations.

The commercial space era is here, offering industries opportunities to generate revenue and expand capabilities beyond Earth.

Public Handoff to Private

The shift of LEO operations to the private sector and lunar commercialization presents major business opportunities. Private companies can lead in spaceflight, cargo transport, and sustainable lunar economies. This in turn will foster innovation and investment in technologies like lunar habitats, resource extraction, and autonomous vehicles, driving growth across various sectors.

Geopolitical Risk Management

Organizations must navigate increasing geopolitical tensions in space, which could disrupt operations and supply chains. Companies reliant on satellite technologies for communication or logistics must develop risk management strategies to safeguard against potential disruptions from malicious actors.

Cybersecurity Demand Surge

As the military adopts commercial technologies and as cyberthreats to space assets become more common, the demand for cybersecurity solutions in space increases. Companies specializing in space cybersecurity will find new markets by focusing on protecting sensitive data and satellite operations from potential cyberthreats.

Harnessing Space Data for Decision-Making

The space-for-Earth economy promotes data-driven decision-making based on Earth observation data. Companies that utilize space-based insights can boost operational efficiency, improve disaster management, and optimize resource allocation. Some applications include tracking deforestation, monitoring supply chain disruptions, and analyzing changes in land use and urban development.

ISRU R&D Benefits Space and Earth

The push for sustainability in space exploration is fueling innovation in green propulsion, reusable rockets, and in-situ resource utilization (ISRU). Companies investing in these technologies reduce their environmental impact while gaining competitive advantages. A new ecosystem of sustainable solutions will open up with diverse applications and revenue streams both in space and on Earth.

Tragedy of the Space Commons

Unchecked space traffic directly impacts any organization relying on satellites or space-based infrastructure. As Earth's orbit becomes increasingly crowded, space debris poses a growing threat to assets critical for communication, navigation, and research. Even small debris can cause catastrophic damage at high velocities, risking millions in investments.

These individuals are leading the charge in advancing space technology, driving discoveries, and unlocking the commercialization of space.

- **Fay Abdul Ghani, medical researcher at the Mayo Clinic's Center for Regenerative Biotherapeutics,** for her collaboration with NASA on studying stem cells in space and developing regenerative medicine therapies in microgravity.
- **Delian Asparouhov, co-founder of Varda Space Industries,** for his work on creating a platform for in-space manufacturing, especially related to the development of in-space pharmaceutical production.
- **Trevor Bennett, CEO and founder of Starfish Space,** for his work on satellite servicing and in-orbit sustainability, including satellite life extension and debris removal.
- **Jorge Rubén Casir Ricaño, Ph.D. candidate at the Space Robotics Laboratory of Kyushu Institute of Technology,** for his research on developing self-diagnosis, prediction, and fault-detection systems for lunar rovers.
- **Lee Steinke, chief operating officer of CisLunar Industries,** for her significant contributions to the commercialization of space.
- **Dr. Tabitha Dodson, program manager at DARPA,** for overseeing the DRACO effort in the development of nuclear thermal propulsion technology.
- **Dr. Michael Levi, director of the Dark Energy Spectroscopic Instrument,** for leading efforts to create the largest 3D map of the universe.
- **Nobu Okada, founder and CEO of Astroscale,** for his pioneering work on space debris removal.
- **Dr. Eliah Overbey and Dr. Chris Mason, professors at Weill Cornell Medicine,** for their work on the Space Omics and Medical Atlas (SOMA).
- **Stefan Powell, co-founder, CEO, and CTO of Dawn Aerospace,** for his work in developing green propulsion systems.
- **John Vellinger, president of Redwire's In-Space Industries division,** for his leadership on space-based manufacturing initiatives, particularly in the semiconductor sector.
- **Dr. Ethan Waisberg, Academic Foundation Programme Doctor at the University of Cambridge,** for his research on mitochondrial function changes during spaceflight.

Space offers vast opportunities for profit and advancing life on Earth...

...but as it becomes more accessible, new threats and challenges emerge.

OPPORTUNITIES

EO Data Impacts Industry

Earth observation (EO) data, combined with AI and machine learning, offers unprecedented insights waiting to be uncovered. By thinking creatively, we can transform industries in ways we've yet to imagine.

Cislunar Networking

As we return to the moon, infrastructure like fiber optics and reliable internet will be essential, mirroring Earth's networks. This presents a significant opportunity to shape the future of lunar communications.

Space-based Manufacturing

Pharmaceutical companies, like Merck and Varda Space Industries, are exploring drug crystallization in microgravity, potentially developing new, more effective medicines to significantly advance health care and disease treatment.

Human Tolerance for Space

Consider investing in research that adapts human biology for space. By making humans biologically suited for space exploration, we'll enhance our ability to thrive beyond Earth.

THREATS

New Military Threats

The proliferation of space-based military technologies and anti-sats could trigger a new arms race. This increases the risk of conflicts in space, with destructive outcomes affecting global networks and economies reliant on space infrastructure.

Kessler Syndrome Gets Real

Space debris poses a significant threat to operational satellites and future missions. Collisions could render orbits unusable, endangering global satellite services that support everyday activities like GPS navigation.

Satellite Vulnerabilities

Satellites and space infrastructure are vulnerable to cyberattacks. Nations and non-state actors could compromise networks, disrupting military operations, critical infrastructure, and global communications.

Lunar Territorial Claims

Competition over lunar territory and resources could lead to geopolitical disputes. Nations that secure key lunar areas may challenge existing international agreements, risking conflict and undermining cooperative space exploration.

There are abundant opportunities to serve as an early partner in the space ecosystem as it transitions to commercial first.

Waste management, architecture, and entertainment companies can expand into space by leveraging their expertise and partnering with space specialists. For instance, developing infrastructure for lunar exploration—like power systems, habitats, or communication networks—positions leaders in the growing space economy to tap into new markets beyond Earth.

Invest in advanced cybersecurity technologies to protect critical space infrastructure and satellite communications from increasing cyberthreats. There will be a growing market for cyber defense services, offering opportunities to provide solutions that ensure the safety and integrity of space missions.

Develop analytics platforms leveraging Earth observation data for industries like agriculture and logistics. By investing in data-driven solutions, companies can enhance decision-making, improve operational efficiency, and create value-added services, tapping into new market opportunities.

As governments transfer more space responsibilities to commercial industries, opportunities are rapidly expanding. Public-private partnerships, such as the Department of Defense's "buy what we can, build what we must" policy, opens new markets, spurs growth, and attracts private investment, positioning businesses to lead in future space operations.

Invest in space-based nuclear and solar power systems that can transmit energy back to Earth and be used to power space operations. This approach offers a sustainable solution for global energy challenges while also supporting lunar bases, satellites, and deep space missions, helping to create a self-sustaining energy infrastructure both on Earth and beyond.

Invest in enabling technologies like advanced materials. Focus on companies developing materials for space, such as radiation-resistant electronics or lightweight structures. These innovations are critical for advancing space exploration and building durable, efficient spacecraft and habitats; investments in them will position supporters at the forefront of space technology.

Technology Deployment

Capital Expenditure

Talent Development

Regulatory Influence

Important terms to know before reading.

ARTEMIS ACCORDS
A US-led international agreement to establish norms for lunar exploration and cooperation, focusing on peaceful, transparent space activities and resource utilization.

BIOREGENERATIVE LIFE SUPPORT SYSTEMS (BLSS)
These systems, designed to use biological processes to regenerate life support elements, like oxygen and water, are crucial for long-term space missions.

CISLUNAR ECONOMY
The economic activities between Earth and the moon, including resource extraction, transportation, and infrastructure development, are critical for sustained human presence.

DIRECT-TO-DEVICE (D2D) COMMUNICATIONS
A technology enabling direct communication between satellites and consumer devices, like smartphones, bypassing ground infrastructure and revolutionizing global connectivity.

IN-SITU RESOURCE UTILIZATION (ISRU)
The practice of using resources found on other celestial bodies, such as lunar water ice, for mission sustainability, reducing the need for supply missions from Earth.

INTERNATIONAL LUNAR RESEARCH STATION
A joint effort by China and Russia to establish a permanent lunar base, signaling growing geopolitical interest in lunar resources.

KESSLER SYNDROME
A scenario in which space debris collisions create more debris, leading to a cascade of collisions that could render parts of Earth's orbit unusable.

LOW EARTH ORBIT (LEO)
This orbit is situated relatively close to the Earth's surface, typically at altitudes below 1,000 kilometers, though it can be as low as 160 kilometers. While LEO is considered "low" compared to other orbital distances, it remains significantly high above the Earth's surface.

LUNAR GATEWAY
A planned space station in lunar orbit developed by NASA and its partners, intended to serve as a staging point for missions to the moon and beyond.

LUNAR TERRAIN VEHICLES (LTVS)
Vehicles designed for mobility on the lunar surface, critical for transporting cargo and supporting long-term exploration and resource extraction missions.

MEGA-CONSTELLATIONS
Large networks of small satellites working together to provide global coverage for communications or Earth observation, such as SpaceX's Starlink.

MICROGRAVITY
The condition of very weak gravity experienced in orbit, crucial for research in space-based manufacturing and scientific experiments, particularly in biopharma and materials science.

QUANTUM KEY DISTRIBUTION (QKD)
A method of secure communication using quantum mechanics that's being explored for space-based communications to ensure ultra-secure data transmission.

REUSABLE ROCKETS
Rockets designed to be launched, landed, and reused multiple times, dramatically lowering the cost of space access and increasing the frequency of launches.

SMALL SATELLITE (SMALLSAT)
Satellites with a mass under 500 kilograms used for various purposes like Earth observation, communications, and scientific research, increasingly dominant in space missions.

SPACE-BASED SOLAR POWER (SBSP)
The concept of harnessing solar energy in space and transmitting it to Earth, offering a clean energy solution with global environmental benefits.

SPACE DEBRIS
Nonfunctional objects in orbit, such as defunct satellites and rocket fragments, which pose significant risks to operational spacecraft and space missions.

SPACE OMICS
The study of biological systems and changes in astronauts due to space conditions, particularly in long-term missions, vital for understanding human health in space.

SPACE TRAFFIC MANAGEMENT (STM)
The monitoring, coordination, and regulation of all objects in Earth's orbit, including satellites, spacecraft, and space debris. STM aims to ensure the safe operation of satellites and prevent collisions by tracking the location and movement of objects in space.

SWARM ROBOTICS
A technology where multiple robots work autonomously as a coordinated unit, often used in space exploration for tasks such as planetary surface mapping or asteroid mining.

SPACE TRENDS

SPACE POLITICS

“

Violence is the last refuge of the incompetent.

Isaac Asimov, “Foundation” (Gnome Press, 1951)

4TH YEAR ON THE LIST

GEOPOLITICAL SPACE TENSIONS

WHAT IT IS

As countries compete for strategic dominance over space and its valuable resources, this new frontier will reshape global power dynamics, with control of space assets and extraterrestrial resources becoming crucial for 21st-century geopolitical influence and economic advantage.

HOW IT WORKS

Geopolitical tensions in space are intensifying as nations vie for control over this increasingly strategic domain, and the competition could determine which countries emerge as the leading superpowers in the 21st century and beyond. At the forefront are China, Russia, and the US, each investing heavily in R&D, and deployment of advanced space technologies. France, India, Iran, Japan, and North Korea are also ramping up counter-space capabilities aimed to disrupt or neutralize adversarial space assets. Recent reports of Russia developing a nuclear space weapon have reinforced the Pentagon's view that space is no longer an uncontested domain. China's advancements in anti-satellite weapons and satellite network technologies also directly challenge US space supremacy. In response, the US is enhancing resilience through improved missile warning systems and satellite tracking. International rivalries are extending into new arenas, as evidenced by the presence of Chinese-operated space facilities in Latin America. These installations, which blur the line between civilian and military applications, have raised concerns about foreign space infrastructure and its strategic implications. The moon has also become a focal point of geopolitical interest due to its mineral resources. As countries and private entities plan lunar missions, the race to secure the moon's prime real estate intensifies. Success in harnessing these resources could grant nations significant economic advantages and influence over future lunar governance.

WHY IT MATTERS

The increasing geopolitical competition in space holds profound implications for global security and international relations. Control over space is becoming as crucial as dominance over air, land, and sea, with the potential to dictate which nations emerge as 21st-century superpowers. The militarization of space risks escalating conflicts, especially if adversaries perceive threats to their space assets. This could lead to direct confrontations in orbit or even influence terrestrial military strategies. In addition, the competition for lunar resources could determine economic dominance for decades to come: Nations that secure these resources first will not only have economic advantages but will also shape the rules and governance structures for future extraterrestrial activities. This scramble for lunar land raises questions about the sustainability of international cooperation in space, which has historically been a domain of shared scientific exploration rather than military rivalry.

As the militarization of space becomes more pronounced, new technologies developed for space warfare might also find their way into civilian use, altering technological landscapes on Earth. However, this trend also raises the stakes for maintaining international peace and cooperation in a domain that is inherently global and borderless. Nations and private actors must carefully navigate this complex environment to prevent space from becoming a new frontier for warfare.

1ST YEAR ON THE LIST

COMMERCIAL AND MILITARY SPACE INTEGRATION

WHAT IT IS

The US military—including both the DoD and Space Force—is rapidly integrating commercial space technologies, blurring lines between private and defense sectors. This shift creates new opportunities and challenges for space-based intelligence and national security.

HOW IT WORKS

The U.S. military is formalizing partnerships with commercial space companies through new strategies from both the DoD and Space Force aimed at integrating commercial capabilities while managing security risks. A DoD pilot program enlisted private satellite operators to deliver intelligence directly to battlefield commanders, sparking a debate between defense and intelligence agencies over control of military commercial space imagery. Space Systems Command tasked a private operator to give US Indo-Pacific Command 24-hour notice of a Chinese military satellite launch. Within a week of the launch, the company provided in-space imagery of the satellite. Interestingly, just seven days earlier, on April 15, China launched the first commercial imaging satellite in a new constellation, though any connection remains unclear.

The US government's Commercial Augmentation Space Reserve program focuses on defending critical space assets against cyberthreats. The government's increasing reliance on commercial satellite intelligence presents both opportunities and dilemmas for the commercial sector. Companies like Maxar Technologies and Planet Labs have demonstrated the value of commercial satellite data in conflict zones like Ukraine. Still, they face ethical and legal challenges related to data access and control. Recognizing these complexities, the Space Force has opened communication lines with VCs to better align commercial space technology development with national security requirements.

WHY IT MATTERS

The integration of commercial space capabilities in military operations represents a significant shift in how space is utilized for national security. This trend underscores the evolving nature of space as a contested domain where commercial actors play a crucial role in supporting defense strategies. The reliance on commercial satellite data for military operations can enhance situational awareness and strategic decision-making but also introduces new risks and ethical dilemmas.

For commercial entities, this integration presents opportunities to expand their market and collaborate closely with government agencies. However, it also requires them to navigate a complex landscape of legal, ethical, and operational challenges. The demand for commercial satellite data is rising, driven by its strategic value, but so are concerns over data security, privacy, and the potential misuse of information in conflict zones.

The dialogue between the Space Force and venture capitalists marks a new era of collaboration, emphasizing the importance of aligning commercial innovation with national security interests. This approach could lead to a more robust and secure space infrastructure, benefiting both military and commercial actors. However, the commercialization of space intelligence also necessitates careful management to avoid unintended consequences that could affect global security and geopolitical stability.

3RD YEAR ON THE LIST

EMERGING SPACEFARING COUNTRIES

WHAT IT IS

Emerging spacefaring countries like India, Brazil, and the UAE are advancing space capabilities and establishing themselves as significant players in space exploration. This intensifies global space competition while opening avenues for unprecedented international collaboration.

HOW IT WORKS

The countries new to ramping up space exploration initiatives are developing advanced capabilities and establishing national space agencies to compete in the global space race. In Canada, NordSpace is helping the country move toward space self-reliance; the space engineering company has allocated $5 million for the initial phase of Spaceport Canada, reflecting the country's ambition to develop its own launch capabilities and reduce dependence on foreign entities. Japan, having landed a rover on the moon, is now targeting Mars' moons for 2026 exploration. India achieved major milestones in 2024 with missions including XPoSat, NISAR, INSAT-3DS, and Gaganyaan 1, marking the first uncrewed test flight of its human spaceflight program. South Korea's new space agency, KASA, aims to advance satellite technology and defense capabilities, with goals of multiple launches by 2027 and a Mars landing by 2045. Saudi Arabia has elevated its space program with the Saudi Space Agency's upgrade to full agency status in 2023, aligning with the country's Saudi Vision 2030 plan to diversify the economy through investments in satellite technology, space research, and partnerships. In Latin America, Argentina, Brazil, and Chile are increasingly integrating space into regional discussions, and joining international agreements like the Artemis Accords. They're focusing on regional challenges like environmental monitoring, while building robust national space programs through collaborative efforts.

WHY IT MATTERS

The emergence of new spacefaring nations introduces a broader array of players in the global space landscape, reshaping the dynamics of space exploration, collaboration, and competition. These countries are not only building their own space capabilities but are also becoming valuable partners in international space initiatives, and they're bringing new perspectives, resources, and innovation to global space activities. For established space powers, the rise of new entrants presents both opportunities and challenges: While these potential partnerships can enhance scientific discovery and technological advancement, the increased competition may also lead to strategic realignments, especially in areas like lunar exploration, planetary science, and satellite deployment. For global governance, the participation of these emerging nations in international agreements and forums adds complexity but also promotes a more cooperative space environment. It encourages dialogue on issues like space debris management, satellite communication protocols, and planetary protection, ensuring that space remains a domain for peaceful exploration and scientific collaboration. As these countries invest in space, they contribute to the commercialization and democratization of space. Their involvement also underscores the growing recognition of space as a critical domain for national security, economic growth, and technological innovation. The bottom line: Countries that succeed in space first are the nations that will lead our future space economy.

2ND YEAR ON THE LIST

SPACE BLOCS AND STRATEGIC PARTNERSHIPS

WHAT IT IS

The formation of new space blocs and partnerships are crucial for sharing resources, fostering collaboration, and advancing joint missions in space. Nations aligning space policies are shaping the future of space utilization while signaling broader geopolitical alliances.

HOW IT WORKS

The US-led Artemis Accords—committed to peaceful space exploration and focused on establishing a sustainable presence on the moon—have expanded to include 51 nations. The coalition doesn't include China and Russia, and despite a slight cooling in relations between the two countries after Russia's invasion of Ukraine, they've recently ramped up their space cooperation. Now, Russia and China have formalized plans to jointly develop the International Lunar Research Station (ILRS) and are planning a Sino-Russo lunar nuclear plant. Several countries, such as Venezuela, Pakistan, and South Africa, have also expressed interest in participating in the ILRS.

Other countries are also forming their own strategic space alliances. Japan collaborates with the United States on the lunar Gateway project, and India partners with France on space research. The European Space Agency (ESA) has also shifted its collaborations due to geopolitical tensions; the ESA suspended its Roscosmos partnership on the Rosalind Franklin rover after Russia invaded Ukraine, and partnered with NASA instead to continue the mission. China continues to expand its global footprint through strategic bilateral partnerships, such as with Argentina, where a deep-space radar facility and a new radio telescope project enhance China's satellite communication capabilities and strategic command over advanced missile systems. While these initiatives are ostensibly for scientific purposes, the dual-use nature raises significant geopolitical and strategic implications.

WHY IT MATTERS

The formation of these distinct space blocs signals a new era of geopolitical competition and cooperation beyond Earth. The Artemis Accords represent an effort to consolidate a democratic alliance in space, promoting norms that reflect Western values of transparency, collaboration, and the peaceful use of space. In contrast, the Sino-Russian alliance, exemplified by the ILRS and lunar nuclear plant plans, represents a counterweight to Western influence, underscoring the geopolitical underpinnings of space exploration.

These developments reflect a strategic realignment of nations in response to broader geopolitical dynamics, such as the United States-China rivalry and Russia's shifting alliances post-Ukraine invasion. The expansion of space activities, including lunar bases and deep-space infrastructure, raises crucial questions about space governance, resource utilization, and the militarization of space. As more countries and private entities join these blocs, the rules of engagement and collaboration in space will become increasingly complex, influencing global power structures and strategic interests.

1ST YEAR ON THE LIST

DOMESTIC POLICY DRIVES GOVERNANCE

WHAT IT IS

The existing international legal framework is being challenged by new technologies and the growing commercial and military use of space. Governance may shift primarily to the domestic level, with varying degrees of cross-border cooperation.

HOW IT WORKS

The 1967 Outer Space Treaty, the foundation of space governance, established key principles like prohibiting national sovereignty claims in space and promoting peaceful use. But it's increasingly seen as inadequate for today's challenges. Modern issues like space debris, orbital traffic management, and cybersecurity lack comprehensive guidelines, creating significant safety and security gaps. Effective space governance of these areas requires real-time, round-the-clock communication between governments—a level of cooperation that is challenging to achieve amid deepening geopolitical rifts particularly among the US, China, and Russia. In the absence of modern international agreements, governance is largely occurring at the domestic level. Nations are implementing laws to regulate space activities within their jurisdictions, covering aspects such as authorization and supervision of space activities, liability for damages, and protection of space environments. Countries are focusing on regulating specific space activities, including satellite launches, orbital debris mitigation, and space traffic management. For instance, the US Federal Communications Commission has implemented stricter regulations on orbital debris and satellite operations. The EU is also developing its own law that would harmonize diverse national space laws across its member states. This initiative aims to create a "true single market" for space activities, reducing fragmentation and boosting competitiveness within the EU space industry.

WHY IT MATTERS

Modernizing space governance is crucial to ensure the sustainable and safe use of space. The current framework is insufficient to address the complex and evolving challenges posed by new technologies, increased space traffic, and growing private-sector involvement. Without updates, we risk collisions, conflicts, and a potential arms race in space. Space debris, for example, could render certain orbits unusable for centuries, impacting satellite services that are vital for navigation, communication, and Earth observation.

Effective governance also requires addressing cybersecurity threats to space assets, which are increasingly targeted by state and non-state actors. As space becomes a contested domain, there is a heightened risk of conflict. A lack of updated international agreements leaves room for misunderstandings and potential confrontations. Additionally, the growing fragmentation in national space laws, with governments in the United States and the European Union developing their own regulatory frameworks, may lead to inconsistencies and conflicts in enforcement and compliance.

Addressing these issues requires international cooperation, robust legal frameworks, and shared technological standards. It also necessitates trust-building measures to reduce geopolitical tensions and foster collaborative efforts for the benefit of all humanity. By updating and expanding our space governance frameworks, we can ensure a sustainable and secure future in space.

3RD YEAR ON THE LIST

COUNTERSPACE CAPABILITIES

WHAT IT IS

Countries are swiftly advancing counterspace technologies like direct-ascent anti-satellite (DA-ASAT) systems and co-orbital weapons. The US, China, and Russia are leading these efforts, driven by the pursuit of space dominance and asset protection.

HOW IT WORKS

DA-ASAT systems, co-orbital weapons, electronic warfare, and cyber capabilities are all part of the evolving counterspace landscape. DA-ASAT systems are designed to destroy satellites by launching a missile that directly impacts a target in LEO or higher. China has made significant advancements in this field, with tests demonstrating the ability to target both LEO and geostationary satellites.

Co-orbital weapons, which maneuver in space to approach and engage a target, offer another means of attack. Russia's Burevestnik program, for example, includes co-orbital ASAT capabilities that can either collide with or disrupt satellites through nondestructive methods like jamming or sensor blinding. These systems use rendezvous and proximity operations to get close to their targets, raising concerns about the potential for surveillance or attacks on critical space assets.

The United States, while not focusing as much on destructive DA-ASAT weapons, has developed significant electronic warfare systems like the Counter Communications System, which is used to jam satellite communications. The US is also advancing its capabilities in directed energy weapons, such as ground-based lasers that can dazzle or blind satellite sensors without creating debris.

WHY IT MATTERS

The rapid development of counterspace technologies highlights the growing militarization of space, where satellites are vital for communications and military operations. With destructive weapons like DA-ASAT missiles and co-orbital systems, the risk of conflict targeting these assets is rising. China's advancements in DA-ASAT capabilities pose a threat to US and allied satellites in both LEO and geosynchronous Earth orbit, crucial for intelligence and surveillance. The ability to target geostationary satellites marks a strategic shift in space warfare, challenging US space dominance. Russia's co-orbital systems, like Burevestnik, further complicate space security with their ability to maneuver close to satellites, enabling espionage or non-kinetic disabling. The dual-use nature of satellites, where they can serve both civil and military functions, makes it harder to differentiate between peaceful and hostile operations, increasing the risk of miscalculation.

As the space domain becomes more critical to national security, countries will need to develop norms and agreements to prevent escalation. However, the current pace of technological development suggests that space may become a theater of conflict, where anti-satellite weapons and other counterspace technologies play a central role. In this evolving environment, maintaining space dominance will require not only technological advancements but also diplomatic efforts to establish rules that prevent the weaponization of space.

1ST YEAR ON THE LIST

CYBER WARFARE IN SPACE

WHAT IT IS

Cyber warfare has become a key aspect of counterspace capabilities. By targeting the digital systems that control satellites and space infrastructure, the goal is to compromise satellite functionality, access sensitive information, or manipulate operations for hostile purposes.

HOW IT WORKS

In 2024, Russia and China ramped up cyberattacks on satellite networks, disrupting military communications and surveillance. Russia first showcased its use of this tactic during its 2022 invasion of Ukraine by targeting Viasat's KA-SAT network, infecting modems with malware and cutting internet access for thousands. Soon after, Russia expanded its efforts to jam Starlink terminals, prompting Starlink to deploy software updates to counter these attacks.

The US has also flagged increasing cyberthreats from China, which is developing advanced jamming and satellite hijacking capabilities. Leaked CIA documents suggest these cyber weapons are more sophisticated than those used by Russia, heightening concerns about the potential for US satellites to be disabled or controlled. In response, the US has ramped up space cybersecurity efforts: The Space Force's 2024 budget rose to $30 billion, with $76 million allocated to the Defense Cyber Operations-Space program.

The Space Force is shifting toward a warfighting stance to prepare for potential space conflicts, focusing on advanced defense tools like quantum-resistant cryptography and homomorphic encryption, which enable secure data processing without decryption. The agency is also using AI technologies to autonomously detect orbital vulnerabilities and counter cyberattacks. Additionally, they're exploring laser communication links for their enhanced data protection compared to traditional radio frequencies.

WHY IT MATTERS

As space becomes a contested domain, the potential for cyberattacks to disrupt or disable critical satellite infrastructure poses a direct threat to national security and Earth's economy. Disruptions to satellite networks can impact not only military operations but also civilian services, such as communication, navigation, and financial transactions, which rely on satellite infrastructure.

Russia's attacks on Viasat and Starlink serve as a stark reminder of the vulnerabilities in space-based communications and underscore the need for robust cybersecurity measures. With China and Russia developing advanced cyber capabilities, the US must innovate rapidly to protect its assets in orbit. The Space Force's increased budget and focus on advanced encryption, AI defenses, and laser communication represent a proactive approach to these emerging threats.

By preparing for a contested space environment, the US aims to maintain its strategic advantage and ensure the continuity of operations in the face of potential adversarial actions. This shift also signals a broader recognition of space as a critical theater for future military conflicts, necessitating a comprehensive approach to defense and resilience in space.

3RD YEAR ON THE LIST

PLANETARY DEFENSE

WHAT IT IS

Governments are implementing measures to detect, monitor, and mitigate potential threats posed by near-Earth objects (NEOs), such as asteroids. The goal is to prevent or minimize the damage to Earth, which could range from localized destruction to global catastrophic events.

HOW IT WORKS

The risk of asteroid collisions with Earth, although low, carries catastrophic potential, and countries are focusing on detecting, tracking, and developing methods to deflect or disrupt these hazards. Early detection of NEOs is crucial, with NASA's repurposed NEOWISE telescope playing a key role in identifying threats. The 2026 NEO Surveyor mission will offer more comprehensive sky coverage to detect smaller, potentially dangerous asteroids that may have previously gone unnoticed. China is also enhancing its NEO detection capabilities. In 2023, China's 2.5-meter Wide Field Survey Telescope became operational and quickly demonstrated its effectiveness by spotting two new asteroids. The Lijiang 2.4-meter and the Xinglong 2.16-meter telescopes are active, and the country is proposing survey telescopes and a constellation of six surveyor spacecraft in Venus-adjacent orbits. This constellation aims to offer an early warning system, providing better coverage and monitoring of space within Earth's orbit. Researchers are also testing various methods for altering the trajectory of hazardous asteroids. These include kinetic impactors, nuclear explosive devices, gravity tractors, laser ablation, and ion beam deflection. NASA's Double Asteroid Redirection Test (DART) mission, which successfully altered the orbit of the asteroid moonlet Dimorphos in 2022, is a prime example of the kinetic impact approach. Following DART's success, ESA is preparing the Hera mission to gather detailed data on the effects of the DART impact to refine future planetary defense strategies.

WHY IT MATTERS

A collision with even a relatively small asteroid could have devastating regional or global consequences, including massive loss of life, environmental damage, and economic disruption. As our ability to detect these objects improves, so too does our capacity to develop effective strategies to mitigate potential impacts. The Hera mission and China's upcoming planetary defense initiatives represent critical steps in refining our understanding of asteroid dynamics and the effectiveness of deflection techniques. By studying the outcomes of these missions, scientists can improve predictive models and refine technology to prevent future collisions.

The global nature of the planetary defense effort—spanning the United States, Europe, China, and beyond—underscores the need for international cooperation in space. As countries enhance their capabilities to detect and deflect potentially hazardous asteroids, shared data and collaborative missions become crucial for ensuring planetary safety.

These developments also pave the way for future space missions, potentially turning planetary defense technologies into dual-use systems that can support broader scientific exploration and planetary science initiatives. As space becomes more accessible, the strategies developed today will likely influence future missions' scope, safety, and success.

2ND YEAR ON THE LIST

STATES COMPETE FOR SPACE INVESTMENTS

WHAT IT IS

US states are intensifying efforts to attract space industry investments, leveraging economic incentives, legislative support, and infrastructure expansions. The goal is to boost local economies, create jobs, and secure leadership in the burgeoning space sector.

HOW IT WORKS

The race is driven by the substantial economic benefits that come with hosting space assets. Texas has emerged as a leading contender in this competitive landscape because of its business-friendly environment—as well as substantial economic incentives for the industry, including tax abatements and grants aimed at attracting aerospace companies. A prime example is SpaceX's presence in Boca Chica, where it's significantly contributing to the local economy. Florida continues to reinforce its status as a major space hub, primarily due to its established infrastructure at Cape Canaveral and the Kennedy Space Center. The state's aerospace finance and development authority, Space Florida, is focused on expanding spaceport territories and advocating for tax-exempt spaceport bonds. Recent legislative efforts such as Senate Bill 968, which extends spaceport systems to encompass additional military bases, aims to attract a broader array of aerospace companies and investors. California remains a space powerhouse, with a rich ecosystem of aerospace companies and startups. A notable area of innovation is El Segundo, which has become a hotbed for hard tech companies focused on aerospace and advanced manufacturing. However, the state's position is being challenged by its own regulatory environment and the lure of other states' incentives, as demonstrated by the loss of SpaceX's headquarters to Texas. This shift indicates a broader trend of space companies seeking more favorable regulatory and economic climates.

WHY IT MATTERS

As states compete for dominance in the space sector, each leverages unique strategies and assets to attract investment. Texas focuses on fostering a comprehensive aerospace ecosystem through legislative support and economic incentives, Florida expands its spaceport infrastructure and integrates military bases to strengthen aerospace capabilities, and California rests on its existing startup network and tech infrastructure, backed by significant public-private partnerships. By attracting space companies, these states are fostering local high-tech industries, creating high-paying jobs, and generating significant economic benefits. The key lies in nurturing an ecosystem that combines talent, resources, and capital.

This influx of investment and talent can have far-reaching effects on regional prosperity. For instance, space research often leads to technologies with wide-ranging terrestrial applications. States hosting vibrant space sectors are more likely to benefit from these spinoffs, potentially spurring innovation in fields like health care, transportation, and environmental monitoring.

But perhaps just as important, the domestic competition among states to attract and nurture space industries serves as a valuable real-world experiment in economic policy and industry development. This "laboratory of democracy" approach, where different states implement varied strategies, provides invaluable insights into the most effective ways to foster a thriving space sector.

SCENARIO YEAR 2035

A NEW HOMESTEAD ACT

As global demand for advanced batteries soars, humanity turns to the moon. Its rich deposits of lithium and rare earth elements, essential for next-gen energy storage, make lunar soil an economic gold mine — but as nations and private companies rush to establish a presence, the lack of clear governance leads to rising tensions.

The US, leveraging its thriving private space sector, introduces the Lunar Homestead Act. This policy, carefully crafted to navigate the constraints of the Outer Space Treaty, doesn't directly grant land ownership. Instead, it provides substantial financial incentives and support for US-based companies to develop lunar infrastructure and mine for resources. Under the act, companies receive funding to establish bases and extract lithium and other valuable minerals. In return, they agree to operate under US law. This clever workaround allows the US to extend its influence without explicitly claiming sovereignty, creating a de facto American presence on the moon. Tech giants and startups alike rush to stake their claims, seeing the potential to dominate the global battery market. Within years, the lunar surface will be dotted with American corporate outposts, each flying the US flag alongside their company logos.

The lunar land grab doesn't go unchallenged. China and Russia protest the US's "lunar imperialism," arguing that it violates the spirit of the Outer Space Treaty. The ESA, caught between its American allies and its own ambitions, proposes an international lunar authority to oversee all extraterrestrial mining activities. The situation grows more complex when a consortium of developing nations, left behind in the lunar gold rush, demands access to the moon's resources under the principle of the "common heritage of mankind." They propose a system where lunar wealth is shared globally, challenging the US-led capitalist model of space development.

SPACE INDUSTRY (B2B)

If we are to find new frontiers for industry and energy, then the mines of space will provide.

Isaac Asimov, “Foundation and Empire” (Gnome Press, 1952)

1ST YEAR ON THE LIST

NEW SPACE

WHAT IT IS

New Space refers to the rapidly evolving commercial space sector. Unlike the traditional space industry, dominated by government agencies, New Space focuses on entrepreneurship, competition, and technological progress, leading to reduced costs and democratized space access.

HOW IT WORKS

The New Space era reached a significant milestone with Intuitive Machines' Odysseus mission, an ambitious attempt to achieve the first U.S. lunar landing since 1972. Competition driven by private companies like SpaceX, Rocket Lab, Relativity Space, and Planet Labs is fueling the New Space revolution, propelling innovation and slashing costs across the industry. SpaceX has transformed space travel with its reusable Falcon rockets, drastically lowering the cost of reaching orbit. Blue Origin's New Glenn rocket made its inaugural flight in January 2025, joining SpaceX as another option for commercial satellite launches. The successful launch underpins Blue Origin's future plans for lunar missions, space resource utilization, and establishing a sustained human presence in space. Rocket Lab's Electron rocket, designed for small satellite launches, is now the second most frequently launched US rocket, achieving over 50 successful missions since 2017. Relativity Space is revolutionizing rocket manufacturing with 3D printing technology, aiming to produce fully reusable rockets, like the Terran R, which are more cost-effective and quicker to produce. Planet Labs focuses on Earth observation, operating a large constellation of small satellites that provide imaging and monitoring services for sectors such as agriculture, environmental monitoring, and disaster response. Small satellites have become a key focus in the New Space sector, offering cost-effective solutions for diverse applications. But the influx of companies brings new challenges, such as managing space traffic and debris.

WHY IT MATTERS

The New Space movement is transforming our approach to space exploration and utilization, with profound implications for society, the economy, and scientific advancement. By dramatically reducing launch costs, New Space companies are democratizing access to orbit, enabling a wider range of entities to participate in space activities. This democratization is accelerating scientific research, Earth observation, and commercial applications of space technology—and is also creating high-skilled jobs and driving technological innovation with spillover effects benefiting industries like health care and renewable energy.

Increased private investment in these space-based technologies has the potential to speed up solutions that address global challenges, providing vital data for climate change research, disaster management, and precision agriculture. The entrepreneurial spirit of New Space is also inspiring the next generation of scientists and engineers, crucial for maintaining technological competitiveness. Many New Space technologies have direct applications for improving life on Earth, from enhanced GPS accuracy to high-speed satellite internet for remote areas. As space activities increase, these New Space companies are also developing technologies for sustainable space utilization, ensuring the long-term viability of space operations.

1ST YEAR ON THE LIST

SPACE-FOR-EARTH ECONOMY

WHAT IT IS

The space-for-Earth economy leverages space-based infrastructure and activities to benefit life on Earth. Earth observation enhances weather forecasting, disaster management, and agriculture, while GPS systems power transportation, logistics, and everyday services.

HOW IT WORKS

People around the world rely on space technology to connect to the internet, monitor the environment, navigate the world, and access health care. Companies like Starlink and OneWeb are extending internet access to previously unconnected regions, while Earth observation satellites from Planet are revolutionizing multiple industries. In environmental sustainability, GHGSat and Carbon Mapper track methane emissions globally, providing crucial data for environmental protection, while Hummingbird's satellite imagery helps farmers optimize crop management. In transportation and logistics, Xona Space Systems is developing the Pulsar satellite constellation to provide precise positioning for autonomous vehicles, potentially reshaping the future of transportation. In health care, satellite technology is breaking down geographic barriers, with Viasat and 19Labs delivering telemedicine services to remote communities that previously had limited access to medical care. As satellite technology continues to advance, it's creating new opportunities across sectors, from environmental sustainability to health care.

WHY IT MATTERS

Although launch costs have dropped and private-sector spaceflights are becoming more frequent, space still feels largely beyond reach for most people. We often forget that our lives are constantly supported by technologies developed for space—we don't see the satellites orbiting overhead unless we look closely at the night sky—and even many everyday technologies originated from space innovations. Memory foam, commonly found in pillows and mattresses, was originally developed to improve aircraft seat safety. Scratch-resistant lenses, now standard in eyeglasses and cameras, were first created for space helmets. Smoke detectors were initially used in early US space stations, and water purification systems designed for long-duration space missions now have widespread use on Earth. Space exploration does more than fuel human curiosity—it significantly drives economic growth and improves life on Earth. Satellite imagery, for instance, enables farmers to monitor crops and manage irrigation more efficiently, while also allowing precise tracking of emissions and environmental changes. Satellites are streamlining supply chains, optimizing delivery services, and expanding internet access to underserved regions, helping bridge the digital divide. In the insurance industry, satellite data enhances risk models. The potential for space-based drug manufacturing is vast, and space exploration is opening doors to revolutionary advancements like space-based solar power and asteroid mining, which could significantly impact Earth's economy.

1ST YEAR ON THE LIST

SATELLITE DATA

WHAT IT IS

Satellite data advancements, powered by AI, are transforming industries like precision agriculture and smart city management. Real-time, actionable insights are driving innovation in geospatial data analysis, environmental monitoring, and space asset tracking.

HOW IT WORKS

Advancements in satellites are creating an explosion of data that is revolutionizing both space and terrestrial industries, expanding the space economy's reach. To harness the data's potential, AI and machine learning rapidly analyze satellite imagery, providing real-time insights for applications ranging from precision agriculture to smart city management. Companies like Planet Labs, Kleos, and LeoLabs are leading the way with their satellite constellations, offering high-resolution, high-frequency Earth imagery. These satellites gather geospatial data, which is processed and analyzed with AI to provide actionable insights. For instance, Planet Labs' small satellite constellation captures detailed global imagery, useful for environmental monitoring, urban planning, land use changes, disaster tracking, and agricultural decision-making. In September 2024, the company introduced its Forest Carbon Monitoring dataset, leveraging earth observation to estimate the carbon stored in above-ground plant biomass—branches, leaves, and other vegetation—at an impressive resolution of three meters per pixel.

The space data economy is expanding beyond earthly use cases to include the tracking and management of space assets, which will become increasingly important as the number of these assets grows. US-based startup LeoLabs contributes by offering precise tracking of satellites and space debris, essential for collision avoidance and space situational awareness.

WHY IT MATTERS

Satellite data is becoming indispensable across various sectors due to its ability to provide timely, precise, and comprehensive information about the Earth's surface. In agriculture, satellite imagery helps monitor crop health, forecast yields, and optimize water usage, enhancing food security and reducing waste. The energy sector uses satellite data for resource exploration, monitoring infrastructure like pipelines and power grids, and optimizing energy production, thus improving operational efficiency and safety.

In logistics and transportation, satellite data supports traffic management, route optimization, and fleet monitoring, reducing fuel consumption and enhancing delivery efficiency. For environmental monitoring, satellites offer critical data for tracking deforestation, glacial melting, and other indicators of climate change, allowing governments and organizations to formulate more effective environmental policies and disaster management strategies.

Consumer applications such as GPS navigation, satellite television, and internet connectivity heavily rely on satellite data, affecting everyday life and business operations. And as companies continue to integrate emerging technologies like AI in satellite data processing, the combination is unlocking new possibilities for real-time decision-making and automation, accelerating innovation and creating new business opportunities.

3RD YEAR ON THE LIST

SPACE FACTORIES

WHAT IT IS

Low Earth orbit (LEO) could offer a more favorable environment for manufacturing certain goods and products, such as semiconductors and artificial proteins. With the reduction in orbital transport costs, companies might consider shifting specialized production to space.

HOW IT WORKS

The weightless environment of space could be a platform for advanced materials manufacturing. The vacuum of space provides an ultra-clean environment devoid of terrestrial contaminants, while enabling novel thin-layer deposition techniques that could transform semiconductor production beyond traditional silicon-based approaches. In February 2024, Redwire's Microgravity Semiconductor Technology and Innovation Center made history aboard the ISS. Their pathfinder mission successfully demonstrated autonomous semiconductor manufacturing in orbit, producing 18 thin-film samples with superior crystal microstructure compared to their Earth-manufactured counterparts. These results validate microgravity's promise for creating enhanced semiconductor components for both space and terrestrial applications.

The industry continues to expand, with Momentus Space securing a DARPA contract under the Novel Orbital and Moon Manufacturing, Materials, and Mass-efficient Design program. Their ambitious vision involves transporting raw materials from Earth to manufacture space-optimized structures, including solar arrays, antennas, and optical systems. Meanwhile, Varda Space achieved a significant milestone when their orbital factory returned to Earth in February after an eight-month mission, carrying microgravity-manufactured biologics despite earlier regulatory challenges. These developments suggest we're approaching an era in manufacturing, where products bearing the label "Made in Space" could become commonplace in our daily lives.

WHY IT MATTERS

Space-based manufacturing could transform both industrial production and space exploration by leveraging the unique advantages of the microgravity environment. Companies are using space to produce high-value materials with greater quality and efficiency than is possible on Earth. Manufacturing goods with space-related applications in space can reduce the need for costly Earth-to-space launches—but there is also great potential to create materials that cannot be made under terrestrial conditions and to offshore some pollutive industries to space, reducing their environmental impact on Earth.

Citibank predicts that microgravity-based research and development could generate $14 billion in annual sales by 2040, showcasing the immense economic potential of space-based industrial activities. The broader impact of fully functional space factories is profound. In industries like semiconductors, space manufacturing can improve yield and quality, potentially unlocking materials beyond silicon, offering a competitive advantage in the AI race. This is not just about space tourism—it's about creating entirely new markets and revenue streams, moving the commercial space industry toward a sustainable economy in low Earth orbit. These developments could drive breakthroughs that will ripple across many sectors, from advanced materials to environmental sustainability, reshaping both space and Earth economies.

1ST YEAR ON THE LIST

BIOPHARMA IN SPACE

WHAT IT IS

Pharmaceutical companies are investing in space-based labs to explore new drug development techniques, leveraging microgravity to enhance chemical processes and crystallization, with companies like Varda Space Industries, Axiom, and Merck leading the way.

HOW IT WORKS

Biopharmaceutical R&D is undergoing a paradigm shift as companies look to the unique environment of space to explore new frontiers in drug discovery. In microgravity, the physical forces that typically influence chemical reactions and material properties—such as buoyancy, convection, sedimentation, and phase separation—are significantly reduced or entirely absent. This presents an opportunity to manipulate chemical processes and biological phenomena in ways not possible on Earth, offering new pathways for drug development. Companies are beginning to capitalize on this potential. Varda Space Industries has positioned itself as a leader in space biopharma after a molecular analysis confirmed the company successfully produced ritonavir crystals—an HIV medication—in space and maintained their stability during the capsule's fiery reentry. Merck is also actively conducting protein crystallization experiments aboard ISS, under the expectation that the crystals grown in space will be higher quality and more uniform than those grown on Earth, potentially leading to more effective therapies with fewer side effects. Lambda Vision is focused on the production of artificial protein-based retinas, which could lead to breakthroughs in treating retinal diseases and restoring vision. Additionally, Axiom Space, partnering with Boryung, a South Korean health care investment company, has established BRAX Space to advance health care technologies designed for space environments. This partnership aims to further expand the scope of biopharma applications beyond traditional Earth-bound limitations.

WHY IT MATTERS

The utilization of space for biopharma R&D represents a significant leap forward in the pursuit of novel and more effective drug therapies. Microgravity offers a unique laboratory environment that fundamentally changes how certain chemical and biological processes occur, opening new possibilities for drug discovery and formulation. This could lead to a new generation of drugs that are more effective, have fewer side effects, and are easier to produce at scale.

The implications extend beyond pharmaceuticals. The ability to manipulate materials in ways that are impossible on Earth could lead to breakthroughs in other fields, such as materials science, regenerative medicine, and even the production of bioengineered organs. The partnerships and initiatives being developed today, such as those between Axiom and Boryung, or the work of companies like Varda and Merck, are laying the foundation for an entirely new sector of space-based biomanufacturing.

Furthermore, this trend aligns with broader efforts to establish sustainable human presence in space. As companies develop more sophisticated methods for producing essential products in microgravity, the feasibility of long-term space habitation and even colonization becomes more tangible. By mastering R&D in space, humanity could significantly reduce the costs and logistical challenges of sustaining life off-Earth.

2ND YEAR ON THE LIST

OFF-PLANET MINING

WHAT IT IS

Advancements in space technology and reduced launch costs are fueling a resurgence in asteroid mining, with companies developing new technologies to target valuable resources like water, precious metals, and industrial materials from near-Earth asteroids.

HOW IT WORKS

Companies are targeting near-Earth asteroids for their abundant resources, including water, precious metals, and industrial materials. Water is particularly valuable, not only for supporting life and human activities in space but also as a crucial component for creating rocket fuel through electrolysis. This capability could support extended space exploration missions and reduce the need to launch large quantities of fuel from Earth. The process of asteroid mining involves several stages, each requiring specialized technology and equipment. The UK-based startup Asteroid Mining Corp. has developed a series of spacecraft designed for those specific stages, from prospecting to exploration and extraction. Australian startup High Earth Orbit Robotics is making its mark in this emerging industry by integrating advanced control systems with space-based cameras to capture high-resolution imagery, enabling the detection and monitoring of asteroids that are suitable for mining.

The absence of gravity in space makes traditional mining methods ineffective, prompting companies to develop new techniques like optical mining. Pioneered by TransAstra, optical mining uses concentrated sunlight to vaporize materials on an asteroid's surface, allowing for resource extraction without heavy Earth-based equipment. This method lowers the weight and cost of mining operations, making them accessible to smaller companies and startups.

WHY IT MATTERS

The ability to extract valuable resources from space could fundamentally change the economics of space travel and development. By establishing a sustainable supply chain of water and other resources in space, companies could significantly reduce the costs and logistical challenges associated with launching materials from Earth. This would not only make long-term space missions more feasible—it could also support the establishment of permanent human settlements on the moon, Mars, and potentially other celestial bodies. The economic implications are equally significant. Asteroids are believed to contain vast amounts of precious metals, including platinum, gold, and rare earth elements, which are in high demand for electronics and other high-tech industries. The ability to mine these materials in space could alleviate some of the supply constraints faced on Earth.

However, for asteroid mining to become a reality, companies will have to overcome significant technical, financial, and regulatory hurdles. Companies need to develop reliable and cost-effective technologies to prospect, explore, and extract resources from asteroids. At the same time, the international community must establish a clear legal framework that balances the interests of commercial entities with the principles of space as a global commons. As these challenges are addressed, asteroid mining could move from the realm of science fiction to a viable industry with profound implications for our future in space.

1ST YEAR ON THE LIST

SMART SMALLSATS

WHAT IT IS

Smallsats are generally considered satellites with a mass under 500 kilograms and are increasingly used in wireless communications, Earth observation, and scientific research. The low cost and ease of deployment have helped give organizations worldwide near real-time data from space.

HOW IT WORKS

The smallsat industry is undergoing significant growth, fueled by advances in miniaturization, AI integration, and lower launch costs. In 2023, smallsats accounted for 97% of all spacecraft launches. Edge computing is set to enhance satellite capabilities by enabling on-board data processing, reducing dependence on ground stations. While concerns about extreme space conditions have slowed adoption, the integration of AI offers immense potential. AI-powered smallsats could autonomously prioritize data, avoid debris, and analyze telemetry with little human intervention. Companies like EnduroSat are leading innovation by testing AI algorithms in orbit through experimental satellites like IBM's Platform 1, which processes Earth observation images on-board. Its modular, software-defined satellite architecture allows for real-time reprogramming, much like connected consumer devices, driving further flexibility in space applications. The trend toward smaller, more versatile satellites is also inspiring advancements in launch technology. British startup Orbex is developing a reusable micro-launch vehicle, incorporating 3D-printed engines and sustainable fuels, to offer low-cost and environmentally friendly orbital launches, supporting the continued expansion of the smallsat ecosystem.

WHY IT MATTERS

The growth of the intelligent smallsat market represents a significant shift in how we utilize space technology. As these satellites become more capable of processing data and making decisions autonomously, they will transition from being passive data collectors to active participants in space operations. This evolution could have profound implications for various industries and sectors.

For instance, in Earth observation, smallsats equipped with AI could analyze environmental changes, detect natural disasters, or monitor illegal activities in real time. This capability could enhance our response to climate change and global security challenges. In communications, the ability of satellites to operate autonomously could reduce the cost and complexity of maintaining global networks, potentially extending high-speed internet to remote and underserved areas.

The rise of edge computing in space also opens up new possibilities for inter-satellite communications, enabling networks of satellites to work together, sharing data and making coordinated decisions. This advancement could lead to more robust and resilient satellite networks that are less dependent on ground-based infrastructure.

2ND YEAR ON THE LIST

CONSTELLATION MANAGEMENT

WHAT IT IS

Constellation management is the process of coordinating and controlling satellite constellations, which can consist of satellites in similar or different orbits. They work together to provide continuous coverage, enhance data collection, or support specific missions like Earth observation or global navigation.

HOW IT WORKS

Modern constellation management faces growing complexity due to challenges like pass scheduling bottlenecks, incapacitated satellites, high data demand areas, orbital congestion, and signal interference. To tackle these issues, the industry is increasingly adopting AI for dynamic constellation management. A key trend is the shift toward multi-orbit constellations, deploying satellites across different orbits (LEO, MEO, GEO) to enhance connectivity and remote sensing coverage. This approach creates more resilient satellite networks that can operate effectively in congested and contested space environments, and AI-driven management is essential for handling the intricacies of these diverse constellations.

The growth in LEO constellations, driven by both commercial entities and government agencies, is particularly significant. The Space Development Agency is spearheading efforts to develop a layered network of military satellites in LEO. To streamline the complex process of satellite control, companies like Spire are developing constellation management platforms. These systems aim to automate operations, simplify tasks, and facilitate direct communication with space assets, moving away from the traditional “one-person-one-satellite” approach.

WHY IT MATTERS

The evolution of satellite constellation management is critical to the future of space-based services and infrastructure. As more satellites are launched into space, especially in LEO, the need for efficient, scalable, and automated management solutions becomes more pressing. The integration of AI and machine learning is revolutionizing this field, enabling faster and more accurate decision-making and reducing the reliance on human operators.

Multi-orbit constellations and proliferated LEO networks represent a new frontier in satellite architecture, providing greater resilience, flexibility, and coverage than ever before. These innovations are essential for supporting a wide range of applications, from commercial communications to national security and scientific research.

As space becomes more congested and contested, the development of advanced constellation management platforms and the integration of ground station networks are crucial. These advancements are setting new standards for efficiency and scalability in space operations, and are an integral part of ensuring sustainable and secure satellite services both on Earth and in orbit.

2ND YEAR ON THE LIST

SPACE TELECOMS

WHAT IT IS

The convergence of direct-to-device (D2D) communications, integration with 5G technology, and expanding satellite constellations are transforming the satellite industry. These developments are enhancing global connectivity, bridging digital divides, and creating new market opportunities.

HOW IT WORKS

The race to revolutionize global connectivity through space-based networks is accelerating. Starlink leads with 4 million active users and recently began beta testing its Direct-to-Cell service, enabling satellites to function as orbital cell towers for standard mobile phones. Competitors including Amazon's Project Kuiper, OneWeb, Telesat Lightspeed, Lynk, and AST SpaceMobile are developing their own satellite constellations to expand global broadband access. China has also entered the arena, planning a 13,000-satellite network in response to strategic concerns.

Technical innovation extends beyond traditional satellite communications. Advanced laser relay systems offer faster, more secure data transmission than radio frequencies, while quantum key distribution promises unbreakable encryption for space-based channels. These technologies aren't limited to Earth applications—NASA's Artemis program is leveraging commercial partnerships, including a $57.5 million investment in Nokia, to establish a 4G network on the lunar surface for the Artemis III mission. This convergence of satellite technology, quantum communications, and lunar infrastructure marks a new chapter in telecommunications, promising to bridge Earth's digital divide while enabling humanity's expansion into space.

WHY IT MATTERS

The convergence of satellite and terrestrial networks represents a paradigm shift in how we think about global connectivity. These advancements are set to democratize access to the internet, providing seamless connectivity to remote and underserved areas and enhancing mobile roaming capabilities. For developing regions, this could mean unprecedented access to digital services, educational resources, and economic opportunities.

The integration of 5G with satellite technology further strengthens this impact by enabling high-speed, low-latency connections across vast geographic areas, including those beyond the reach of traditional terrestrial networks. This development is crucial for industries relying on remote operations, such as oil and gas, shipping, and agriculture, where continuous and reliable communication is paramount.

The geopolitical implications of satellite constellations are also significant. As nations like China ramp up their satellite deployments to compete with Western entities, space is becoming an increasingly strategic domain. The race to deploy mega-constellations of satellites underscores the role that space communications will play in national security and global influence in the coming decades.

3RD YEAR ON THE LIST

SPACE TOURISM

WHAT IT IS

Space tourism gives paying customers the opportunity to travel to space for recreational, leisure, or business purposes. This emerging industry aims to make space travel accessible to private citizens rather than just professional astronauts or government-sponsored missions.

HOW IT WORKS

Space tourism is evolving from a futuristic concept to a burgeoning industry. The primary focus of current space tourism ventures is suborbital flights, which are gaining popularity due to their lower costs compared to orbital missions. By 2025, suborbital flights are expected to account for 60% of the space tourism market. The use of reusable spacecraft is significantly reducing costs, with these vehicles expected to make up 50% of commercial space tourism flights this year. AI integration is also on the rise, with more than 25% of space tourism companies projected to utilize AI for customer support, personalized experiences, and flight safety in 2025.

Leading the way in the space tourism industry are SpaceX, Blue Origin, Virgin Galactic, and Boeing. SpaceX targets ultra-wealthy customers for orbital missions and future moon and Mars trips. Blue Origin and Virgin Galactic focus on suborbital flights, offering space experiences to thrill-seekers. Boeing aims for orbital tourism with its Starliner, despite setbacks. There are also emerging companies like World View Enterprises and Zero 2 Infinity, which provide affordable near-space options, such as high-altitude balloon flights. And in an effort to attract tourists while studying movement dynamics in space, the Space Games Federation is developing new sports, like Inno, Spaceball, Shooting Star, and Space Dodgeball, tailored for zero gravity. These efforts could offer valuable insights for future missions.

WHY IT MATTERS

The economic potential of space tourism is substantial. Financial experts at UBS project the industry could reach a value of $4 billion by 2030, underscoring its significance as an emerging market. This growth is likely to attract further investment and drive continued innovation in spacecraft design, propulsion systems, and space infrastructure. Beyond economics, the dawn of space tourism marks a pivotal shift in human space exploration, transforming a domain once reserved for government astronauts into an arena accessible to private citizens and companies. This democratization of space travel is propelled by groundbreaking innovations like reusable spacecraft, significantly reducing costs and expanding accessibility. Space tourism transcends mere thrill-seeking; it serves as a crucial test bed for technologies vital to future deep space missions. The insights gained from commercial flights will be instrumental in developing sustainable life support systems, radiation protection, and long-duration spaceflight capabilities. But the implications of space tourism could go even further: It has the potential to inspire a new generation of scientists, engineers, and explorers, fostering a global culture of innovation and discovery. As more people experience the overview effect—the profound shift in awareness reported by astronauts upon viewing Earth from space—it could lead to increased environmental consciousness and global cooperation.

SCENARIO YEAR 2051

SPACE PIRATES

Space-based biomanufacturing is a cornerstone of the pharmaceutical industry's R&D, and Celestial Pharmaceuticals is at the forefront: The company operates a state-of-the-art facility in low Earth orbit (LEO), leveraging microgravity conditions to produce a revolutionary new opioid impossible to synthesize on Earth.

Reusable rocket technology has dramatically lowered launch costs, democratizing access to space and paving the way for new opportunities—and challenges. Enter the Voiders, a notorious gang of space pirates, who set their sights on intercepting Celestial Pharma's latest shipment during its descent from orbit.

The Voiders launch a spacecraft cleverly disguised as a standard active debris removal system, blending seamlessly into the bustling LEO environment. This craft approaches Celestial's cargo shuttle under the pretense of routine LEO cleanup. As they get close, the pirates execute a sophisticated cyberattack, intercepting telemetry signals that reveal critical details about the shuttle's systems and operations. Armed with this intelligence, they hack into the propulsion system, altering the shuttle's trajectory right after it departs from the orbital factory.

Now under the pirates' control, the unsuspecting Celestial delivery vehicle veers off course. Instead of landing at its secure destination in the Nevada desert, it is redirected to a remote site in the Sonoran Desert, where the Voiders' ground team awaits to complete their audacious heist.

The successful heist represents a pivotal moment in the space economy, compelling both companies and governments to acknowledge the harsh reality of cosmic crime and the urgent need for enhanced security protocols. As the investigation progresses, this incident acts as a wake-up call for the entire industry, igniting a new arms race between space enterprises and the pirates intent on exploiting their vulnerabilities.

SPACE SUSTAINABILITY

Space travel is the preservation of life, a desperate search for new environments, but we cannot escape the responsibility to preserve the one we came from.

Ursula K. Le Guin, “The Dispossessed” (Harper & Row, 1974)

2ND YEAR ON THE LIST

GREEN POWER AND PROPULSION

WHAT IT IS

As the demand for environmental sustainability grows, the space industry is experimenting with green propulsion technologies. These technologies use renewable energy sources or alternative fuels, offering lower emissions and greater efficiency than conventional fossil fuel–based systems.

HOW IT WORKS

Green propulsion represents a significant shift in the space industry's approach to sustainability, focusing on reducing the environmental impact of space exploration through the use of renewable energy sources and safer propellants. Historically, missions have relied on chemical propellants, like hydrazine, which are highly effective but also hazardous to both human health and the environment. Space agencies and companies are now exploring safer, more sustainable alternatives that maintain mission effectiveness while reducing ecological impact. Electric propulsion—using electrical energy to accelerate ions or other propellants—has emerged as a promising green alternative. Hydrogen is another attractive option, particularly in fuel cells for both propulsion and onboard power systems. Companies like Dawn Aerospace are developing systems that use nontoxic propellants such as nitrous oxide and propylene, which are safer to handle and store compared to traditional fuels. ThrustMe's iodine-based propulsion is another innovative solution for small satellites, offering easier storage and handling than conventional propellants, while also driving down costs and enabling system miniaturization. NASA and ESA are driving green propulsion innovation through programs like NASA's "Green Propulsion Technology Roadmap" and ESA's "CleanSpace." These initiatives focus on reducing space exploration's environmental impact by developing cleaner propellants and integrating renewable energy, like solar power, to enhance mission efficiency, longevity, and sustainability.

WHY IT MATTERS

The shift toward green propulsion technologies is more than just a technological advancement; it represents a critical step in ensuring the sustainability of space exploration. As the number of rocket launches and satellite deployments continues to grow, the environmental impact of space activities becomes an increasingly pressing concern. The use of electric propulsion, hydrogen fuel cells, and iodine-based systems provides a more sustainable alternative to conventional fossil fuels, reducing harmful emissions and promoting cleaner space operations. In addition to environmental benefits, green propulsion also offers practical advantages. Electric propulsion and iodine-based systems, for example, enable efficient satellite deployment and orbit changes, enhancing the operational flexibility of satellite constellations. Hydrogen fuel cells provide a reliable power source for lunar bases and deep-space probes, supporting extended missions with minimal environmental impact.

As regulatory pressures increase, space companies may soon be required to adopt green technologies to comply, and investing in these technologies now could prevent future operational slowdowns. By proactively embracing green propulsion, space companies can ensure continued progress while meeting sustainability requirements, positioning themselves ahead of potential regulatory mandates.

1ST YEAR ON THE LIST

REUSABLE ROCKETS

WHAT IT IS

Reusable rockets are *the* revolutionary force in the space industry. By designing rockets that can be launched, landed, and reused multiple times, companies are drastically reducing the cost per launch, enabling more frequent missions, and enhancing the sustainability of space operations.

HOW IT WORKS

Reusable rockets are significantly reducing costs while increasing sustainability and launch frequency. SpaceX continues to dominate and set new standards with Falcon 9 and Starship. In 2024, Starship reached its intended orbital velocity for the first time, marking a crucial milestone toward its operational deployment. With a projected 100-flight lifespan for the Falcon 9, the amortized cost per launch could decrease by 99% compared to expendable alternatives. SpaceX estimates the marginal launch cost could go as low as $10 million, or even $2 million, excluding fixed costs. In October 2024, SpaceX reached another major milestone in rocket reusability by using “chopstick” mechanical arms on its launch tower to catch the Super Heavy booster during Starship’s fifth test flight.

Rocket Lab is another significant player in reusable rockets. The company is developing the Neutron rocket, a medium-lift reusable vehicle slated for its first launch by the end of 2024. Rocket Lab is also making strides with its smaller Electron rocket; the small launcher hit 50 flights faster than any commercial rocket and set a company record with 15 launches in 2024. Recognizing that reusable rockets are key to lowering costs, China is actively advancing this technology. The Shanghai Academy of Spaceflight Technology is developing reusable systems to compete on a global scale. In Japan, Innovative Space Carrier Inc. is collaborating with a US partner to develop a reusable satellite launch rocket, targeting commercial deployment by 2030.

WHY IT MATTERS

By reducing the cost per launch, reusable rockets make space more accessible, enabling a wider range of missions and applications. This accessibility has profound implications for various sectors, from telecommunications and Earth observation to scientific research and space tourism.

Lower launch costs also accelerate the pace of innovation, allowing more frequent launches and rapid iteration of satellite and spacecraft designs. This rapid pace of innovation is essential for advancing new technologies and expanding the capabilities of space assets. For example, the reduced costs associated with reusable rockets could make it economically viable to deploy large constellations of small satellites, providing global broadband coverage, advanced Earth observation capabilities, and enhanced global positioning systems.

Just as important, the sustainability benefits of reusable rockets align with broader environmental goals. By minimizing the number of rockets that need to be manufactured and launched, reusable rockets reduce the environmental impact of space operations, including the carbon footprint associated with rocket production and launch. This sustainability aspect is particularly significant as the space industry grows and the number of launches increases.

1ST YEAR ON THE LIST

NUCLEAR IN SPACE

WHAT IT IS

In space, nuclear energy can be used to generate electricity and propel spacecraft. Nuclear thermal propulsion heats propellant for high thrust and shorter travel times, while nuclear electric propulsion uses electricity for efficient, low-thrust propulsion.

HOW IT WORKS

Unlike nuclear weapons, which are prohibited in space by international treaties, the use of nuclear energy for space exploration is within the bounds of international law. Nuclear propulsion has the potential to dramatically increase the range, speed, and endurance of spacecraft. NASA is at the forefront of these efforts with its Fission Surface Power Project, which aims to develop small nuclear fission reactors capable of generating about 40 kilowatts of power for use on the moon and potentially Mars. These reactors are designed to operate for up to a decade without human intervention, providing a stable energy source for lunar bases. NASA has awarded contracts to companies like Westinghouse to develop nuclear reactor concepts and is also collaborating with DARPA on a nuclear-propelled spacecraft, with a potential launch set for 2025 or 2026. The interest in nuclear power for space is not limited to the US. In 2022, China considered using a nuclear energy source for its base on the moon's south pole, and Russia and China are reportedly planning a joint lunar nuclear reactor, aiming for completion by the mid-2030s. The UK Space Agency has also invested in nuclear technology, awarding Rolls-Royce research funding to develop a lunar nuclear reactor. Meanwhile, ESA is funding studies on nuclear engines for space exploration, underscoring the global interest in leveraging nuclear technology for space applications. The strategic importance of nuclear power in space is clear: It provides a robust and reliable energy source, critical for missions extending beyond Earth's orbit.

WHY IT MATTERS

Nuclear power in space represents not just a technological advancement but a strategic necessity as humanity explores deeper into the cosmos. Nuclear reactors provide consistent, reliable power for lunar bases, enabling operations during long lunar nights and supporting ambitious missions like permanent outposts on the moon and Mars. Additionally, nuclear propulsion can significantly reduce travel times to distant destinations, minimizing human exposure to cosmic radiation during extended missions. Beyond exploration, nuclear propulsion holds implications for space logistics and military operations. Nuclear-powered spacecraft could facilitate efficient on-orbit servicing, refueling, and defense missions. Their ability to operate for extended periods without frequent refueling is crucial for maintaining a strategic presence in cislunar space. Despite its transformative potential, progress in nuclear power for space is often hampered by public perception. Concerns about catastrophic launch failures or uncontrolled re-entries releasing radioactive materials are prevalent, yet the actual probability of such events is low. Modern safety protocols, including activating nuclear systems only after reaching orbit, greatly mitigate these risks. Incidents like the 1978 Kosmos 954 satellite, which scattered radioactive debris, continue to shape public opinion, but advancements in safety measures since then are significant. The fear of nuclear accidents in space often overshadows the genuine benefits, potentially hindering scientific and exploratory progress.

1ST YEAR ON THE LIST

SPACE TRAFFIC MANAGEMENT

WHAT IT IS

As space gets crowded, managing the volume of satellites and debris in orbit has become a critical priority. Space traffic management (STM) combines tracking, collision avoidance, and regulations to ensure safe, sustainable operations, vital for long-term space sustainability.

HOW IT WORKS

Space debris, which includes nonfunctional spacecraft, fragmentation debris from past collisions, and abandoned rocket stages, poses a significant risk to operational satellites and future missions. More than 35,000 pieces of debris are currently tracked in Earth's orbit, and the number continues to grow due to increasing satellite deployments and past collision events. Even small debris pieces traveling at high velocities can cause severe damage to active satellites, resulting in the loss of critical services and more debris.

Several companies and organizations are making progress in space debris monitoring technology. LeoLabs, with its ground-based radar systems, tracks objects in low Earth orbit and has secured more than $20 million in contracts in 2024 to support space domain awareness and STM missions. In Japan, Mitsubishi Electric is building a deep space radar and developing spacecraft with sensors to monitor geostationary orbit traffic. Space Interactions employs digital twin technology and AI to create real-time virtual replicas of satellites and space objects, helping predict and prevent collisions.

In the US, the Office of Space Commerce is developing a civilian-led system, created with private space situational awareness firms, that seeks to take over space object tracking from the military. But effective space traffic management relies on international cooperation and the creation of global standards; while they're a topic of discussion at the United Nations, comprehensive regulations are not yet in place.

WHY IT MATTERS

The importance of space traffic management is underscored by the rapid growth of space activities and the increasing number of satellites and debris in Earth's orbit. As more countries and companies launch satellites for various purposes—from communications and Earth observation to scientific research and space tourism—the potential for collisions and the creation of additional debris grows. This not only poses risks to current space assets but also threatens the future sustainability of space operations. Effective STM is crucial to prevent catastrophic collisions that could render key orbits unusable, a scenario known as the Kessler Syndrome, where collisions generate more debris, leading to a cascading effect of further collisions and debris creation.

As space becomes increasingly congested, clear guidelines and cooperative efforts are essential to maintain order and safety. By enhancing space situational awareness and deploying advanced monitoring and collision avoidance technologies, the industry can mitigate these risks and ensure the safe and sustainable use of space. Space traffic management is not just about preventing collisions—it is about preserving the long-term viability of space as a resource for all humanity.

2ND YEAR ON THE LIST

DEORBITING DEBRIS

WHAT IT IS

Simply monitoring orbital debris is not enough—we also need to come up with technology to deorbit existing debris and make plans and protocols for deorbiting future space assets. Deorbiting existing debris is difficult and most efforts today are early stage and experimental.

HOW IT WORKS

The proliferation of satellites and space debris in Earth's orbit has heightened the urgency for effective mitigation and removal strategies. These efforts focus on managing end-of-life satellite disposal, removing existing debris, extending satellite lifespans, and ensuring sustainable space activities. Planned satellite disposal is a key aspect of debris mitigation, involving either moving satellites to "graveyard" orbits or facilitating atmospheric reentry. The Aerospace Corporation's Deorbit Motor is designed for this purpose, rapidly lowering satellite orbits to induce atmospheric burn-up. Companies like Astroscale, ClearSpace, and Spaceway are developing robotic systems for active debris removal. Astroscale's ADRAS-J mission, part of JAXA's CRD2 project, recently demonstrated successful debris imaging capabilities. ClearSpace, backed by ESA, is preparing for its ClearSpace-1 mission in 2026, aiming to capture and deorbit a small rocket part. NASA has proposed a "laser nudging" technique using high-powered, ground-based lasers to alter debris orbits by ablating part of a debris object's surface to generate thrust and modify its trajectory. In fall 2024, NASA introduced the Small Spacecraft Propulsion and Inspection Capability mission, featuring Starfish Space's Otter spacecraft, which will inspect several decommissioned US satellites to gather data that could support future deorbiting missions.

WHY IT MATTERS

Deorbiting space junk is vital for maintaining a sustainable and safe space environment. The proliferation of space debris poses a significant threat to active satellites, space stations, and future missions. Collisions with debris can damage or destroy valuable space assets, disrupt essential services such as GPS and communications, and create further debris, exacerbating the problem.

Despite advancements, significant challenges remain, including the high costs of developing and deploying debris removal systems and the technical difficulties in capturing smaller, often untracked debris fragments, which pose considerable risks to operational satellites and space stations. However, emerging technologies like laser-based solutions, robotic debris removal, and deorbit motors offer innovative approaches to tackling this challenge. By developing and deploying these technologies, the space industry can reduce the risk of collisions, protect vital space infrastructure, and extend the operational life of satellites, ensuring that orbits remain viable for future exploration and utilization.

As space activities increase, including plans for mega-constellations of satellites, the need for effective debris mitigation becomes even more critical. Without proactive measures, the growing congestion in space could lead to a situation where certain orbits become unusable due to the high risk of collisions, limiting the potential for scientific discovery, commercial ventures, and international cooperation in space.

1ST YEAR ON THE LIST

SPACE-BASED SOLAR POWER (SBSP)

WHAT IT IS

SBSP is a concept designed to collect solar energy in space and transmit it to Earth as a clean, renewable energy source. As the demand for clean energy grows, especially with the rise of AI workloads and geopolitical pressures, SBSP has gained renewed attention.

HOW IT WORKS

By using large panels in geostationary orbit, SBSP systems are unaffected by weather or night-day cycles, and constantly collect solar energy. This energy is converted to electricity and beamed to Earth via microwaves or lasers, where a ground-based rectenna converts it back to usable electricity. While still in early development, several countries and organizations are actively working on transforming the concept into reality. In 2023, Caltech's Space Solar Power Demonstrator successfully transmitted power wirelessly in space for the first time, marking a significant technological breakthrough. Japan is preparing a small demonstration to transmit 1 kilowatt of power in 2025, while China aims to put a pilot 10-megawatt power plant into orbit by 2035. A 2024 report from NASA's Office of Technology, Policy, and Strategy examines the feasibility of an SBSP system by 2050, noting that while SBSP would be more expensive than terrestrial alternatives, costs could drop if certain technological gaps are bridged. NASA is already working on technologies for its missions that could indirectly benefit SBSP development. In the private sector, companies like Northrop Grumman have collaborated with government agencies on SBSP concepts. A startup, Aetherflux, founded by Robinhood co-founder Baiju Bhatt, is taking a different approach by using a constellation of smaller satellites in low Earth orbit. These satellites, equipped with solar arrays and lasers, aim to accumulate energy on a large scale by transmitting it down to Earth.

WHY IT MATTERS

SBSP has the potential to revolutionize the global energy supply by providing a virtually limitless source of clean energy. If fully developed, it could significantly reduce our reliance on fossil fuels, helping combat climate change and reducing greenhouse gas emissions. SBSP's ability to provide continuous, uninterrupted power—unaffected by night, weather, or seasonal changes—sets it apart from terrestrial solar energy, offering a more stable energy supply. Additionally, SBSP could play a crucial role in powering future space missions, including habitats on the moon, Mars, and beyond. By harnessing solar energy in space, where sunlight is more intense, SBSP can deliver more efficient energy capture and transmission. While still in its theoretical stages, advancements in space technology, energy storage, and launch systems bring the concept closer to reality. Significant hurdles remain. Critics highlight the inefficiency of energy transmission from space to Earth, particularly the conversion process from solar energy to microwaves or lasers and back to electricity. Overcoming these challenges will require substantial research and development, as well as strong political backing. The questions are: Is the renewed interest in SBSP a substantive shift to viable development, or merely another cycle of hype? To what extent do current political and investment climates genuinely support overcoming SBSP's long standing technical challenges? And given the technological hurdles and potential benefits, what critical milestones would signal SBSP's transition from theoretical concept to practical energy solution?

3RD YEAR ON THE LIST

OFF-PLANET RESOURCE PRODUCTION

WHAT IT IS

Off-planet resource production, or in-situ resource utilization (ISRU), involves extracting, processing, and using resources found on celestial bodies like the moon or Mars. It is essential for sustainable long-term habitation and deep space exploration.

HOW IT WORKS

Both NASA and the European Space Agency are actively developing ISRU technologies. On the moon, initiatives like the Lunar Surface Innovation Initiative are working on power generation, management, and storage solutions. One notable project is the Lunar Vertical Solar Array Technology, designed to provide continuous power in the challenging lunar environment. Additionally, the Polar Resources Ice Mining Experiment-1 aims to assess volatile content and water presence at the lunar poles.

For Mars exploration, NASA is integrating ISRU systems into its Mars Pathfinder Mission, focusing on atmospheric and soil processing to produce essential resources like hydrogen and oxygen. These technologies are vital for creating fuel, oxygen, and water on-site, significantly reducing the need for resupply missions from Earth.

Private companies are also contributing to ISRU advancements. Israeli startup Helios has developed a Molten Regolith Electrolysis reactor to extract oxygen and metals from lunar and Martian surfaces. NASA has awarded contracts to companies like Blue Origin, Astrobotic Technology, and Redwire for various ISRU-related projects, including power generation and manufacturing using lunar resources.

WHY IT MATTERS

ISRU is vital for establishing a sustainable human presence on the moon and Mars by reducing reliance on costly Earth-based supply chains. By utilizing local resources, space agencies can significantly lower mission expenses and enable longer, more ambitious missions. Even with cost savings from reusable rockets, launch costs remain high. Accessing resources directly on the moon or Mars can further cut expenses and logistical challenges, making self-sustaining colonies more attainable. Beyond basic survival needs like water and oxygen, ISRU supports the creation of essential infrastructure, shelters, and industrial capabilities for long-term habitation.

This capability not only cuts costs but also promotes sustainability by minimizing the need for continuous resupply from Earth, thereby reducing the environmental impact of frequent launches. ISRU can also help Earth by decreasing the demand for materials extracted from our planet. Additionally, developing and refining ISRU techniques can teach us how to use Earth's resources more efficiently, fostering approaches to resource management and sustainability. ISRU is a strategic necessity for human space exploration, enabling the production of fuel and vital consumables for life support and return missions, which are critical for establishing lunar and Martian bases. These bases can serve as essential stepping stones for future exploration deeper into space, contributing to the sustainable use of both space and Earth resources.

SCENARIO YEAR 2040

THE SPONTANEOUS ORDER EXPERIMENT

As plans for the first permanent Mars settlement take shape, a consortium of space agencies and tech companies launches Project Ares, an ambitious experiment to test the limits of spontaneous order in extreme conditions.

Project Ares is a massive multiplayer online simulation that replicates the harsh realities of Martian colonization. The game world mirrors the physical constraints of Mars: limited resources, extreme temperatures, and radiation hazards. Participants from around the world are invited to join, each taking on the role of a Mars colonist. Players must self-organize, create their own rules, and solve conflicts without external intervention. The only constraints are the physical laws of the simulated Martian environment. As the simulation progresses, fascinating patterns emerge. Players self-organize into specialized roles, develop innovative solutions to resource scarcity, and create complex social structures. However, the simulation also reveals critical failures.

As the simulation concludes, researchers dissect the data, mapping the triumphs and pitfalls of this grand experiment in spontaneous order. They distill these insights into a blueprint, translating the most resilient emergent structures and ingenious solutions from the virtual Mars directly into the architectural and social framework of the impending real-world colony. The blueprint also incorporates safeguards against the failures observed in the simulation.

As the first real Mars colonists prepare for their journey, they train extensively in a final version of the Project Ares simulation. This allows them to familiarize themselves with the emergent systems they'll be using on Mars and to internalize the lessons learned from the virtual experiment. The Mars colony, when finally established, becomes a testament to the power of spontaneous order, tempered by the hard-won wisdom gained from virtual trial and error.

ORIGINS OF A MULTI-PLANETARY SPECIES

If your vision is for a year, plant wheat. If your vision is for 10 years, plant trees. If your vision is for a lifetime, plant people.

Chinese proverb

1ST YEAR ON THE LIST

PRIVATIZED PRESENCE IN LEO

WHAT IT IS

As the ISS approaches decommissioning, NASA is shifting its focus toward transitioning its low Earth orbit (LEO) operations to the private sector, fostering a new era where private companies take the lead in human spaceflight and orbital research.

HOW IT WORKS

Human activity in LEO is in a period of transformation as the ISS era winds down, marked by both setbacks and progress. A key 2024 event was Boeing's Starliner mission, which encountered thruster issues and helium leaks after its June launch. Deemed too risky for a crewed return, NASA has tasked SpaceX with returning astronauts Butch Wilmore and Suni Williams from the ISS this year.

Despite challenges, the commercialization of LEO is progressing quickly. The ISS, a hub of international collaboration for nearly 30 years, is nearing the end of its service. While NASA considers extending its operations beyond 2030 to maintain human presence, it is also preparing to shift its roles to commercial space stations. Companies like Axiom, Blue Origin, Voyager Space, and Vast are at the forefront, with projects like Vast's Haven-1 launching in 2025 and Axiom's first module in 2026. Blue Origin's Orbital Reef and Voyager's Starlab are also in the works. NASA is supporting these initiatives to ensure a smooth transition to private-sector leadership in LEO as the ISS retires. The Polaris Program, initiated by SpaceX, represents another leap in human spaceflight. The first mission, Polaris Dawn, will launch aboard a Falcon 9 rocket, targeting the highest Earth orbit ever reached by a Dragon spacecraft. During the mission, the crew will perform a spacewalk and demonstrate Starlink's laser-based communications technology in space for the first time.

WHY IT MATTERS

The current developments in LEO—notably, Boeing's setback and SpaceX stepping in to fill the gap—are shaping the future of human space exploration. The issues with the Starliner illustrate the challenges in developing reliable, autonomous spacecraft capable of safely ferrying astronauts to and from space. And the industry's increasing reliance on SpaceX and other companies for space transportation could have significant implications for the future of space policy and commercial partnerships.

The rise of commercial space stations represents a fundamental shift in how humans will live and work in LEO. These private stations will serve as new hubs for scientific research, technology testing, and international cooperation. They will provide continuity for LEO activities after the ISS is retired, ensuring that the unique environment of microgravity remains available for scientific and commercial pursuits. The transition to commercial space stations aligns with NASA's broader strategy of focusing on deep-space exploration while leveraging the private sector's capabilities for LEO missions. This approach is designed to foster innovation, reduce costs, and accelerate the pace of discovery. As a result, LEO is increasingly seen as a stepping stone for future missions to the moon, Mars, and beyond, where technologies and systems tested in the relatively safe environment of LEO will be critical for success in more challenging deep-space environments.

2ND YEAR ON THE LIST

MOONSHOTS: PRIVATE VENTURES ON THE MOON

WHAT IT IS

Several private companies are actively pursuing lunar missions, marking a new era of commercial involvement in lunar exploration. These entrepreneurial ventures are not just supporting human missions to the moon; they are laying the groundwork for a sustainable lunar economy.

HOW IT WORKS

NASA's Commercial Lunar Payload Services (CLPS) initiative has opened the door for American companies to collaborate in delivering science and technology payloads to the moon. Through CLPS, companies bid to transport payloads for NASA; these commercial deliveries conduct experiments, test technologies, and demonstrate capabilities that will aid NASA's lunar exploration in preparation for future human missions. CLPS contracts have a maximum value of $2.6 billion through 2028, providing significant opportunities for the private sector.

One of the notable successes in commercial moon ventures is Intuitive Machines (IM), which secured a $116.9 million contract to deliver scientific payloads to the moon's south pole. Its first mission in February 2024 marked the first successful American landing on the moon since 1972 and the first by a private company. IM plans additional missions, including IM-2 in 2024 and IM-3 in 2025, which will explore unique lunar features. Beyond transportation, other private ventures are looking to tap into lunar resources: Startup Starpath Robotics is focused on lunar resource extraction infrastructure, while Lunar Outpost, collaborating with Castrol, is preparing its Lunar Voyage 1 mission to deploy a rover near the moon's south pole.

Meanwhile, the ESA has launched a space resources accelerator to focus on resource extraction and operational technologies that will enable sustainable human presence on the moon.

WHY IT MATTERS

NASA, ESA, and other space agencies are facing mounting budgetary pressures, especially with ambitious programs like Artemis. While the enormous costs of these missions already strain financial resources, a deeper challenge lies in the bureaucratic inefficiencies that often accompany government-led operations. These inefficiencies diminish the effectiveness of each dollar spent, raising concerns about whether governments can achieve and maintain a permanent lunar presence solely through public funding. Without addressing these structural issues, the vision of a sustained lunar foothold may remain financially unsustainable under current government frameworks.

This challenge highlights the crucial role that market forces and the expanding commercial space sector will play in building a sustainable cis-lunar economy. Programs like CLPS are transforming space exploration by integrating a diverse range of companies. From startups like Starpath to established players like Intuitive Machines and SpaceX, these companies compete for contracts, fostering innovation and driving down costs in critical areas such as lunar landers, rovers, and resource extraction systems. This competitive approach not only eases the financial strain on government agencies but also accelerates technological progress. As costs decrease, the moon becomes more accessible, paving the way for it to evolve into a profitable economic zone, moving beyond reliance on government-subsidized missions.

2ND YEAR ON THE LIST

SEARCH FOR NEAR-BY LIFE

WHAT IT IS

NASA's Europa Clipper and other 2024 missions aim to uncover clues about extraterrestrial life by exploring celestial bodies believed to have conditions suitable for life, including Jupiter's moon Europa, Mars' moons, and the lunar south pole.

HOW IT WORKS

The quest to find life beyond Earth is intensifying with multiple high-profile space missions scheduled for 2024. Among the most anticipated is NASA's Europa Clipper mission, set to launch in October 2024. This mission targets Jupiter's moon Europa, one of the most promising candidates for hosting extraterrestrial life due to its subsurface ocean, which lies beneath a thick icy shell. Scientists believe that the interaction between this ocean and the moon's rocky mantle could create conditions favorable for life, akin to hydrothermal vents on Earth's ocean floor.

Europa Clipper will conduct nearly 50 flybys of Europa, using a suite of sophisticated instruments to study its icy crust, surface geology, and subsurface ocean. Key objectives include determining the thickness of Europa's ice shell, the salinity and depth of its ocean, and whether the moon's surface has any direct contact with the ocean beneath. This data will help ascertain if Europa has the necessary chemical energy and ingredients to support life.

In parallel, other missions are also contributing to the search for life. The Hera mission, led by the ESA, will investigate the Didymos-Dimorphos asteroid system to assess its composition and the presence of organic molecules. Meanwhile, Japan's Martian Moon eXploration (MMX) mission will study Mars' moons, Phobos and Deimos, to understand their origins and search for signs of past life or organics. Both missions will provide crucial insights into the broader search for extraterrestrial life in our solar system.

WHY IT MATTERS

The search for extraterrestrial life holds profound significance for science, philosophy, and our understanding of humanity's place in the universe. Discovering even microbial life beyond Earth would fundamentally alter our understanding of biology and the potential for life across the cosmos. The Europa Clipper mission is crucial in this quest, as Europa's subsurface ocean is one of the most promising locations in our solar system to find life. If life exists on this moon, it would have evolved in isolation for billions of years, providing a unique chance to study a second genesis.

These missions will shape future exploration efforts, including potential sample return missions from Europa or Mars' moons. They also drive advancements in planetary science, astrobiology, and the technologies needed to explore extreme environments on Earth and in space. Insights into Europa's habitability could refine our search criteria for exoplanets orbiting distant stars.

But there are challenges: The cancellation of the VIPER mission, which aimed to search for water ice at the moon's south pole, underscores the hurdles space exploration programs face, such as budget constraints and technical setbacks.

2ND YEAR ON THE LIST

SEARCH FOR FAR-OFF LIFE

WHAT IT IS

Earth is teeming with life—from weeds growing in pavement cracks to organisms thriving in the extreme heat of deep-sea thermal vents. So why haven't we found life elsewhere? Discovering even the most basic life-forms on distant exoplanets would suggest that Earth is not a unique exception in the universe.

HOW IT WORKS

The search for extraterrestrial life is entering an exciting new era, driven by cutting-edge technologies. NASA's proposed Habitable Worlds Observatory (HWO) represents a significant leap forward in this quest. Described as a "Super Hubble," this space telescope is designed specifically to directly image and analyze Earth-sized exoplanets. With its large mirror and advanced optics, HWO will be capable of scrutinizing the atmospheres of distant worlds for potential biosignatures, marking a new chapter in our search for life beyond Earth.

Meanwhile, the James Webb Space Telescope has already made groundbreaking discoveries, such as detecting methane and carbon dioxide in the atmosphere of K2-18 b, a potential "Hycean" world. This finding, along with a possible detection of dimethyl sulfide (a molecule typically associated with life on Earth), has expanded our understanding of habitable environments and broadened the scope of our search.

Artificial intelligence is also playing an increasingly crucial role in this cosmic quest. Intelligent swarm robotics could explore terrestrial and aquatic environments on distant planets, while autonomous "artificial astronauts" could manage resources and undertake planetary engineering, essential for establishing human settlements. These AI-driven approaches could enable more thorough and efficient searches across vast cosmic terrains.

WHY IT MATTERS

Searching for life beyond Earth began in earnest in 1960 with Frank Drake's Project Ozma, which used radio telescopes at the National Radio Astronomy Observatory. This effort aimed to detect radio signals from nearby stars, marking the birth of the Search for Extraterrestrial Intelligence (SETI) program. Since then, the technology powering the search has advanced dramatically. The development of HWO and advancements in AI technologies represent a significant shift in our approach to finding life beyond Earth. These innovations focus not only on detecting distant planets but also on analyzing their atmospheres and potential habitability, which could redefine where life might exist in the universe. The potential to detect biosignatures on exoplanets like K2-18 b could provide the first evidence of life beyond Earth. AI-driven technologies enhance our capabilities to explore environments previously considered inaccessible or too dangerous for human or traditional robotic missions. Swarm robots and AI-powered systems could autonomously perform complex tasks in extreme conditions.

Despite advancements, the universe still appears lonely. Discovering even the simplest form of alien life—like a single-celled organism—would be groundbreaking. It would prove that life can emerge elsewhere, reshaping our understanding of biology and existence. In science fiction, such a discovery often unites humanity, and while we haven't found proof of extraterrestrial life yet, even the faintest hint of life beyond Earth could inspire a profound shift in how we see ourselves and our future.

2ND YEAR ON THE LIST

MOON, THEN MARS

WHAT IT IS

NASA's Artemis program, through its "Moon to Mars" initiative, aims to establish a sustainable lunar presence, using the moon as a proving ground and jumping off point for technologies crucial for future Mars missions. China and Russia—both with their own lunar ambitions—are mirroring this strategy.

HOW IT WORKS

To coordinate these efforts, NASA created the "Moon to Mars" office, which synchronizes the development of technologies and strategies for both lunar and Martian missions. The moon serves as a proving ground for equipment and habitats destined for Mars, allowing for testing and refinement in a more accessible environment. Artemis II, the program's first crewed mission, will test deep space exploration capabilities, including the Space Launch System rocket and Orion spacecraft, during a 10-day journey with astronauts.

International collaboration is key, with 29 countries signing the Artemis Accords to support a sustained lunar presence and share the costs and risks of space exploration. Competing with the US-led efforts, China and Russia are pursuing their own lunar goals, including plans for a lunar base by 2036. Meanwhile, various landers and rovers, such as the US-built Odysseus and Japan's Smart Lander, are already demonstrating the ability to land and operate on the lunar surface, although challenges remain. As both NASA and international partners continue to develop lunar infrastructure, these efforts lay the groundwork for extended human exploration of the moon and beyond, ultimately preparing for missions to Mars and deeper into the solar system.

WHY IT MATTERS

The moon is not just a destination but a critical staging ground for future Mars missions, and establishing a sustainable presence there allows for the testing and refinement of technologies in a relatively accessible environment. The moon's proximity to Earth provides a manageable setting for trialing human habitats, life support systems, and other technologies crucial for longer missions to Mars. Lessons learned from lunar operations will directly inform and improve the planning and execution of Mars missions.

Additionally, the international dimension of lunar exploration underlines the geopolitical significance of space. NASA's Artemis program, through the Artemis Accords, aims to foster a cooperative framework for lunar and Martian exploration. This collaborative approach contrasts with the competitive stance of China and Russia, which seek to establish their own lunar research base. This rivalry could shape future space policy, influence international alliances, and determine the trajectory of human presence beyond Earth.

The competition for lunar dominance underscores the importance of technological innovation, international collaboration, and strategic foresight in shaping the future of space exploration. The success of Artemis II and subsequent missions will be critical in demonstrating the viability of a sustainable human presence on the moon and set the stage for the next giant leap to Mars.

3RD YEAR ON THE LIST

SPACE HABITATS AND COLONIZATION

WHAT IT IS

The next lunar landing is aimed at establishing a long-term presence. Sustaining human life off-planet requires building space habitats to shield us from the harsh conditions of space. Plans are in motion to utilize local resources for this purpose.

HOW IT WORKS

Space habitats represent the next frontier in human exploration, offering solutions for a long-term presence on celestial bodies like the moon and Mars. Innovative projects from institutions like MIT are pushing the boundaries of what's possible. The "Rocket Horizon" concept proposes repurposing spent spacecraft, such as SpaceX's Starship HLS, into lunar habitats. This approach maximizes resource utilization by transforming the rocket's interior into living and research spaces, while using lunar regolith for radiation shielding. Another MIT project, the Inflatable Lunar Habitat, is designed as a temporary shelter that can be deployed in minutes and offers life support, communication and supplies in emergencies. Additionally, plans are underway to use existing lunar and Martian geostructures, such as lava tubes, as natural habitats to protect against radiation and extreme temperatures.

NASA's Artemis program aims to build a permanent lunar outpost, known as the Artemis Base Camp, near the lunar south pole to access water ice deposits. The base camp will feature pressurized and unpressurized rovers, nuclear power systems, and a large Foundation Surface Habitat where astronauts can live for extended periods. China's plans for lunar habitats include the International Lunar Research Station, to be constructed in phases, with the comprehensive facility finished by 2045. China also plans to use 3D printing and bricks made from lunar regolith for construction, with designs like the egg-shaped "Lunar Pot Vessel" and robots potentially assisting in construction tasks.

WHY IT MATTERS

Expanding human presence to the moon and Mars is a significant challenge that involves creating sustainable habitats for extreme environments. The moon's lack of atmosphere offers no protection from temperature swings, solar radiation, or micrometeorite impacts. Mars, despite its thicker atmosphere, poses threats from intense radiation, frequent dust storms, and its carbon dioxide-rich, unbreathable atmosphere.

Building habitable structures on these celestial bodies requires innovative solutions and advanced technologies. Habitats must be airtight and feature life support systems to provide breathable air, regulate temperature, and protect against harmful radiation. Eventually, established habitats could evolve into multifaceted facilities, serving as research stations, commercial hubs, and even economic zones. Private entities might lease space or resources, drawing parallels to free trade zones on Earth. This will drive the demand for cutting-edge materials, precision engineering, and sophisticated robotics—and could further spur investment and innovation in space technologies.

This journey to establish permanent human presence on the moon and Mars not only pushes the boundaries of our technological capabilities but also opens up new frontiers for scientific discovery, economic growth, and human achievement. It represents a complex, interdisciplinary endeavor that will reshape industries on Earth while paving the way for humanity's expansion into the solar system.

1ST YEAR ON THE LIST

THE LUNAR CARGO AND MOBILITY GAP

WHAT IT IS

The need for reliable transportation of cargo and assets on the lunar surface is critical for NASA's Artemis program and future Mars missions. Addressing current capability gaps will be crucial for establishing a sustainable lunar presence and leveraging the moon as a testing ground for advanced technologies.

HOW IT WORKS

Along with the Artemis program's efforts to establish a sustainable human presence on the moon, there is a growing need for effective cargo transportation and mobility solutions on the lunar surface. The "Moon to Mars" office within NASA is spearheading efforts to coordinate exploration activities, using the moon as a testbed for technologies and systems designed for Mars.

The Artemis II mission will be a significant step in testing the deep space exploration capabilities of the Space Launch System rocket and the Orion spacecraft. However, a critical aspect of these missions is the ability to transport cargo from landing sites to operational areas on the lunar surface. Existing landers can only handle small to medium-size payloads, and NASA has identified a capability gap for delivering cargo in the range of 500 to 12,000 kilograms.

To bridge this gap, NASA has awarded contracts to several companies for developing lunar terrain vehicles (LTVs) and cargo landers. These vehicles, such as the next-generation LTV led by the Lunar Dawn team and the moon RACER by Intuitive Machines, are designed to enhance the range and capabilities of lunar mobility, enabling astronauts to conduct science missions farther from their landing sites. These vehicles will also support commercial services, contributing to a sustainable cislunar economy. Each team is tasked with conducting feasibility studies and developing prototypes to meet the unique challenges of the lunar environment, such as extreme temperatures, dust, and low gravity.

WHY IT MATTERS

To establish bases on the moon and Mars, we must first develop reliable methods for transporting cargo across these surfaces. Most of the current lunar landers are not well-suited to carry midsize payloads, and developing new cargo transport systems is essential to fill this gap and support logistics and equipment delivery. Enhanced mobility will allow astronauts and equipment to access a broader range of lunar regions for research and resource prospecting. Additionally, advanced cargo and mobility systems will play a key role in the extraction and utilization of lunar resources, potentially reducing dependence on Earth-based supplies and paving the way for more sustainable exploration and settlement efforts.

Establishing bases on the moon is only the first step; achieving strategic dominance will require the ability to navigate the lunar surface and transport resources, particularly between the water-rich south pole and other critical locations. To accomplish this, we must bridge the current gap in lunar cargo and mobility capabilities. Additionally, the moon serves as an ideal testing ground for technologies needed for Mars exploration. Its proximity and relative safety make it a better environment for refining systems that will face even greater challenges on Mars due to its distance. Efficient lunar transport systems will not only support extended missions but also enable broader exploration, facilitate high-priority scientific research, and ensure the logistical flow necessary for long-term lunar and interplanetary operations.

1ST YEAR ON THE LIST

AI SPACE ROBOTS

WHAT IT IS

An AI space robot is a robotic system designed for space exploration that utilizes AI to perform tasks autonomously without human intervention. These robots are equipped with advanced algorithms that make decisions, navigate extraterrestrial environments, and interact with human astronauts.

HOW IT WORKS

AI is playing a pivotal role in advancing the capabilities of space robots, particularly in NASA's Mars missions. One example is the Perseverance rover, which is equipped with the AI-powered PIXL (Planetary Instrument for X-ray Lithochemistry) instrument. Using an AI technique called adaptive sampling, PIXL can autonomously scan rocks on Mars and pinpoint areas of interest without human intervention. This enables it to perform more detailed scans, known as long dwells, in real time, enhancing the precision and efficiency of scientific investigations. In addition to mineral analysis, AI significantly boosts the rovers' autonomous navigation abilities: The AI algorithms handle tasks like obstacle avoidance and path planning without the need for constant human control. This autonomy allows them to explore the Martian surface more effectively, making real-time decisions to avoid hazards and choose optimal routes.

China's Chang'e 6 mission introduced an AI-powered mini-rover, a compact 11-pound vehicle equipped with advanced AI software designed to operate autonomously on the lunar surface. This previously undisclosed rover showcased impressive capabilities in navigation and image capture, utilizing AI to make real-time decisions about its path and positioning, select the best angles for photographs, and send images back to Earth through a fully automated process. This integration of AI technology marks a significant step forward in robotic space exploration, demonstrating how small, autonomous systems can enhance the scope and efficiency of lunar missions.

WHY IT MATTERS

The integration of AI into Mars rovers significantly enhances their operational capabilities, making them more autonomous and effective in exploring the Red Planet. With AI-driven tools like PIXL and adaptive sampling, Perseverance can perform complex mineral analyses without waiting for instructions from Earth, speeding up the discovery process and increasing the mission's scientific output. This is especially crucial for identifying signs of past life or habitable conditions on Mars, one of the primary goals of the mission.

Autonomous navigation systems are equally important, allowing rovers to traverse the Martian terrain safely and efficiently. This capability not only extends the range and duration of the mission but also reduces risks associated with human error and communication delays. By enabling the rovers to make real-time decisions, NASA can focus on higher-level mission planning and data analysis, knowing that routine operations are being handled autonomously.

The use of AI for tasks like crater detection and sample collection further demonstrates its versatility and value in space exploration. AI tools can quickly analyze large datasets, such as images from the Mars Reconnaissance Orbiter, providing timely insights into current Martian conditions and activities. This rapid analysis is invaluable for adjusting mission parameters and strategies in near real time.

2ND YEAR ON THE LIST

UNIVERSE MAPPING

WHAT IT IS

Advancements in astronomical mapping are enhancing our understanding of the universe's structure, expansion, and composition. These initiatives aim to uncover the mysteries of the universe's formation, study its components—including dark matter—and broaden our knowledge of the universe.

HOW IT WORKS

Universe mapping has advanced dramatically. The Dark Energy Spectroscopic Instrument (DESI) has produced the largest 3D map of the universe, encompassing over 6 million galaxies—three times more than previous maps. This extensive mapping enables astronomers to measure the universe's expansion rate more accurately. Additionally, NYU astronomers have created a 3D map of about 1.3 million quasars, covering a large volume of the universe and extending back to when it was just 1.5 billion years old.

Dark matter and dark energy, which constitute 95% of the universe, remain elusive, but new mapping initiatives aim to shed light on these mysteries. The nearly completed Vera C. Rubin Observatory in Chile will conduct the Legacy Survey of Space and Time, capturing images of the Southern Hemisphere's sky every three nights for a decade to map dark matter. The SETI@home project at UC Berkeley uses AI to analyze radio telescope data for signs of extraterrestrial intelligence. Although it no longer sends new data to volunteers, it has compiled a significant database that still holds potential discoveries. Fast radio bursts (FRBs)—brief, intense flashes of radio waves from distant cosmic sources—have also emerged as powerful tools in cosmic cartography. By analyzing how FRBs interact with diffuse gas and dust between galaxies, scientists gain insights into the universe's density, composition, and evolution, revealing otherwise elusive matter and enhancing our understanding of cosmic architecture.

WHY IT MATTERS

These groundbreaking mapping efforts are reshaping our understanding of the universe at multiple levels. The DESI's 3D map allows astronomers to explore the distribution of millions of galaxies and better understand the universe's expansion history. This data is crucial for testing models of cosmology, particularly those concerning dark energy, which remains one of the biggest mysteries in physics.

The quasar catalog adds another layer to this understanding by extending the reach of our cosmic maps back to the universe's early days. Studying the distribution and properties of these ancient, luminous objects provides insights into the formation and evolution of the earliest cosmic structures and the role of supermassive black holes. Dark matter mapping, particularly with the upcoming capabilities of the Vera C. Rubin Observatory, will fill in the gaps left by optical surveys. By understanding dark matter's distribution, astronomers can learn more about the invisible scaffolding that shapes galaxies. AI's application in this field is a leap forward, offering more precise estimates and potentially unveiling new facets of the universe's makeup.

Together, these maps not only enhance our comprehension of the cosmos but also help refine theories on the fundamental forces that govern it, including gravity and the elusive dark energy. They provide critical data that could lead to breakthroughs in understanding the universe's ultimate fate, its origins, and the unseen forces that drive its expansion.

1ST YEAR ON THE LIST

PHYSICAL HEALTH IN SPACE

WHAT IT IS

Physical health in space research focuses on muscle atrophy, bone loss, cardiovascular changes, and radiation effects, while exploring countermeasures such as exercise, nutrition, and protective technologies to maintain astronauts' health during long-duration missions.

HOW IT WORKS

The Space Omics and Medical Atlas (SOMA), released in 2024, is the largest aerospace medicine and space biology data collection, involving over 100 institutions from 25+ countries. It includes extensive molecular, cellular, and physiological data, with key insights from the Inspiration4 mission. SOMA significantly advanced our understanding of human health in space by boosting next-generation sequencing and single-cell data and establishing the CAMbank biobank. It revealed critical information on DNA damage, immune function, and health risks from long-term space exposure. Wearable technologies, like the "Lab on Body" platform, offer solutions to monitor and mitigate space's effects on health. This wearable device tracks human biomarkers from fluids like saliva, using biochemical sensors for both real-time health feedback and long-term studies. Another frontier in physical health research in space is stem cell research, with the Mayo Clinic exploring how microgravity affects mesenchymal stem cells responsible for bone formation. This research is particularly relevant for addressing the bone density loss experienced by astronauts during long-duration missions and holds potential applications for treating osteoporosis on Earth. The Sanford Stem Cell Institute is investigating the impact of space on cancer. Its studies on tumor organoids in microgravity aim to uncover how spaceflight influences cancer stem cell growth. The goal is to identify early markers of cancer development, potentially leading to new diagnostic and treatment strategies applicable both in space and on Earth.

WHY IT MATTERS

Understanding how the human body reacts to the unique conditions of spaceflight is crucial as we embark on longer missions to the moon, Mars, and beyond. Prolonged exposure to microgravity, radiation, and isolated environments poses significant risks to astronaut health, affecting everything from bone density to cognitive function. The findings from these NASA-funded studies could lead to groundbreaking methods to counteract these effects, ensuring safer and more effective space missions.

Moreover, the insights gained are not limited to space travel; they have the potential to revolutionize medical treatments on Earth. For instance, novel therapies for osteoporosis, muscle wasting, and neurodegenerative diseases could emerge from this research, benefiting the aging population and those with chronic conditions. Additionally, developing better psychological support systems and understanding team dynamics in confined spaces could improve how we manage remote work and other Earth-based challenges.

2ND YEAR ON THE LIST

BIOLOGICAL ADAPTATIONS FOR SPACE

WHAT IT IS

By leveraging advances in biotechnology, scientists aim to enhance astronauts' natural resilience to extreme conditions, such as radiation and microgravity, reducing the reliance on external life support systems.

HOW IT WORKS

Biological adaptations in space go beyond simply addressing the physical and mental health concerns of astronauts. With long-term missions in mind, scientists are increasingly focused on how human biology itself can be modified or enhanced to better withstand the extreme conditions of space. One promising area of research is mitochondrial biology. Studies indicate that spaceflight disrupts mitochondrial activity, leading to conditions like Spaceflight Associated Neuro-Ocular Syndrome, which affects vision. Ongoing research on these mechanisms aims to develop effective countermeasures to safeguard astronauts' ocular health during long-duration missions. This research suggests that monitoring and possibly manipulating mitochondrial activity could provide biomarkers for tracking and enhancing astronauts' physiological resilience during extended missions.

Another groundbreaking line of inquiry involves cryptobiosis, a survival mechanism found in tardigrades, microscopic organisms capable of enduring extreme conditions. By entering a state of suspended animation, tardigrades can shut down their biological functions, enabling them to survive harsh environments. Scientists are investigating the possibility of transferring similar survival traits to human biology. This could involve genetic or biochemical interventions to give human cells greater resistance to radiation or the ability to function under severe stress, such as extreme desiccation or oxygen deprivation, which are common challenges in space.

WHY IT MATTERS

A future where humans are biologically adapted to space would dramatically alter mission planning, allowing for more extended periods away from Earth and reducing the weight and complexity of the necessary life support systems. Understanding mitochondrial function in space could also unlock new ways to prevent or mitigate space-induced ailments like muscle atrophy, bone density loss, and cognitive decline, common in microgravity. By identifying mitochondrial activity as a key player, space agencies may develop therapies or preventative measures that enhance energy efficiency and cellular repair processes. Additionally, leveraging cryptobiosis-inspired technologies could revolutionize human space survival. If we can transfer even a fraction of tardigrades' resilience into humans, astronauts would be better equipped to handle catastrophic failures in life support systems or exposure to cosmic radiation. This would not only increase survival rates during missions but also open the door to more ambitious projects, such as permanent colonies on other planets.

These advancements hold promise beyond space travel, as well. Insights gained from studying mitochondrial function and cryptobiosis could yield significant breakthroughs in medicine on Earth, particularly in fields like aging, cancer treatment, and organ preservation.

1ST YEAR ON THE LIST

MENTAL FORTITUDE IN SPACE

WHAT IT IS

Mental health in space research explores the psychological and cognitive challenges astronauts face in microgravity and isolation. The research studies how stress, isolation, and disrupted sleep affects astronauts and tests solutions like adaptive environments, social robotics, and VR.

HOW IT WORKS

Neurocognitive function and mental health are vital concerns for space missions due to the unique challenges astronauts face in microgravity. A study from the SpaceX Inspiration4 mission revealed that astronauts experienced physiological stress and neurovestibular changes, like ocular misalignment, during short-duration space travel. While these effects largely returned to normal after reentry, suggesting minimal long-term risks, the findings highlight the importance of continued research into neurocognitive effects, as they are closely tied to overall mental health in space. MIT is exploring innovative solutions to support astronauts' mental well-being. The Personal Robots in Space project aims to foster social connectivity between astronauts in space and people back on Earth through an embodied social agent that interacts with astronauts in zero gravity. The Mediated Atmospheres in Space project focuses on designing adaptive environments that improve cognitive function by adjusting the atmosphere based on bio-signals. Ongoing experiments aboard the ISS further contribute to our understanding of mental health in space. For instance, Circadian Light tests lighting systems designed to regulate astronauts' daily rhythms, essential for mental well-being. Other projects, like the VR Mental Care initiative by ESA, use VR to promote relaxation, while Crew Earth Observations has shown that photographing Earth can improve astronauts' mental health by connecting them to familiar environments. These efforts are critical for ensuring astronauts are mentally healthy while in space.

WHY IT MATTERS

Understanding and addressing neurocognitive function in space is crucial for the long-term success of space exploration, especially as missions become longer and more ambitious, such as trips to Mars or permanent lunar bases. The mental well-being of astronauts is paramount, as impaired cognitive function could lead to poor decision-making, increased stress, or decreased team coordination. As space travel progresses, sustaining astronaut mental health will not only ensure mission success but also prevent long-term psychological effects post-mission.

The innovations being explored—such as adaptive environments and embodied AI companions—demonstrate the intersection of technology, biology, and human psychology. These advancements have broader implications beyond space exploration. For instance, they could inform designs for stressful environments on Earth, such as submarines, remote military bases, or long-duration isolation conditions. Additionally, the technologies used to monitor and support cognitive function could influence mental health treatments in clinical settings.

Long-term expeditions necessitate a comprehensive approach to human health that includes psychological and neurological considerations. Technologies that mitigate stress and improve mental well-being in space may one day become commonplace in our daily lives, offering new ways to manage stress, enhance cognitive performance, and foster emotional well-being in challenging environments.

2ND YEAR ON THE LIST

SIMULATED SPACE ENVIRONMENTS

WHAT IT IS

Simulated space environments prepare astronauts and researchers for the challenges of space exploration. These controlled environments replicate the conditions of extraterrestrial worlds so scientists can anticipate the physical and psychological hurdles that crews will face during long-duration missions.

HOW IT WORKS

Four volunteers recently spent more than a year inside a 3D-printed habitat, isolated from the outside world at NASA's Johnson Space Center in Houston. Throughout their 378-day stay, they engaged in simulated Mars walks, grew food, and dealt with the limited resources, equipment failures, and communication delays that would occur on a real mission to Mars. The goal was to study how humans cope with the demands of long-term isolation and resource constraints, providing insights for future human expeditions to the Red Planet.

But this isn't the only simulation. At the LUNA facility in Germany, a system called Puppeteer simulates the gravity of the moon and Mars. Using advanced mechanical systems, the technology allows astronauts to train in conditions mimicking the reduced gravity of these environments. This is critical as space agencies and companies prepare for a sustained human presence on the moon and, eventually, Mars.

Virtual reality platforms are also being developed to offer immersive training experiences. Researchers are using high-resolution 3D data of lunar landscapes to create virtual environments that replicate the surface of the moon. For example, experiments in Lanzarote, Spain, where the landscape resembles the moon's volcanic terrain, are capturing topographical and subsurface data to produce highly detailed virtual models. These models can be used to train astronauts for lunar rover missions or even to search for potential human habitats, such as lava tubes on the moon.

WHY IT MATTERS

Simulated space environments are crucial for several reasons. First, they provide a safe and controlled environment to test the physical and psychological demands that humans will face during long-duration space missions. Space missions to the moon, Mars, or beyond involve extended isolation, limited resources, and exposure to extreme conditions. Simulating these environments on Earth allows scientists to observe how humans cope with these stressors, helping to develop strategies that improve crew health and performance. Additionally, these environments help train astronauts in the technical and operational skills needed for space missions. Whether it's practicing spacewalks, maintaining equipment, or growing food, these simulations enable astronauts to rehearse real-life scenarios they will encounter in space.

These virtual simulations also allow for in-depth exploration of extraterrestrial terrains before physically setting foot on them. By creating detailed virtual models of lunar and Martian landscapes, scientists can plan missions, explore potential landing sites, and identify key resources like lava tubes that could be used for habitation. This reduces the risk and uncertainty associated with sending humans to these uncharted territories, and ultimately ensures that astronauts and space missions are better prepared.

2ND YEAR ON THE LIST

OFFICIAL INVESTIGATIONS OF UAPS

WHAT IT IS

Government initiatives to investigate unidentified aerial phenomena (UAP) are picking up pace. Congressional hearings and the creation of official offices mark early moves toward increased transparency and public disclosure, as well as efforts to remove the stigma associated with UAP reporting.

HOW IT WORKS

In February 2024, the US government's All-domain Anomaly Resolution Office (AARO) released the first of two planned public investigation reports on UAPs, historically referred to as UFOs. This comprehensive review analyzed evidence dating back to 1945, incorporating witness interviews and archival research. The report largely attributed UAP sightings to misidentified ordinary objects and phenomena, finding no evidence to support extraterrestrial origins. Then, in March, Pentagon Press Secretary Maj. Gen. Pat Ryder issued a statement reinforcing the lack of verifiable evidence for UFO sightings and denying any government or private access to extraterrestrial technology. Nevertheless, AARO continued to expand its operations throughout 2024, employing over 40 DoD personnel and aiming for full operational capability by September 30. The office focused on investigating UAP reports near military installations and other areas of interest, emphasizing detection, identification, and attribution.

On the legislative front, South Dakota Republican Sen. Mike Rounds proposed the UAP Disclosure Act of 2024 in July, aiming to establish oversight, a review board, and a public disclosure plan for UAP investigations over the next seven years. This would mandate that the federal government acquire ownership of "all recovered UAP materials and any biological evidence of nonhuman intelligence" that has been passed on to private defense contractors. The act has bipartisan support, and reflects a growing political interest in ensuring transparency and accountability in UAP research.

WHY IT MATTERS

For years, UAPs were largely relegated to the margins of social discussion, dismissed as mere conspiracy theories. For over 60 years, the US government has followed an official policy of debunking, ridiculing, and dismissing even the most credible UAP reports, often providing explanations that were unscientific or seemingly absurd. Recently, the conversation around UAPs has gained credibility through congressional hearings, reputable witness accounts, and the establishment of official government offices dedicated to their investigation. This shift from fringe to mainstream is notable, regardless of what these phenomena ultimately prove to be, showing how swiftly a once-taboo topic can gain acceptance. Testimonies from former military officials suggest that UAPs are more than just unusual sightings—they may pose a genuine national security risk whether they are terrestrial in origin or not. The mysterious nature of these objects complicates the military's ability to distinguish between potential threats and harmless entities, a longstanding challenge in defense. The advanced materials and capabilities observed in these UAPs exceed known technology, hinting at either a significant, covert advancement in human engineering or possibly an extraterrestrial origin. As discussions move from sensational headlines to serious governmental inquiry, the demand for greater transparency grows. Efforts to declassify UAP information and consolidate investigations represent a step forward, but the quest to fully understand these perplexing phenomena is only beginning.

SCENARIO YEAR 2050

THE BIRTH OF LUNA RODRIGUEZ

At 10:17 UTC on November 15, 2050, Luna Rodriguez became the first human born off-planet. Weighing just over 6 pounds, Luna was immediately placed in a specially designed incubator to monitor her vital signs and protect her from the unique environmental factors of space.

Luna's mother, 36 weeks pregnant, went into early labor shortly after reaching orbit. Due to the challenges posed by microgravity, a C-section was performed. The procedure took place in a specially designed "surgery bubble"—a transparent, sterile enclosure that contained all necessary equipment and prevented contamination from floating bodily fluids. This bubble featured magnetic surgical tools, fabric fastener strips, and magnetic pads for organizing supplies, a "flypaper" area for suture ends, foam blocks for sharp items, and biohazard containment pockets. A complex restraint system secured the patient, surgeons, and equipment. The mother was fastened to a specialized operating table, while surgeons used waist-level restraints, foot bars, and floor-level tethers for stability and dexterity.

The C-section was complicated by the behavior of organs and fluids in zero gravity, but the carefully designed environment allowed for precise control. Immediately after birth, the baby was placed in a specially designed incubator to monitor vital signs and protect against unique space environmental factors. The medical team closely monitored the newborn for any signs of developmental issues related to microgravity exposure, particularly concerning bone density, muscle development, cardiovascular system adaptation, and visual and vestibular system formation.

The success of the procedure proves that human birth is possible beyond Earth, opening up new possibilities for long-term space habitation. However, it also raised questions about fetal and early childhood development in microgravity, as previous animal studies had shown some abnormalities in fetal development in space. This milestone provided crucial data for future research into space-based reproduction and early childhood development in microgravity environments that could lead to future space colonization efforts.

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HOSPITALITY & RESTAURANTS

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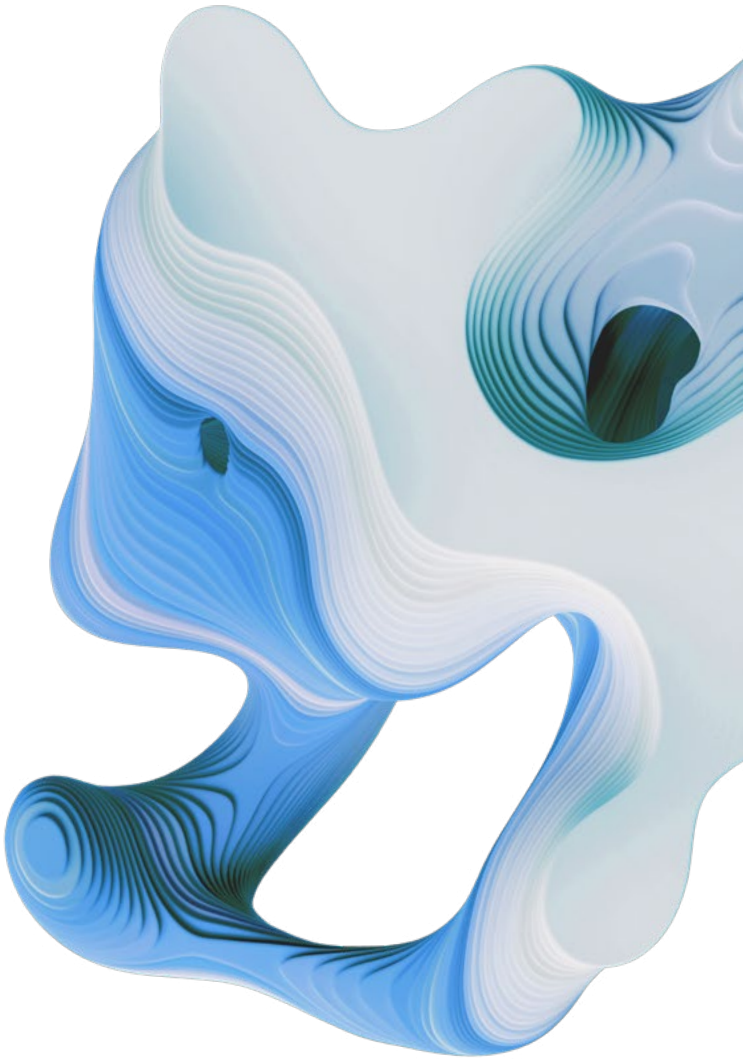


Mark Bryan
Hospitality Lead

Move past the back-of-house and into the future.

The hospitality industry is falling behind. While a few trailblazers are redefining what's possible with bold innovations, much of the sector is struggling to adapt, burdened by rising costs, labor shortages, and waning consumer confidence. This growing divide is holding the industry back at a time when transformation is critical. To move forward, the industry must take bold, collective action to close these gaps and embrace a more agile, innovative future.

This means more than making behind-the-scenes improvements, which are valuable but insufficient to secure guest loyalty. Instead, the solution lies in focusing on visible, guest-facing innovations that create emotional connections and unforgettable experiences. Sustainability is paramount, and businesses that innovate through waste reduction, energy-efficient systems, and regenerative practices will have an advantage. But ultimately, personalization must evolve beyond transactions, to offer meaningful moments that connect guests with the authenticity and culture of their destinations.

In restaurants, this means going beyond a fixed menu to provide a curated tasting based on guest sustainability preferences. For hotels, it goes beyond providing rooms; instead, their curated experiences could immerse guests in local stories and create lasting impressions.

To achieve this industrywide transformation, the pace of progress needs to accelerate. Advanced technologies that help businesses improve their agility—like AI-driven personalization, contactless systems, and seamless guest engagement tools—are no longer optional. Anticipating change, rather than reacting to it, will be the key to sustained success.

Hospitality has always been about creating connections and memories that last. Now, more than ever, the industry must pair those values with bold innovation to build a future that is resilient, vibrant, and inclusive. The time to act is now.

Tech-driven wellness, personalized experiences, and planetary expansions are redefining luxury and innovation.

1

Luxury hotel demand reaches “insatiable” levels globally

High-end properties are experiencing unprecedented occupancy rates and daily revenue growth, particularly in Asia and the Middle East, as affluent travelers seek premium experiences.

2

Sustainability becomes nonnegotiable in hospitality

More than 80% of global hotel chains commit to net-zero carbon emissions by 2050, with guests increasingly choosing eco-friendly accommodations.

3

Labor challenges persist despite industry growth

While the industry is projected to add jobs by the end of 2024, 45% of operators still report needing more employees to meet customer demand.

4

Global hotel industry hits $1 trillion milestone

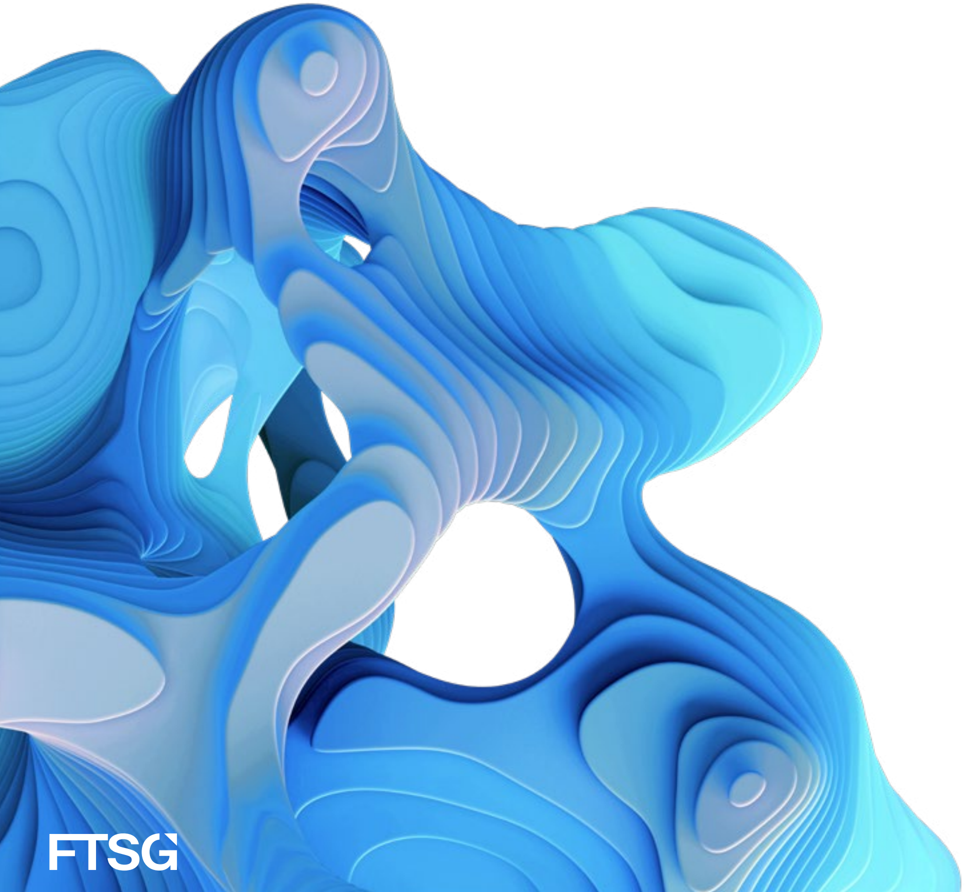
Despite economic challenges, the worldwide hospitality sector achieves record-breaking revenue, driven by pent-up travel demand and increased spending.

5

AI and automation reshape operations

Forty-one percent of restaurants plan to invest in AI technology to improve business forecasting, increase operational efficiency, and enhance customer experiences. At hotels worldwide, AI-driven chatbots handle up to 70% of customer inquiries.

The hospitality industry must move forward as one to overcome pocketed stagnation.



The hospitality industry is facing critical stagnation that threatens its long-term future. Companies have been slow to adapt to changing consumer demands and have struggled to balance growth with sustainability. While some businesses are innovating and thriving, the widening gap between leaders and laggards highlights the urgent need for transformation.

In the hotel sector, recovery remains uneven, with significant variation across regions and property types. Companies that have embraced experiential travel and wellness-focused stays are thriving, as are luxury brands that have expanded aggressively into high-growth regions such as India, Southeast Asia, and the Middle East. And direct bookings have surged, offering operators better control over pricing and deeper customer relationships. But elsewhere, the picture isn’t as rosy. In much of the world, outdated infrastructure and limited innovation in other markets are stifling growth and leaving significant opportunities untapped.

The restaurant sector reflects a similar pattern of divergence. Quick-service and off-premise dining models are booming, driven by the convenience-focused behaviors of modern consumers and the essential role of delivery services. But many operators are struggling to integrate loyalty programs, streamline operations, or meet rising customer expectations. Economic pressures have forced many businesses to adopt creative pricing strategies and rethink their offerings just to stay afloat.

Sustainability has become both an imperative and a challenge. Leading properties are setting the standard by adopting eco-friendly practices, such as energy-efficient systems and regenerative agriculture. However, progress is fragmented and some markets lag behind due to financial and operational constraints. For the industry to meet growing expectations for environmentally conscious options, bridging this gap is essential.

Ultimately, outdated systems and resistance to innovation remain major barriers to progress in both hotels and restaurants. To overcome these challenges, businesses must prioritize targeted investments in infrastructure, streamline operations with advanced technologies, and develop flexible, forward-thinking business models. Agility and adaptability will be key to navigating external pressures, from economic uncertainty to evolving guest behaviors.

A new era dawns with opportunities for location and loyalty.

MAY 2024

Hilton Introduces Modular Construction

By using modular construction for its new Garden Inn in Townsville, Australia, Hilton saved both time and money.

JULY 2024

Robots Offer High-End Spa Services

Combining efficiency with relaxation, Lotte New York Palace's robotic massagers are setting a new bar for spa services.

JULY 2024

Blockchain Revolutionizes Restaurant Loyalty

Blackbird Labs introduces $FLY cryptocurrency rewards for diners checking into participating restaurants.

OCTOBER 2024

Sindalah Island Welcomes Guests

Saudi Arabia's NEOM project transforms a barren island into a luxury destination in the Red Sea.

DECEMBER 2024

Space-Oriented Travel on Earth

Orbite and Accor are partnering on luxury astronaut training experiences in places like Paris, Curaçao, and Antarctica.

« PAST

Top-tier services and guest inputs will evolve through cobot-human-data integration.

FUTURE »

EARLY 2027

Hotel Room Personalization Through AR

Hotel guests will use augmented reality to customize room elements like virtual wallpaper and lighting in real time.

LATE 2028

Robot Concierges Expand to Mid-Tier Hotels

As prices drop, robotic concierge services handling tasks like check-in and room service delivery won't be limited to luxury hotels.

LATE 2029

Restaurants Adopt Edible Packaging

The packaging eliminates waste while introducing unique flavors and textures to complement meals.

EARLY 2032

Biometric and Neural Feedback in Dining

Restaurants will monitor diners' emotional and sensory responses, adjusting taste and texture of meals in real time.

MID 2037

A Food Accessibility Revolution

Autonomous restaurants featuring robot chefs and dynamic menus will provide restaurant-quality food but won't require a fixed location.

Emerging trends offer unique opportunities to reduce costs, while maintaining customer satisfaction and company commitments.

Enhancing Customer Experience

Hospitality trends, such as hyper-personalization and frictionless stays, are in direct response to consumers' increasing expectations for seamless, tailored experiences. These innovations enhance guest satisfaction and loyalty, which are critical for retaining competitive advantages in a crowded marketplace.

Operational Efficiency and Cost Management

When companies integrate automation and smart technologies in hospitality operations, they can help streamline workflows, reduce waste, and optimize resource allocation. For example, AI-driven safety tools and predictive systems can make operations more cost-efficient while maintaining service quality.

Alignment With Sustainability Goals

Sustainability is increasingly interwoven throughout hospitality trends, from predictive systems that minimize energy waste to modular hotels with self-sufficient energy systems. These innovations can both align businesses with global environmental standards and attract eco-conscious travelers.

Adaptability to Market Changes

As the demand for hotels, restaurants, and hospitality experiences evolves, trends like modular and nomadic buildings allow businesses to rapidly adapt to changing market demands and geographic opportunities. This flexibility helps businesses stay resilient against economic fluctuations and infrastructure limitations.

Staying Competitive in a Tech-Driven World

Consumers now expect technology to anchor their experiences; in this environment, businesses that fail to integrate augmented technologies or automation risk being outpaced by competitors. The ongoing evolution of customer needs makes these advancements a necessity for growth and survival in the digital era.

Focusing on the Right Data

New systems and embedded technologies generate vast amounts of actionable data. By preparing for these innovations, hospitality and restaurant businesses can gain deeper insights into which data is relevant. This will help them to understand customer behavior and preferences both now and in the future.

These individuals are at the forefront of development and transformation in the hospitality and restaurant industry.

- **Robert Macrae, lead for Dynamic Interaction: Generative AI at SoundHound,** for their work on managing voice recognition with multiple users.
- **Dr. Yiming Liu, researcher at City University of Hong Kong,** for their work on creating lickable devices.
- **Dr. Laia Domingo, chief science officer, Ingenii,** for their work on quantum computing applications to monitor food waste.
- **David Nussbaum, CEO of Proto,** for their work on holographic concierge in hotel rooms.
- **Yang Yong, CEO at Nanjing JuYun Intelligence Information Technology Co.,** for their work on tracking fabric and linen usage in hotels using RFID tags.
- **Jolie Fleming, chief product and technology officer at InterContinental Hotels Group,** for their AI-powered trip planner.
- **Fatima Nasser, founder of Yummy,** for expanding the homemade meal delivery app service into Benghazi, Libya.
- **Speed Bancroft, founder and CEO of Speedy Eats,** for the launch of their first unmanned drive-thru.
- **Dr. Kevin Verstrepen, professor in genetics and genomics at Leuven University and codirector of the Leuven Institute for Beer Research,** for their work in using AI to improve the taste of beer.
- **Dr. Vayu Hill-Maini, assistant professor at Stanford University's Department of Bioengineering,** for their work on improving the taste and nutrition of edible mycelium.
- **Dr. Pasi Vainikka, cofounder and CEO of Solar Foods,** for their work on developing a new edible protein from electricity and carbon dioxide.
- **Alfonso de Gaetano, founder and CEO of Curated,** for their work on offering immersive wine experiences.

Technology that empowers with smarter personalization, efficiency, and transparency...

OPPORTUNITIES

Customized Hotel Fees

Hotels that introduce dynamic pricing for in-room amenities and experiences will give guests the ability to pay only for the features they use, such as enhanced room functionalities, virtual reality entertainment, or wellness add-ons.

Embedded Health and Safety

AI-driven monitoring systems are more discreet than ever, and companies can employ them strategically. In high-touch areas, this technology can ensure health and safety without intrusive measures, to blend guest comfort with operational vigilance.

Produce Provenance

Food producers and distributors can implement blockchain to certify the nutritional authenticity of engineered foods, giving consumers greater confidence in synthetic or lab-grown options.

Recipe Flexibility

In personal and professional kitchens, AI can recommend alternative sustainable ingredients in real time for recipes, ensuring consistent flavors while promoting eco-consciousness.

...must be balanced to protect privacy, maintain trust, and preserve human expertise.

THREATS

Privacy Concerns from Personalization

A heavy dependence on AI over-personalization in loyalty programs risks crossing privacy boundaries, leading to regulatory scrutiny or consumer trust erosion as brands increasingly monetize user data.

Consumer Adoption and Trust

Consumer mistrust of genetically engineered foods or lab-grown ingredients could hinder adoption, fueled by misinformation or cultural resistance to artificial innovations.

Workforce and Community Impacts

Overreliance on automation could reduce job opportunities, leading to tension between businesses and local communities dependent on traditional employment.

Cyber Breach Risk

The interconnected nature of optimized management systems creates attractive targets for hackers, potentially compromising sensitive operational data.

AI-driven operations, eco-efficient management, and advanced security systems are requirements for resilience, profitability, and trust in a rapidly evolving world.

Expand eco-friendly amenities by implementing attribute-based booking and gamified options so guests can curate stays that align with their values. This approach enhances engagement, incentivizes sustainable choices, and increases ancillary revenue.

Use biometric data from wearables or in-room sensors to offer tailored wellness recommendations, from curated spa treatments to personalized meal plans. This could evolve into premium wellness packages or subscription services tied to health analytics.

Invest in smart resource management and predictive maintenance tools to overcome the outdated infrastructure and technological systems that are common in the hospitality and restaurant industry.

Prioritize robust cybersecurity measures. With the rise of interconnected AI-driven management and blockchain systems, investments in advanced encryption, real-time threat detection, and staff training will mitigate vulnerabilities and protect sensitive data.

Balance automation with workforce adaptation strategies, including training for high-tech roles and reskilling programs. Maintaining a harmonious balance between technology and human touch will be key to sustainable growth.

Establish R&D hubs within hotels or restaurants. These labs could test and refine AI-driven personalization, robotics, or immersive technologies like virtual reality dining or augmented reality concierge services. They could also double as guest engagement tools, letting early adopters experience innovation firsthand.

Technology Deployment

Capital Expenditure

Talent Development

Regulatory Influence

Important terms to know before reading.

BACK-OF-HOUSE (BOH)
The area in a hospitality establishment for food preparation, storage, and staff administration, generally away from customers.

BIOMETRIC PAYMENTS
Technology that uses biometric data like facial recognition, gestures, voice, or fingerprints for identification to complete a transaction.

DIGITAL LOYALTY PROGRAMS
Membership or rewards programs that use digital technology like blockchain to track customer interactions and provide membership benefits.

ENVIRONMENTAL, SOCIAL, AND GOVERNANCE (ESG)
The framework and disclosure practices that measure how a company addresses ethical, governance, and sustainability issues.

EXTENDED REALITY (XR)
A technology that can augment the physical world through either virtual or augmented reality.

FACIAL RECOGNITION TECHNOLOGY
Technology used to authenticate customers by analyzing their facial features.

FRICTIONLESS EXPERIENCES
Experiences that minimize physical contact, remove obstacles, and create seamless interactions for guests and customers.

FRONT-OF-HOUSE (FOH)
The area in a hospitality establishment where interactions between guests and staff occur.

KIOSKS
Self-service terminals of any kind, typically used for ordering or obtaining information.

MID-AIR HAPTICS
Technology that can track movement and enable the sense of touch without actually touching a physical object.

MODULARLY BUILT
A construction technique that uses prefabricated components to create a space, building, or other structure.

NATURAL LANGUAGE PROCESSING (NLP)
AI that can understand the human language and respond in a human-like manner.

QUICK-SERVICE RESTAURANTS (QSR)
Restaurants that prioritize fast and convenient service over longer-stay dine-in experiences.

REVENUE PER AVAILABLE ROOM (REVPAR)
A key performance metric of the hospitality industry that divides the total room revenue by the number of available rooms and assesses a property’s performance.

SMART MANAGEMENT
The use of technology to automate certain parts of the operational management of a restaurant or hotel.

HOSPITALITY & RESTAURANTS TRENDS

ENHANCED HOSPITALITY EXPERIENCES

2ND YEAR ON THE LIST

AUGMENTED EXPERIENCES

WHAT IT IS

Augmented experiences are redefining the hospitality sector by blending innovative technology and traditional guest services to offer personalized, immersive, and efficient solutions that cater to diverse customer needs.

HOW IT WORKS

Augmented experiences leverage advanced technologies, such as holographic concierge services, extended reality (XR) studios, and AI-powered systems to elevate guest interactions and operational efficiency. These are already being deployed around the world: InterContinental Hotels has partnered with Timeshifter, an app using circadian rhythm science to combat jet lag, while the Beverly Wilshire Hotel is using Proto's holographic concierge technology to enable realistic virtual interactions with staff. These advancements bring the industry even closer to merging physical and digital touchpoints.

Also, these technologies are enabling deeper travel experiences, whether in-person or virtual. The Hilton Tokyo's XR studio, powered by Vega Global, integrates high-tech visual solutions for hybrid events, bridging in-person and virtual participation. Similarly, Renaissance Hotels' RENAI program combines AI-driven recommendations with local expertise to enhance trip personalization. Platforms like Travly tap into the creator economy, turning user-generated video reviews into a booking incentive. These integrations create tailored, engaging, and functional guest journeys, powered by cutting-edge tools and data-driven insights.

WHY IT MATTERS

Augmented experiences are more than just tech innovations; they signal a transformative shift in how businesses engage with customers. By embedding these technologies, hospitality leaders can tap into new revenue streams, enhance brand loyalty, and achieve operational efficiencies. These developments also align with consumer demands for personalized and seamless experiences, ensuring competitiveness in a rapidly evolving market landscape.

For businesses, integrating augmented technologies makes it easier to scale up offerings, take advantage of plentiful data, and respond quickly to customer needs. The trend extends far beyond hospitality, influencing sectors such as health care, retail, and entertainment. The stakes are high: The evolution of these technologies will redefine customer expectations, making tech integration not a luxury but a necessity for survival and growth in the digital age. Failure to adopt augmented experiences risks alienating tech-savvy consumers, eroding market share, and leaving businesses unable to compete with innovators that are reshaping the standard for guest expectations. Successful entrants to this field will prioritize preferred experiences first, and then test and meet guest expectations.

2ND YEAR ON THE LIST

SMART ROOMS

WHAT IT IS

Smart rooms, powered by the Internet of Things and AI, combine personalization, efficiency, and security.

HOW IT WORKS

Increasingly, hotels are turning toward smart technology to keep guests happy and safe. At Grand Copthorne Waterfront Hotel in Singapore, the Aiello Voice Assistant (AVA) is integrated with the hotel's property management system and task management system; they work together to transform rooms into voice-activated hubs, replacing traditional telephones. Guests take advantage of customizable modes like "Good Morning" and "Good Night" to adjust room settings for enhanced convenience and comfort; they can also control their own lights and air conditioning, and request services hands-free. Guests at the New Zealand hotel manage lighting, temperature, and security via smartphone apps that ensure elevated safety through credential encryption.

Beyond comfort, advanced technologies enhance safety and reputation. UK-based startup Spotta uses AI and image sensors for real-time bedbug detection, mitigating risks that could lower room rates by $23 to $38 per bad review. Now expanding into the US with Comcast's MachineQ, Spotta exemplifies AI's role in addressing persistent challenges. Meanwhile, futuristic concepts like Japan's "Mirai Ningen Sentakuki" highlight the potential for hyper-personalized wellness in hospitality: The biometric-monitoring "human washing machine" uses AI and ultrasound waves to cleanse and relax customers. Though currently a prototype, it reflects growing trends toward technology-driven guest experiences.

WHY IT MATTERS

These innovations not only meet growing consumer demand for hyper-personalized services but also enhance operational efficiency and cost management. Voice-activated systems like AVA simplify interactions, while mobile integration streamlines services and increases convenience. Behind the scenes, AI-driven systems like Spotta ensure safety and minimize risks to hotel reputations.

But the implications extend beyond guest satisfaction. Enhanced security features and proactive safety measures set new industry benchmarks. These trends also align with broader sustainability goals, as predictive systems reduce energy waste. For hotel operators, the ability to monitor and adapt to guest preferences allows for better resource allocation and staff utilization, and can be a profitability driver.

Companies that fail to adopt some of these technologies risk falling behind competitors. Long term, this trend underscores a broader societal shift toward smart, automated living environments, presenting opportunities for Internet of Things expansion across industries. It also offers the opportunity to expand a brand to new locations outside the hotel—even to rooms in a guest's home.

2ND YEAR ON THE LIST

DIGITAL WELLNESS TREATMENTS

WHAT IT IS

The fusion of advanced technology and wellness is revolutionizing hospitality, as companies can offer guests bespoke experiences that prioritize health and recovery. This shift positions digital wellness as a competitive advantage for industry players.

HOW IT WORKS

As the industry continues to focus on catering to consumers' desire for greater well-being, this trend spans multiple innovations. There are partnerships like that of The Set Collection with Therabody, where high-tech suites equipped with devices like the Theragun massager offer deep tissue therapy. There are robotic massage technologies, such as WaverMat's gravity wave systems, where consumers can enjoy contact-free treatments using frequency-based therapy to alleviate stress and enhance relaxation. And there are luxury retreats, including the Carillon Miami's Sleep Well Retreat, that combine features like smart beds with touchless energy therapies to optimize sleep and recovery.

Hotels are also embracing immersive technologies like VR for mindfulness. TreeHouse Hotels' Aura experience employs VR headsets to reduce stress, while Kimpton Fitzroy's "Room to Dream" integrates virtual reality with curated kits to encourage lucid dreaming. Fitness-forward hotels, like Dubai's SIRO One Za'abeel, feature cryogenic chambers and performance-tracking gyms designed in collaboration with athletes. These advances cater to growing consumer demand for wellness options that blend science, technology, and comfort.

WHY IT MATTERS

Digital wellness treatments position hospitality businesses as leaders in a growing global movement toward preventive health and self-care. By offering accessible and innovative wellness options, hotels and resorts can differentiate themselves in crowded markets, particularly as travelers increasingly prioritize mental and physical well-being during their stays. Beyond enhancing guest satisfaction, digital wellness can unlock new revenue streams, such as premium wellness packages and in-room technology experiences. And often, integrating digital wellness aligns with broader sustainability goals by enabling resource-efficient practices, such as virtual fitness classes that minimize physical space requirements and energy use. The broader implications include reshaping the competitive landscape, as hotels with advanced wellness offerings report higher occupancy rates and stronger brand loyalty.

These advancements also reflect shifts in consumer behavior toward health-conscious, tech-savvy lifestyles. With wellness tourism expenditures exceeding $500 daily per traveler, businesses integrating digital wellness technology can capitalize on a lucrative market. Plus, the trend offers broader opportunities for collaboration among tech developers, wellness providers, and the hospitality industry to create a cross-sector innovation hub.

2ND YEAR ON THE LIST

SMART RESOURCE MANAGEMENT

WHAT IT IS

With smart resource management, companies can enhance operational efficiency, sustainability, and the overall guest experience even while addressing industry challenges like labor shortages and cost optimization.

HOW IT WORKS

A standout innovation in this space is a centralized hotel operations management system, which organizes and tracks tasks like room cleaning, maintenance, and staff communication. Using a graphical user interface (GUI) as the central control hub, this system provides real-time updates on room statuses, task assignments, and staff schedules. This centralized approach is complemented by innovations such as RFID-enabled fabric tracking systems, which manage linens and towels throughout their life cycle. These systems reduce losses, prevent errors, and ensure efficient inventory management, enabling staff to focus on higher-value tasks. IoT-driven disinfection robots automate cleaning processes by employing sensors and making real-time adjustments to deliver consistent hygiene standards that reduce the need for human labor and optimize resource use.

Robotic automation, as seen in the Climia Benidorm Plaza, adds another layer of efficiency. Robots handle diverse tasks, from check-ins to food service and cleaning, enabling hotels to optimize staff workloads. These robots, equipped with AI and multilingual capabilities, ensure high-quality service, freeing up human staff to focus on personalized guest experiences.

Sustainability initiatives, like the all-electric hotel systems and water-saving IoT devices seen at Hotel Marcel, which operates on solar energy and innovative water management, significantly cut operational costs and appeal to eco-conscious travelers.

WHY IT MATTERS

Smart resource management is imperative for the hospitality industry, as it provides a path to greater efficiency, sustainability, and adaptability. As labor shortages and operational costs challenge traditional models, these new systems provide innovative solutions to manage resources with precision. And by automating routine tasks and optimizing workflows, hotels can reduce waste, improve staff productivity, and increase revenue. Beyond operational gains, these systems support broader sustainability goals so that hotels can meet regulatory standards and cater to environmentally conscious travelers. Smart technologies also enhance service delivery, creating personalized and seamless experiences that foster guest loyalty.

These systems can also fill in labor gaps. Because they reduce some of the complexity of managing a completely human workforce, less experienced managers could take on more responsibility. For hotel operators concerned about talent drought, these systems also improve the quality of working conditions by reducing the demand for menial tasks. As the hospitality sector becomes increasingly competitive, adopting smart resource management will be essential for businesses seeking to remain relevant and resilient in a rapidly evolving market.

2ND YEAR ON THE LIST

NOMADIC AND MODULAR HOTELS

WHAT IT IS

Modular and nomadic hotels are transforming hospitality with rapid construction, sustainable designs, and innovative guest experiences, offering agility and reduced costs for developers while meeting the evolving demands of modern travelers.

HOW IT WORKS

Modular hotels are at the forefront of hospitality innovation with their ability to leverage cutting-edge construction techniques, energy-efficient designs, and rapid adaptability to create self-sufficient accommodations in diverse environments. Their structures incorporate prefabricated units with photovoltaic roof panels, integrated water systems, and advanced climate controls. Reducing energy consumption by more than 20% and meeting near-zero energy requirements, their sustainability-focused approach not only lowers operational costs but also aligns with environmental goals.

In New Zealand, a $75 million modular Moxy Hotel in Auckland combines modular construction on its upper floors with traditional methods for its base, addressing logistical challenges through precise planning. Meanwhile, Dreams Curaçao Resort is enhancing its offerings with 52 modular oceanfront suites as part of an adults-only expansion that blends luxury with sustainability.

Adding another layer of innovation to modular construction are 3D printing technologies. The El Cosmico 2.0 project in Marfa, Texas, uses ICON's technology to create organic architectural forms while reducing labor costs and seamlessly integrating with natural landscapes. These advancements enable modular hotels to be constructed rapidly and efficiently, offering a versatile solution for various terrains.

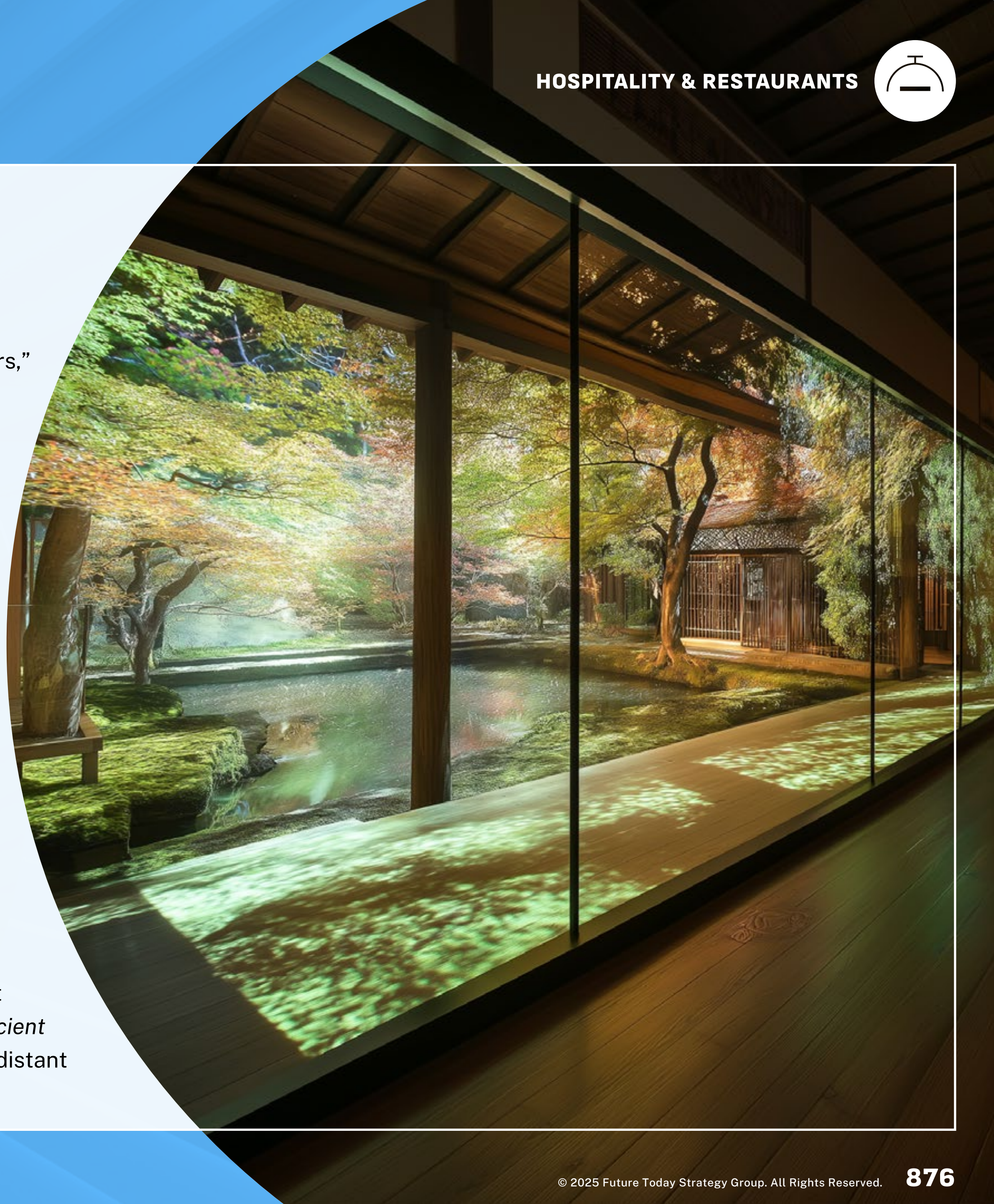
WHY IT MATTERS

For businesses, modular hotels represent a transformative opportunity to expand into new markets, optimize operational costs, and address shifting consumer demands. Their rapid construction timelines and cost efficiencies allow companies to adapt to changing market conditions and deploy assets where demand is highest. Self-sufficient energy systems reduce long-term reliance on traditional utilities, cutting expenses and bolstering environmental credentials.

Portability and adaptability enable hotels to capture underserved markets, from remote ecotourism destinations to urban areas requiring quick redevelopment. These innovations also foster resilience against fluctuating economic conditions and infrastructure limitations, ensuring sustainable growth. Businesses that adopt modular and nomadic hotel solutions can enhance their brand reputation, attract eco-conscious travelers, and gain a competitive edge in a dynamic hospitality landscape. Modular hotels are not just a solution for today's challenges—they are a blueprint for the future of agile, sustainable hospitality.

SCENARIO YEAR 2036

TIMELESS TRANSFERS



March 2036 marks a transformative moment in luxury travel as Four Seasons unveils “Timeless Transfers,” a pioneering initiative designed to alleviate the strain of overtourism on popular cultural destinations while offering guests immersive, authentic experiences. This innovative program re-creates the essence of World Heritage Sites within Four Seasons properties worldwide by blending cutting-edge technology with deep cultural storytelling. The debut theme, *Timeless Kyoto*, transports guests to Japan’s historic capital through immersive experiences. For example, they could participate in a traditional tea ceremony guided by a holographic version of legendary teamaster Sadō Matsumoto digitally captured in 360-degree VR. Visitors can explore endangered culinary traditions by joining virtual cooking classes that celebrate Kyoto’s iconic Kyo-Kaiseki and shojin ryori dishes, complete with interactive storytelling about their centuries-old origins. By partnering with local artisans, employing them as cultural consultants, and dedicating a portion of proceeds to community education programs, the initiative ensures that the people and traditions of Kyoto remain at the heart of this groundbreaking concept.

The “Timeless Transfers” model is as much about preservation as it is about reimagination. Four Seasons has created a platform that addresses overtourism concerns while providing sustainable support for the communities from which it draws inspiration. Through collaborations with local historians, schools, and craftspeople, the program channels resources back to cultural preservation efforts, ensuring the longevity of endangered traditions. This initiative represents a blueprint for the future of luxury tourism—one where technology bridges the gap between travelers and the world’s most cherished cultural legacies without jeopardizing their integrity. With plans for future themes such as *Ancient Egypt* and *Renaissance Florence*, Four Seasons is poised to redefine cultural engagement, making once-distant destinations—and eras—accessible while preserving their essence for generations to come.

2ND YEAR ON THE LIST

FRICTIONLESS STAYS

WHAT IT IS

Technologies like facial recognition, AI-driven guest services, and digital wallets are transforming hospitality. These innovations enhance convenience, reduce friction, and redefine guest expectations, creating seamless and personalized travel experiences.

HOW IT WORKS

From the moment a guest makes a reservation until they check out, new technologies are reducing traditional pain points throughout the process. New digital booking platforms make it even easier for guests to customize their stay by selecting amenities, all while tracking the environmental impact of their choices. Carbon footprint data, presented in CO_2 equivalents, incentivizes eco-friendly decisions. This gamified approach, combined with rewards for sustainable choices, empowers travelers to curate experiences that align with their values—without additional human intervention.

When they go to a property, innovative systems further simplify the guest journey by providing quick and secure access. These systems generate unique codes for each reservation that guests simply scan at check-in. For group bookings, these systems dynamically adapt to changes, like modifying guest details or reassigning rooms, by updating codes in real time. This reduces administrative overhead while enhancing security.

When travelers make it to their rooms, digital keys integrated with platforms like Google Wallet eliminate the need for physical cards or standalone apps. At hotels like the Clarion Hotel Post, guests can unlock rooms and access amenities with their smartphones using NFC technology. Piaggio Fast Forward's Kilo robots take convenience a step further by assisting with luggage transport and other tasks, ensuring a seamless transition from arrival to relaxation.

WHY IT MATTERS

This evolution of frictionless stays signals a broader shift in the hospitality industry: Consumers want more tech-enabled experiences that balance personalization, security, sustainability, and fewer forced interactions. Waiting in lines is no longer tolerable. As competition for guests intensifies, these technologies present opportunities for businesses to differentiate themselves from more traditional and potentially cumbersome hotel stays by meeting rising guest expectations for seamless experiences that they can navigate with ease.

The inclusion of sustainability as a core feature has broader implications, as it encourages behavioral changes among travelers and gets hotels to align with global environmental goals. While consumer preferences increasingly favor eco-conscious options, this alignment not only drives customer loyalty but also positions hotels as leaders in sustainability. Enhanced digital identity systems further mitigate security risks while offering flexibility for real-world scenarios, ensuring operational resilience. This focus on frictionless experiences is starting to move past check-in, with guests becoming unwilling to wait for an operator to answer their call when booking the room or maintenance to arrive to fix the thermostat or TV. Hotels should expect this trend to continue to grow and converge with other guest experiences.

2ND YEAR ON THE LIST

HYPER-PERSONALIZATION

WHAT IT IS

Hyper-personalization is reshaping industries by leveraging AI, data analytics, and real-time technology to deliver individualized customer experiences.

HOW IT WORKS

IHG Hotels & Resorts' Mind Lobby initiative is a prime example of this trend: The experience unveiled in Sydney uses eye-tracking technology to analyze subconscious reactions to travel imagery and offer guests highly personalized recommendations based on a list of preferences. IHG's technology investments also include $300 million in data analytics, AI-powered trip planners, and a reimagined booking experience. The IHG One Rewards mobile app, updated with features like attribute-based booking and AI-powered itinerary planning, further enhances guest personalization. Collaborations with companies like Apple for in-room AirPlay functionality also highlight IHG's commitment to convenience and customization.

Elsewhere, new patented technologies are transforming service delivery. A recently introduced system assigns each guest a dedicated robot whose tasks and routes are customized based on individual requests and hotel conditions. Complementing robotics, another innovative transient personalization mode makes it so guests can interact with a hotel's automated assistant without logging in to personal accounts. This system securely syncs with the guest's personal assistant to deliver tailored responses while maintaining privacy. Designed for environments like hotel rooms or shared devices, it combines ease of use with robust security, for a seamless, personalized experience in transient scenarios.

WHY IT MATTERS

Personalization is not a new trend but has evolved into hyper-personalization, to address even nuanced customer needs. This continuing paradigm shift in customer engagement requires businesses to deliver customized experiences at scale. Even more so than price, hyper-personalization will be a deciding factor for some guests, and it will foster deeper brand loyalty. The integration of AI, robotics, and transient personalization tools represents a convergence of technologies that simplifies decision-making, optimizes resource allocation, and anticipates customer needs. Guests may soon be able to select these experiences as part of their frictionless stay, or choose them as an enhanced add-on that could result in greater revenue for the hotel and brand. Personalization options could also differ by hotel locale, which could entice guests to travel to a new destination to try out its curated personalization. As consumer expectations rise, organizations must adopt these advanced solutions to remain relevant, responsive, and innovative in a rapidly evolving marketplace. Hyper-personalization is not just a competitive advantage—it's becoming a core differentiator and marketing tool.

2ND YEAR ON THE LIST

BUSINESS AUTOMATION

WHAT IT IS

Hospitality businesses are embracing automation to enhance guest experiences and operational efficiencies.

HOW IT WORKS

While automation has been part of the hospitality industry for years, ZentrumHub's partnership with Mize takes it a step further by enhancing hotel connectivity for online travel agencies. These platforms optimize processes, reduce post-booking costs, and provide business intelligence to maximize profitability. Meanwhile, tools like Stayflexi's Empower provide real-time market intelligence with features such as price predictions and competitor analysis, so hotels can dynamically adjust their strategies.

Another example is Mews, which acquired Atomize last year to integrate real-time revenue management capabilities. This acquisition equips hotels with dynamic pricing strategies, ensuring competitive and optimized offerings. Additionally, Grazzy's digital payment solutions streamline tipping processes, which enhance employee satisfaction, reducing turnover costs.

In emerging markets like China, Shiji's WeChat booking engine exemplifies localized automation as it seamlessly integrates with consumer behavior trends to create a frictionless booking experience. A newly patented blockchain-based hotel system introduces tamper-proof records for room reservations, transfers, and check-ins. During check-in, the blockchain verifies the token and reservation details, to both prevent fraud and enhance customer trust.

WHY IT MATTERS

This wave of automation is addressing multiple challenges in the hospitality industry—everything from labor shortages to rising consumer expectations for personalized experiences. As with the "Frictionless Stays" trend, by automating repetitive tasks and enabling data-driven decision-making, businesses can reduce operational costs, improve employee retention, and drive customer loyalty. However, this shift has broader implications, such as the potential for workforce displacement and ethical considerations around data privacy. Brands must be cautious to choose which automations will be beneficial without completely disintermediating their core labor force.

The trend also democratizes access to advanced tools for smaller businesses, leveling the playing field and fostering innovation in an industry historically dominated by major players. As these systems scale, and connectable technologies or generative AI platforms introduce new innovations, the hospitality sector is likely to experience a shift toward new business practices that companies should start considering today. Creating these new standards now means that businesses can own the competitive market with its own standards rather than reacting to a competitor's. By creating new standards, brands can begin reshaping competitive landscapes to their advantage.

SCENARIO YEAR 2034

THE EVERYDAY HOTEL AI WORKFORCE STRIKE OF 2034

In June 2034, more than 10,000 Everyday hotel workers in San Francisco are staging a citywide strike to protest the rollout of the company's Autonomous Workforce Deployment system. The AI-driven platform, designed to dynamically allocate labor across tasks like housekeeping and front desk operations, is accused of displacing workers, reducing hours, and creating chaotic mid-shift reassignments. Employees have reported being replaced by cleaning bots and AI concierge systems without proper consultation or retraining. Union leaders have criticized Everyday for prioritizing efficiency over workforce sustainability, and demanded better protections and transition programs. The strike quickly gains support in tech-forward cities like Seattle and Boston, where automation tensions are also rising.

The disruption underscores the broader conflict between technological innovation and job stability in the hospitality industry. When guest services falter under AI-only operations, local governments intervene to mediate, pushing Everyday to suspend further AI rollouts. Company officials quickly shift their priorities to invest in retraining displaced workers and implement a two-year employment buffer. The strike becomes a defining moment in 21st century labor, prompting new regulations to govern workforce automation and highlighting the importance of balancing innovation with social responsibility in an increasingly automated world.

AUGMENTED RESTAURANTS AND DINING

2ND YEAR ON THE LIST

CONTACTLESS PAYMENTS

WHAT IT IS

Contactless payment technologies are transforming customer interactions across industries by enhancing convenience, increasing efficiency, and boosting sales.

HOW IT WORKS

Companies are taking advantage of new technology to make it easier for customers to order and pay—which then often results in increased sales. Grubbrr, in partnership with Olo, combines self-ordering kiosks and digital menu boards with data-driven insights, boosting restaurant sales by 12%–22% and streamlining in-store and online operations. GoTab's Phone-Only POS offers an NFC-enabled, compact design compatible with Apple Pay and Google Wallet, increasing check averages by 35% and driving $83 in sales per hour of labor.

Steak 'n Shake, through a partnership with PopID, has deployed facial recognition payment kiosks across 300 US locations, cutting transaction times to seconds and improving customer loyalty. Similarly, Whataburger's pay-by-face system, also powered by PopID, has expedited checkout and boosted convenience at select locations. Meanwhile, blockchain innovation is entering the space with Blackbird Pay, which reduces transaction fees to 2% and includes instant settlements with integrated loyalty rewards.

Raydiant's Order & Pay Kiosks feature real-time inventory syncing, digital receipts, and customizable branding, with plans for AI-driven personalization. Across these examples, contactless systems are boosting sales, reducing costs, and aligning businesses with digital-first consumer demands while providing invaluable data insights to drive profitability.

WHY IT MATTERS

These technologies meet the growing consumer demand for convenience and personalization, creating seamless interactions that enhance satisfaction and build loyalty. They improve the overall customer experience by reducing wait times and eliminating inefficiencies in payment processes. But they also help businesses streamline their operations and reduce costs, so they can focus their resources on strategic initiatives and growth. Plus, another significant advantage of contactless payments is the valuable data they generate: data that businesses can use to gain insights into customer behavior, optimize inventory, design targeted marketing strategies, and ultimately drive increased revenue and operational efficiency.

Adopting contactless payment solutions positions businesses to align with evolving digital-first consumer preferences, ensuring they stay competitive in a fast-paced market. Additionally, these systems future-proof operations by reducing dependency on legacy technologies, increasing agility, and enabling companies to adapt quickly to new trends.

2ND YEAR ON THE LIST

AUTONOMOUS RESTAURANTS

WHAT IT IS

The rise of autonomous restaurants—dining establishments where customers can order, pay, and get their food without human help—reflects a broader societal trend toward frictionless, technology-driven experiences that blend convenience, personalization, and sustainability.

HOW IT WORKS

Costa Coffee's Costa Coffee Creations, debuting in August 2024 at Austin-Bergstrom Airport, exemplifies this industry evolution toward autonomy: The system operates independently for up to seven days, offering up to 8 million drink combinations in a compact 24-square-foot space. Without a human barista, the kiosk has established a more efficient process while still meeting customers' demands for ultra-customized coffee drinks.

Other chains are experimenting with augmenting human labor with automation. Chipotle is piloting Autocado, which processes avocados in just 26 seconds; it's also testing an automated makeline for digital orders, which now make up 65% of the company's sales. Developed with Hyphen, these systems optimize workflows and enhance speed without compromising quality. In Manhattan, vegan fast-casual restaurant Kernel uses a Kuka robotic arm to reheat centrally prepared meals, reducing on-site staff and maximizing efficiency. Meanwhile, Richtech Robotics' humanoid bartender ADAM serves drinks at Texas' Globe Life Field, reducing wait times and freeing staff for guest interactions.

Beyond hardware, AI systems like Nory revolutionize restaurant management by optimizing staffing, inventory, and demand forecasting using historical and real-time data. Additionally, predictive systems synchronize kitchen operations with customer demand, streamlining workflows and reducing waste while enhancing diner satisfaction with real-time order updates.

WHY IT MATTERS

Automation can help restaurants mitigate labor shortages, reduce costs, and maintain 24/7 operations, fundamentally changing the economics of the food service industry. These technologies enable a level of scalability and consistency previously unattainable, offering a pathway for smaller operators to compete with large chains by adopting modular, tech-driven models. These innovations also provide ways for smaller brands to enter new markets: Now, capital investments are focused solely on space and technology, as opposed to hiring more humans that require additional benefit plans and management teams.

From a societal perspective, the trend reflects shifting consumer preferences for seamless, personalized experiences. It also reflects a distrust of human intervention in the everyday dining experience. Automation empowers restaurants to meet these demands and expectations. In the future, this means that restaurants can use their human staff to focus on high-value tasks like customer engagement and marketing while the industry redefines the traditional serving roles. For example, a restaurant could have staff members devoted to making human contact for reservations and post-dining follow-up, engagement designed to entice guests back. As cities become denser and real estate costs rise, compact and efficient autonomous systems can also provide a blueprint for sustainable, space-conscious urban dining.

2ND YEAR ON THE LIST

EVERYWHERE ORDER AND DELIVERY

WHAT IT IS

Innovative technologies like autonomous robots, drones, and AI-driven solutions are making it possible for consumers to order and receive products anytime and anywhere, enhancing speed, sustainability, and accessibility in the evolving delivery ecosystem.

HOW IT WORKS

In Los Angeles, Shake Shack and Serve Robotics have partnered to deploy 2,000 self-driving robots, showcasing the potential of Level 4 autonomous bots to navigate independently and deliver orders sustainably. Customers select "robot delivery" through the Uber Eats app and then track the robot's progress and unlock the order with a passcode when it arrives. Similarly, Speedy Eats vending machines offer fresh meals 24/7, stored for up to 10 days in refrigerated lockers, with an automatic system to discard expired items. These machines fill a market gap for convenient, high-quality food.

AI-driven solutions like the chatbot FIFE add a personalized dimension to food ordering. Using natural language processing, FIFE tailors recommendations based on allergies, health needs, and mood, to create a highly engaging user experience. In crowded kitchens or dining rooms, advanced voice interface systems associate commands with specific tasks without interference so that voice commands can be heard and understood.

Innovations also address the unique challenges of delivering food to remote locations, such as beaches, parks, or event venues. Autonomous kiosks integrated with an app, enable seamless ordering from nearby restaurants with food getting delivered to secure lockers where customers can retrieve their meals with passcodes. These solutions eliminate the need to leave the area while ensuring safe, private, contactless, and convenient service.

WHY IT MATTERS

For businesses, this transformation to anytime, anywhere ordering and delivery will necessitate changes in operational strategies, including adjustments to ordering parameters. Companies must consider order size, preparation time, and delivery radius when designing logistics systems that balance speed and cost-effectiveness. Daily pop-up locations are becoming a viable strategy that involves using mobile or temporary hubs to meet demand in high-traffic areas or underserved regions. Businesses can use these locations, powered by smart inventory systems and autonomous delivery options, to respond dynamically to customer needs without investing in permanent infrastructure.

As they shift to automation, businesses will need to rethink customer interactions. AI-powered chatbots and personalized ordering systems enhance engagement by offering tailored recommendations based on customer preferences and behaviors. This deeper level of customization builds loyalty and satisfaction while streamlining the ordering process.

Ultimately, this trend not only improves the customer experience but also drives significant cost savings, reduces environmental impact, and introduces new revenue streams through expanded service capabilities. Businesses that leverage these technologies will be better positioned to compete in an increasingly fast-paced, convenience-driven economy, where flexibility and innovation are key to staying ahead.

2ND YEAR ON THE LIST

MONITORING FOOD WASTE & IMPACT

WHAT IT IS

Advanced technologies like AI, IoT, and computer vision are transforming how businesses monitor, reduce, and manage food waste, enabling smarter operations and fostering sustainability across the food supply chain.

HOW IT WORKS

As companies integrate food system innovations, food waste monitoring has evolved. AI-powered solutions, such as those by Winnow, weigh and photograph discarded food, categorize waste by type, and generate actionable insights; chefs can use those insights to refine menu designs and optimize purchasing. In grocery distribution, predictive systems like Afresh leverage AI to account for seasonal trends, promotions, and shelf-life data, to improve inventory management and reduce spoilage.

IoT-enabled solutions, such as RFID-embedded plates combined with smart scales, track portions in real time, provide nutritional data, and facilitate automated billing, helping restaurants align consumption with actual needs. These systems reduce buffet waste and empower customers to make healthier, more informed decisions. At a systemic level, Quantum Reservoir Computing (QRC) represents a new leap forward in addressing food waste: By incorporating complex quantum circuit designs and external data like trade volumes and production levels, QRC helps companies more accurately predict price trends. These forecasts help stabilize supply chains, reduce overstocking, and minimize food waste at large scales.

In addition, deep learning models like MobileNetV2 are 93% accurate in estimating weight and classifying food waste. These systems, trained on datasets like Food11, enable rapid and lightweight deployment in kitchens and retail applications, to optimize operational efficiency.

WHY IT MATTERS

At its core, this trend addresses inefficiencies in the food supply chain that are both expensive for businesses and bad for the environment. By integrating advanced waste monitoring technologies, businesses can make data-driven decisions that optimize production, inventory, and resource allocation.

The implications stretch far beyond immediate cost savings, which are significant. Businesses that use food waste monitoring can align their strategies with the growing customer demand for sustainability, and strengthen their relationships with environmentally conscious consumers as a result. And as regulations around waste management tighten globally, adopting these technologies can also ensure compliance and reduce risks associated with fines or reputational damage.

In addition, the data companies can collect from waste monitoring opens doors for even more innovation. Businesses can refine their forecasting methods to align with real-time consumer behavior, enabling hyper-efficient production models and reducing spoilage. In industries like hospitality and retail, these systems can support new business models, such as dynamic pricing or subscription services tailored to minimize surplus.

2ND YEAR ON THE LIST

IMMERSIVE EXPERIENCES

WHAT IT IS

Immersive experiences in hospitality, dining, and retail are redefining engagement, blending technology and multisensory storytelling to foster participation and emotional connection.

HOW IT WORKS

Immersive experiences use interactive technologies to transform passive consumption into active participation. Ideum's Tasting Table is one example of this; the table integrates a 55-inch touch display, wine-recognition technology, and customizable digital tasting wheels. This allows for interactive wine-tasting sessions where guests explore flavor profiles while their preferences are captured for analytics. Similarly, virtual reality (VR) environments are moving beyond visual engagement by incorporating olfactory and tactile elements to replicate real-world scenarios. Driven by research that shows adding synthetic scents enhances VR's ability to evoke food cravings, multisensory inputs are becoming more important for companies building authentic virtual dining experiences.

Innovations in taste simulation are also advancing rapidly. AI-driven models are powering a terahertz-based digital taste bud sensing system that enables precise, noninvasive flavor analysis. In addition to this, researchers at City University of Hong Kong have developed a "lickable VR device" that can replicate up to nine flavors using food-grade chemicals activated by voltage and saliva. Projection mapping also plays a crucial role: Mutti's immersive dining at London's Saatchi Gallery used this technology to animate the life cycle of a tomato on guests' tables, as a complement to a multicourse meal. Such initiatives turn mundane activities into narrative-driven spectacles.

WHY IT MATTERS

Immersive experiences represent a continued need for new and experiential moments in order to capture consumers' attention and wallets. More immersive dining experiences help to create memorable interactions, deepen emotional ties, and enhance brand differentiation. Not only that, they also offer a reason for diners to come back if those experiences change over time, evolve with the diner, or are personalized. Industries from retail to hospitality can leverage this trend to increase customer dwell time, boost spending, and gather behavioral insights. For businesses, immersive technologies provide tools for personalization, creating tailored experiences that align with consumer preferences. For example, AI-driven platforms can adapt sensory elements in real time, offering an unprecedented level of customization.

In a world becoming more connected, immersive settings blur the lines between online and offline, as virtual dining, interactive projections, and augmented reality attract digitally native consumers. By blending narrative, technology, and multisensory elements, businesses can turn ordinary transactions into extraordinary experiences, and foster long-term loyalty and engagement.

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We enter our second century with the same commitment to innovation, harnessing the power of our people and technology to respond to guest demands. Our research paints an exciting future for the hospitality industry, highlighting the growing importance of human interaction in an increasingly tech-centric world.

Simon Vincent, EVP & President, EMEA, Hilton

2ND YEAR ON THE LIST

ENGINEERED FOOD AND MEALS

WHAT IT IS

Engineered food technologies are redefining the global food ecosystem with innovations like edible QR codes, solar-powered proteins, and biocompatible colorants.

HOW IT WORKS

Researchers and companies are utilizing synthetic biology, 3D printing, and advanced materials to reimagine food systems. For instance, researchers at the Singapore University of Technology and Design have developed 3D-printed edible QR codes that blend flavors and nutrients into codes with personalized nutrition information. Finnish company Solar Foods has introduced Solein, a protein-rich powder made from CO2 and electricity that only requires 1% of the energy used by traditional farming methods. And the technology is scalable: Solar Foods' Factory 01 is capable of producing enough edible biomass for 6 million meals annually. Meanwhile, researchers are addressing consumer demand for natural food colorants by leveraging the unique properties of hydroxypropyl cellulose, which can display vibrant, food-safe colors without synthetic additives. This not only enhances a food's visual appeal but also aligns with the rise in health-conscious and environmentally aware consumer preferences.

Startups like BloomSpoon are also creating dual-purpose products, such as cutlery made from biodegradable wheat straw that can sprout into plants after disposal. In the realm of automation, advanced spectrometric methods are improving food safety and aiming for consistent quality control by precisely detecting spoilage through the acid value in oils and greases. These examples illustrate the versatility and potential of engineered food technologies, which span from sustainable ingredient production to personalized, data-driven meal solutions.

WHY IT MATTERS

The rise of engineered food technologies has profound implications for businesses and industries globally. Using these scalable and efficient innovations to replace traditional agricultural systems could mitigate supply chain vulnerabilities, reduce environmental impact, and address global food security challenges. They also enable hyper-personalized nutrition, to align with the growing consumer demand for tailored dietary options and transparency in food production. As these technologies mature, industries must adapt to a future where engineered food becomes integral to mainstream consumption, requiring investments in infrastructure, talent, and regulatory frameworks. There are environmental benefits too, as the shift from resource-intensive farming to laboratory-based production can significantly reduce greenhouse gas emissions and land use while contributing to broader sustainability goals. For businesses, this trend offers opportunities to innovate, differentiate products, and respond to the increasing prioritization of health, convenience, and environmental stewardship among consumers. The evolution of engineered food underscores a pivotal shift in how industries must approach food production and distribution in an era defined by climate urgency and technological advancement.

SCENARIO YEAR 2044

BHOJAN NIRVANA: SAVOR WITHOUT WASTE

In the heart of Mumbai, a bold new restaurant is taking the popularity of edible utensils and turning the concept into an art form. Known simply as Bhojan Nirvana, this culinary marvel has reimagined the practice of eating by blurring the lines between what you savor and what you hold in your hands. The restaurant boasts that it offers the ultimate bliss: food that includes its own utensils and doesn't produce any waste.

The innovation begins the moment your meal arrives. A creamy dal makhani is cradled in a delicately spiced bowl made entirely of lentil flour, baked to a crisp, golden perfection. The accompanying naan spoons are infused with garlic and coriander, sturdy enough to scoop every last bit of the rich, velvety dal, yet tender enough to melt in your mouth when you take the final bite. Desserts steal the show—a saffron kulfi served atop a cardamom-scented almond disc that cracks satisfyingly under a spoon made of jaggery and coconut.

Bhojan Nirvana goes further by incorporating modern technology into these time-honored practices. Its edible bowls, plates, and cutlery are engineered using advanced food science to ensure sustainability, flavor harmony, and zero waste. It's a feast for both the palate and the planet, and it might just change the way we think about food entirely.

2ND YEAR ON THE LIST

AUTOMATING LOYALTY

WHAT IT IS

Brands are integrating AI, gamification, and immersive technologies to reimagine loyalty programs, creating deeper engagement and more meaningful customer relationships.

HOW IT WORKS

Most brands know that loyalty increases share of wallet. Companies in a variety of industries are already experimenting with using new technologies to up their member loyalty game and keep them top of mind with their consumers. Video-based review app Franki is doing this well: It replaces traditional reviews with engaging user-generated videos. Its Social Club rewards program offers cash back for spending and video creation, while its "Adventures" feature gamifies dining with scavenger hunt-style challenges. Among restaurants, Chipotle's gamified promotions tagged to events like National Burrito Day have driven record-breaking app engagement and loyalty program enrollments. Similarly, Burger King's in-app games, such as Balloon Burst and Cloud Float, connect with customers emotionally as they blend nostalgia with interactivity.

AI further enhances these systems by enabling deeper personalization. Wendy's uses the AI-driven platform Par Punchh to create gamified and tailored offers, while Le Pain Quotidien's Alain.AI pulls from customer data to develop region-specific menus and expand loyalty benefits. Uber Eats' TikTok-style video feed showcases nearby restaurants to promote authentic discovery without relying on ads. Meanwhile, DoorDash's "Dine Out" feature rewards users for in-restaurant dining with app-based credits, incentivizing foot traffic.

WHY IT MATTERS

Personalized, technology-driven programs improve customer retention, ultimately increasing lifetime value and fostering deeper emotional connections with brands. These automated systems increase efficiency by streamlining loyalty program management, reducing labor costs while driving measurable outcomes. Plus, they can reduce traditional marketing costs, which means less spend on ads, commercials, or print materials. And the data these programs produce is invaluable: It can lead to key insights that empower companies to predict customer behavior and respond quickly to evolving consumer expectations.

These gamification and immersive technologies also allow businesses to scale engagement beyond physical locations, creating a competitive edge in crowded markets. These innovations set new consumer expectations, compelling industries to adopt similar practices or risk losing relevance. Automated loyalty programs not only boost revenue but also drive long-term growth by embedding brands more deeply into customers' daily lives. Trust and satisfaction grow as a result. This trend signals a future where engagement is personalized, seamless, and increasingly indispensable for business success.

1ST YEAR ON THE LIST

DYNAMIC MENUS

WHAT IT IS

Dynamic menus, powered by AI and real-time data, are reshaping consumer interactions across industries, offering hyper-personalized choices, flexible pricing, and streamlined operations.

HOW IT WORKS

Dynamic menus give companies the ultimate flexibility, allowing them to adapt in real time to changing customer tastes, inventory shortages, and market trends. These advanced systems now employ reinforcement learning, simulating "trial and error" processes to refine strategies. Menus are treated as "states," with actions like adding or removing dishes evaluated based on metrics such as customer satisfaction, sales, and profitability. This reinforcement learning ensures ongoing optimization by learning from interactions and refining recommendations. The customization potential for this technology is vast, as companies can tailor menus for specific segments or seasonal trends while balancing satisfaction with profitability.

Data collection is key for this trend, including capturing customer feedback, ordering patterns, and inventory status. With this data, the system dynamically adds new dishes that align with preferences, removes underperformers, and adjusts pricing to balance the menu's affordability with the company's profit. Even where the dish is placed on the menu is optimized for visibility and sales. These systems are already rolling out in some fast-food locations: Wendy's is investing $20 million in digital menu boards that use dynamic pricing during peak times, while Taco Bell is using voice-activated AI to improve order accuracy in hundreds of locations.

WHY IT MATTERS

By leveraging AI-driven adaptability, these systems provide hyper-personalized experiences that enhance customer satisfaction and loyalty. The ability to adjust offerings in real time based on live data—such as inventory levels, demand surges, and individual preferences—keeps businesses agile in rapidly changing markets. This capability not only improves operational efficiency but also maximizes revenue by aligning products and pricing with customer behaviors.

For businesses, dynamic menus represent an evolution in decision-making. Instead of relying on static strategies, companies can now employ data-driven insights to predict trends, optimize inventory, and allocate resources more effectively. This adaptability is crucial in industries like retail, hospitality, and health care, where customers' needs are diverse and always evolving. Key to this is the integration of reinforcement learning, which ensures continuous improvement and drives innovation while reducing manual workload.

Beyond operational benefits, dynamic menus address critical challenges in customer engagement. Personalized recommendations reduce decision fatigue, while real-time updates foster transparency and trust. However, this trend also raises questions about pricing fairness, data privacy, and the balance between automation and human connection.

SCENARIO YEAR 2027

JOIN THE PRE-DINING CLUB: WHERE DINING MEETS COMMUNITY

Ready to turn every meal into a global adventure? The Pre-Dining Club invites you to join a community of food lovers where dining is about more than what's on your plate—it's about building connections, exploring cultures, and discovering new flavors.

Here's how it works: Sign up to join our micro-dining communities and rotate through curated, themed groups like the Sweet-Tooth Seekers or the Umami Enthusiasts. Each week, you'll be paired with fellow diners who share your tastes and values—even those from across the globe. Imagine dining at a top restaurant in your city while companions in Sweden and Mexico experience the same vibe, and then connecting afterward to share stories, build friendships, and plan your next adventure together.

But that's just the beginning. As a member, you'll also get access to Pre-Dining Loyalty Training, immersive programs that prepare your palate for bold culinary experiences. Receive interactive kits from partner restaurants, refine your tastes, and earn rewards before you even step foot in the door. This isn't about gamification—it's about transforming dining into a journey of discovery, connection, and confidence. Sign up and meet your global taste community today!

1ST YEAR ON THE LIST

MANAGEMENT OPTIMIZATION

WHAT IT IS

Real-time data integration, AI-driven decision-making, and advanced supply chain transparency are redefining management optimization as we know it.

HOW IT WORKS

Increasingly, hospitality companies are using advanced technology to ensure efficiency across their operations. At Chipotle, a nationwide rollout of RFID technology ensures automatic inventory tracking; this enables the chain to manage limited-time offers and monitor supplier compliance in real time. It also integrates seamlessly with the company's upgraded Oracle ERP system, to achieve comprehensive data-driven insights.

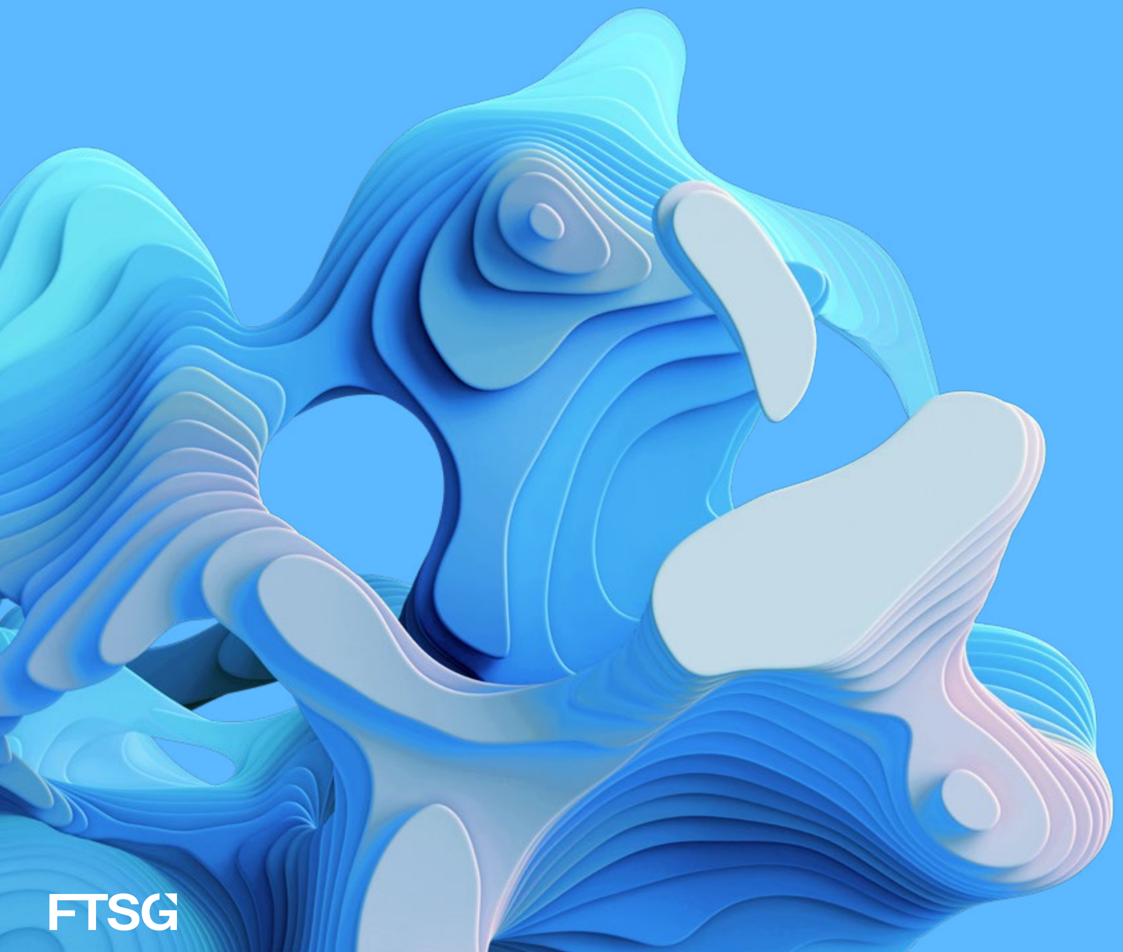
Yum Brands has implemented an AI-first strategy across its fast-food properties, deploying tools like AI-driven inventory systems and the Poseidon POS system in Taco Bell locations. The company's SuperApp provides restaurant managers with AI-enhanced operational advice, including inventory predictions and employee training involving augmented reality technologies.

Wendy's partnership with Palantir Technologies demonstrates how AI can unify disparate data streams for optimized supply chain management. Through predictive modeling, Wendy's anticipates the inventory its stores will need, and figures out how to transport the products. Meanwhile, Chipotle's investment in Lumachain's computer vision-based platform tracks product conditions throughout its supply chain, boosting food safety and reducing waste. Automation also plays a role in reducing labor-intensive processes, as seen in Chipotle's testing of the Autocado machine and automated food assembly lines. These and other developments point toward scalable efficiencies in food preparation.

WHY IT MATTERS

For smaller brands, operational efficiency is the difference between a successful location or one that closes due to economic failure. Enhanced supply chain visibility minimizes disruptions, leading to improved product availability and customer satisfaction. By automating routine tasks, businesses redirect human capital toward strategic and creative roles, fostering innovation. The integration of AI enables predictive decision-making that empowers organizations to adapt swiftly to market changes. Furthermore, real-time data accessibility cultivates transparency and trust, benefiting both stakeholders and consumers.

For industries at large, management optimization promises scalability, reduced operational costs, and a competitive edge. For quick-service restaurants, this could help optimize produce orders, determine which staff members are most efficient at daily tasks like food prep, and reduce the need for costly equipment if it proves to be ineffective. Using optimization tools to uncover and address these needs can help improve revenue per store as each store may have different optimization needs. As these technologies become mainstream, businesses must navigate ethical considerations, like job displacement and data privacy, to ensure sustainable adoption.



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In his work at FTSG, Mark has explored the future of communities, housing in urban settings, certifications and testing, product development cycles, parent and children's needs, digital interactions, supply chain and logistics, geographic cities, the workplace, immersive experiences, hotels and restaurants, design, manufacturing, urban planning, engineering, and artificial intelligence's impact on various industries and sectors. He has researched and developed hundreds of evidence-based trends, scenarios, and strategic insights for FTSG's global clientele.

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SUPPLY CHAIN, LOGISTICS, & MANUFACTURING

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Mark Bryan
Supply Chain Lead

We need a decisive vision for a fluid supply chain future.

Today's supply chain, logistics, and manufacturing industries sit at a critical juncture, yet each industry is too focused on the near term, mostly because of geopolitical and economic crises. While these challenges are pressing and monumental, this moment—and the future—calls for more expansive thinking and adoption of new practices instead of incremental changes. In an era defined by rapid technological advancements and market evolution, our industries must transcend traditional models, by embracing a holistic and forward-thinking approach. We will have to reimagine what the supply chain looks like, and prepare for a future where self-optimizing, adaptive supply chain networks not only exist but are the norm. We won't just see an enhancement of existing processes; we'll experience a fundamental change in how we manage and optimize supply chains, setting a new standard for operational excellence.

However, it won't be easy, and this approach presents risks. Increased digitization and flexibility bring heightened cybersecurity threats. The complexities of environmental, social, and governance (ESG) compliance and the potential biases in AI-driven procurement processes pose significant challenges. Environmental implications from increased automation, alongside the high costs of implementing advanced tracking systems, further underscore the need for strategic and inclusive approaches.

In light of these opportunities and threats, our actions must be both decisive and visionary. As we move beyond traditional limitations, we have the opportunity to transform supply chains, logistics, and manufacturing into dynamic ecosystems of innovation and resilience. By harnessing advanced technologies and fostering a culture of continuous improvement, we can lead our industries into a future that is efficient, robust, and adaptable to our rapidly changing world. This journey is about building a future that is not only sustainable but also vibrant, resilient, and full of possibility.

Global industries face challenges as infrastructure setbacks, economic pressures, labor disputes, and rising automation reshape markets worldwide.

1

Baltimore bridge collapse closes port

The economy takes a $15 million hit every day that ships cannot make it through the Port of Baltimore.

2

Beijing lacks new demand

China's manufacturers struggle at home despite being feared in the West for their cheap goods.

3

JD.com plans $5 billion stock buyback

JD.com wants to stabilize its share price and reassure investors after the unexpected exit of its major shareholder, Walmart, in a bid to compete in the Chinese e-commerce market against rivals like Alibaba.

4

Railway union disputes back-to-work orders

In Canada, the orders to end worker strikes at two major railways get hit by lawsuits.

5

1 in 10 South Korea workers are robots

Due to its rapid adoption of automation, South Korea reaches a robot density of 1,012 units per 10,000 employees in the manufacturing sector.

Tackling global instability with innovation and resilience

In 2025, the supply chain, logistics, and manufacturing industries are grappling with a mix of economic challenges, geopolitical shifts, and rapid technological transformation. The predicted slowdown of global growth has pushed companies to diversify their operations away from traditional regions like China, with southeast Asian countries such as Vietnam, Malaysia, and India becoming central manufacturing hubs. Much of this movement is an attempt to keep up with ever-increasing customer fulfillment expectations—and prevent customer loyalties from wavering.

Several regions are dealing with the combination of inflation, raw material shortages, and extreme weather disruptions. Fold in geopolitical tensions, and global supply chains have become incredibly complex to navigate. Conflicts in the Red Sea and Ukraine are disrupting shipping routes and upping transportation costs, pushing companies to seek alternative routes and more agile logistics solutions. Latin America faces its own set of issues—including political instability and insufficient reforms—that are hindering growth and adding to economic inefficiencies. China's and Russia's growing influence in the region, particularly through investments in energy and infrastructure, brings another layer of intricacy to supply chain networks.

At the same time, sustainability movements and preparation for climate change impacts are keeping the industries investing for the future. In the EU, new ESG standards are spurring investments in electrification, resource management, and carbon footprint reduction, with more than 40% of companies making strides toward more sustainable operations.

Despite technological advances, supply chain professionals are still spending considerable time on manual processes, including how they track data, and most don't have a predictive view of supply and demand. The lack of visibility and real-time information hinders the balance between preparing for disruptions and properly managing inventories. To make up for it, the vast majority of supply chain executives plan to increase their investments in preparedness strategies, which will have to include better data integration.

Indeed, this is a year for focusing on building resilience. Companies in the supply chain, logistics, and manufacturing sectors will be looking to diversify sourcing and invest in technology and sustainable practices, while they navigate a complex global landscape of economic volatility and geopolitical risk.

Innovations abounded in the industry that enhanced productivity and processes.

FEBRUARY 2024

C.H. Robinson's AI Load Scheduling

The transportation company's touchless appointment technology saves 7.4 hours per load by optimizing carrier schedules.

MARCH 2024

Cargo Thefts Near $700 Million

Organized efforts to steal goods sharply rise compared to the start of the COVID-19 pandemic.

APRIL 2024

Tracking for Textile Supply Chains

RFID technology tracks cotton and fiber origins, improving traceability in textile manufacturing processes.

JULY 2024

Japan's Underground Conveyor Belt

Plans have begun for a 310-mile automated underground package transportation system between Tokyo and Osaka.

AUGUST 2024

Ryder Completes AI Yard Pilot

So far, the Ryder AI program designed to automate yard operations has processed 10,000 truck detections with 99% accuracy.

« PAST

Augmented operations will enable new forms of fulfillment and local production.

FUTURE »

MID 2027

Nearshoring Regulations Expand

Governments will implement expanded regional trade agreements and incentives to localize supply chains, fostering more secure and resilient trade ecosystems.

MID 2028

Path Optimization Algorithms Enable New Fulfillment Options

AI-powered path optimization algorithms will allow companies to offer flexible delivery options, improving customer satisfaction and reducing fulfillment costs.

LATE 2029

Magnetically Responsive Inks Transform Production

Real-time control over particle alignment using magnetically responsive inks will accelerate manufacturing speeds while improving the structural integrity of printed materials.

LATE 2030

Immersive Digital Twins Transform Supply Chain Monitoring

24/7 immersive digital twin technology will give the majority of large companies real-time insights into their supply chains, enabling predictive troubleshooting and optimized planning.

MID 2033

Underground Nano-Fulfillment Centers Streamline Logistics

Automated underground transport systems will revolutionize urban logistics, moving goods seamlessly between hubs and delivery points while alleviating surface congestion.

Emerging trends offer leaders a way to prioritize and focus.

Prioritize Technological Debt Hurdles

Companies with technological debt face the cyclical effect of constantly losing out on operational efficiency. As reliance on real-time data and automation increases, laggards will experience bottlenecks, leading to higher costs, lower productivity, and delayed decision-making.

The Labor of the Future Is Here

Labor shortages are rapidly being circumvented through strategic automation and cobot integration. This is now the norm for what was once considered the future. Before implementation, determine how production practices and management will change as humans and cobots work alongside one another.

Shipping and Manufacturing Practices Will Change

In response to rising transportation costs and geopolitical challenges, businesses will shift toward more sustainable and flexible manufacturing and shipping practices. Go beyond nearshoring to rethink the local supply chain and production process.

Networks Will Become Autonomous

Automation is becoming a requirement for all back-of-house and manual processes. Include sourcing and procurement on that list, with secondary and tertiary backup plans (that are also automated) for potential disruptions.

Operational Skills Are Shifting

Gesture control and voice control operations are scaling, upending traditional operator activities. Companies will need to identify what skill void that leaves in their current human labor force.

Last Mile Could Become Instantaneous

With companies increasingly focused on local production and new developments in hyperlogistics, products might be offered instantaneously. Most manufacturers and e-commerce platforms are not prepared for this type of delivery model and should consider pricing and operational restructuring.

These individuals are at the forefront of development and transformation in the supply chain, logistics, and manufacturing industries.

- **Mark Albrecht, vice president for artificial intelligence at C.H. Robinson,** for progress on using AI to automate logistics management tasks.
- **Arun Rajan, chief operating officer at C.H. Robinson,** for working toward automating management tasks in the supply chain and logistics industries.
- **Dr. Alexandra Brintrup, professor at the University of Cambridge,** for leading efforts in using AI in supply chain networks.
- **Rupert Cruise and Phill Davies, co-founders of Magway,** for their work on underground delivery systems.
- **Aaron Zhang, co-founder and CEO of A2Z Drone Delivery,** for a drone-network-as-a-service model.
- **Juyoung Lee, research assistant at Korea Advanced Institute of Science and Technology,** for insights on gesture control in XR technology.
- **Dipali Goenka, CEO and managing director of Welspun Living Ltd.,** for work on automating data capture throughout the supply chain.
- **Jiaguo Yu, professor at China University of Geosciences,** for advancements on intelligent labels that can self-heal.
- **Patrick B.M. Fahim, for research with Delft University of Technology** on transforming ports into a physical internet.
- **Devin Bhushan, founder of Squint,** for work on automating data entry and augmented reality.
- **Shameek Ghosh, CEO of TrusTrace,** for its Forced Labor Prevention Solution.
- **Stephanie Gabriela Gomez Prieto, recent MIT graduate student,** for work on enabling demand forecasting for family-owned nanostores.

Supply chain could soon see opportunities for advanced tracking and procurement...

...but with increased automation comes new threats and challenges to address.

OPPORTUNITIES

Advanced RFID and DNA tracking

The development of these systems in the agriculture and textile industries creates opportunities to enhance transparency and traceability across supply chains, which in turn ensures product authenticity and reduces contamination risks.

Automated data relationships in manufacturing

With automatic data connections in the textile industry, manufacturers can improve production quality, track fiber authenticity, and meet customer expectations for premium products.

Dual-sourcing procurement models

New systems that integrate dual-sourcing and penalty constraints can help manufacturers mitigate their supply chain risks. Spreading dependencies across multiple suppliers ensures a reliable flow of goods even during disruptions.

Rapid production of advanced materials

The innovation of magnetically responsive inks in continuous 3D printing allows for greater control over material properties, giving industries like aerospace and robotics the ability to rapidly produce stronger and more specialized components.

THREATS

Cybersecurity vulnerabilities in smart ports

Increased digitization and automation of operations expose ports to cybersecurity risks. Vulnerabilities in connected systems could lead to service disruptions, data theft, or compromised infrastructure that affect global supply chains.

AI bias in procurement decisions

AI algorithms used in procurement processes could introduce biases that unfairly exclude suppliers, leading to a lack of diversity in the supply chain and potential reputational harm for companies relying on these systems.

Environmental risks from increased automation

The growing use of automated machinery, robotics, and AI systems in supply chains could result in higher energy consumption and increased carbon emissions, potentially clashing with global sustainability goals and regulations.

High costs of advanced tracking systems

The implementation of advanced tracking systems could lead to increased costs for smaller businesses, potentially limiting the widespread adoption of these technologies.

Companies must be purposeful in how they explore and ultimately integrate emerging technologies into their value chain.

Implement flexible omnichannel management systems that integrate across the entire supply chain. This will improve efficiency and adaptability in diverse operational needs, and help companies maintain a competitive edge in evolving markets.

Prepare for adaptive, self-healing supply chains that anticipate disruptions, reroute shipments, and resolve issues in real time without human intervention.

Make real-time route optimization and localized production capabilities a priority to improve operational efficiency and meet customer demands.

Facilitate DNA testing in the supply chain on site and at customer locations, using technology solutions to automate data collection and analysis, while improving efficiency and accuracy.

Leverage sector-agnostic data for omnichannel platforms where possible. Larger companies may find this easier, while smaller ones should seek partnerships to stay competitive.

Standardize gesture control across the supply chain, to make transitions between workers seamless and raise efficiencies during periods of high demand.

Technology Deployment
Capital Expenditure
Talent Development
Regulatory Influence

Important terms to know before reading.

ADDITIVE MANUFACTURING (AM)
A process of creating objects by adding material layer by layer, synonymous with 3D printing. It includes 4D printing, where objects evolve in response to external stimuli such as heat or moisture.

CUSTOMER RELATIONSHIP MANAGEMENT (CRM)
A system for managing a company's interactions with current and potential customers, often integrating data to deliver personalized customer experiences and improve sales processes.

DIGITAL TWIN
A digital representation of a physical object or system used to simulate, monitor, and optimize real-world operations. In logistics and manufacturing, digital twins allow for real-time monitoring and decision-making, improving accuracy and reducing downtime.

ENTERPRISE RESOURCE PLANNING (ERP)
A system that integrates various functions of an organization—such as development, manufacturing, sales, and marketing—into a single unified solution for better coordination and efficiency.

ENVIRONMENTAL, SOCIAL, AND GOVERNANCE (ESG)
A set of criteria used to evaluate a company's operations based on sustainability, ethical impact, and governance practices.

FULFILLMENT CENTERS
Warehouse facilities used for storing, packaging, and shipping consumer goods, often supporting e-commerce and retail logistics operations.

GENERATIVE ADVERSARIAL NETWORKS (GANS)
A class of machine learning models consisting of two neural networks—one generating data and the other evaluating it—used to create realistic synthetic data.

IMMERSIVE REALITY (XR)
A collective term for immersive technologies such as virtual reality, augmented reality, and mixed reality, used in applications ranging from entertainment to workforce training.

INTERNET OF THINGS (IOT)
A network of interconnected devices that collect, share, and analyze data to automate and improve operations. IoT spans sectors such as manufacturing, transportation, health care, and smart cities.

LAST-MILE DELIVERY
The final stage of the delivery process, where a product is transported from a distribution center or hub to its final destination, typically a residence or business.

LOGISTICS
The detailed coordination and management of the movement of goods, services, and information from the point of origin to the point of consumption.

MULTIMODAL LOGISTICS
The coordination and movement of goods using multiple modes of transportation—such as trucks, ships, trains, and airplanes—within a single shipment. Multimodal logistics integrates different transportation methods to optimize the efficiency, cost, and speed of moving goods across various distances and regions, often involving seamless transitions between carriers and transportation modes.

NANO-FULFILLMENT CENTERS
Small, hyperlocal fulfillment centers that leverage automation and 3D printing to produce and deliver goods quickly and efficiently. These centers are often integrated into urban environments to reduce shipping times and costs.

ORDER MANAGEMENT SYSTEM (OMS)
A system that manages the order fulfillment process, including inventory tracking, order processing, and delivery scheduling.

PRODUCT LIFECYCLE MANAGEMENT (PLM)
A software system that manages a product's lifecycle from its initial concept through design, manufacturing, service, and disposal, helping companies optimize product development and operations.

PROCUREMENT
The process of sourcing and acquiring the goods and services a company needs to meet its business objectives. It includes negotiations, contract management, and supplier relations.

QUANTUM COMPUTING
A computing technology based on quantum mechanics that enables complex calculations to be processed much faster than with traditional computers.

SMART CONTRACT
A self-executing contract with the terms of the agreement directly written into code. In logistics, smart contracts enable automated enforcement of agreements, such as making a payment based on predefined conditions.

SMART WAREHOUSES
Warehouses that use advanced technologies like AI, real-time data monitoring, and robotics to optimize storage, inventory management, and product picking. These warehouses improve operational efficiency and reduce human intervention.

SUPPLY CHAIN
The network of organizations, people, activities, information, and resources involved in the production and delivery of a product or service, from the sourcing of raw materials to delivery to the end consumer.

TRANSPORTATION MANAGEMENT SYSTEM (TMS)
A system used to plan, execute, and optimize the physical movement of goods, ensuring efficient transportation, cost control, and timely delivery.

WAREHOUSE MANAGEMENT SYSTEM (WMS)
A software system that manages and optimizes the operations of warehouses and distribution centers, including inventory tracking, order picking, and shipping.

SUPPLY CHAIN, LOGISTICS, & MANUFACTURING TRENDS

SUPPLY CHAIN & LOGISTICS MANAGEMENT

3RD YEAR ON THE LIST

AUGMENTED & AUTOMATED PROCESSES

WHAT IT IS

AI-powered automation is revolutionizing supply chains as it enhances precision, efficiency, and decision-making across logistics, procurement, and operational workflows.

HOW IT WORKS

Ryder Systems' integration of AI-powered computer vision in yard management is a prime example of how augmented and autonomous processes are transforming supply chain efficiency. Using Terminal Industries' technology, the company automated truck tracking and boasts a 99% accuracy rate in identifying more than 10,000 vehicles. This automation replaces manual tasks like recording license plates and DOT numbers, as well as integrates with third-party databases to provide complete vehicle profiles. The result of instant action to such information: streamlined, real-time decision-making.

Logistics firm Qued employs AI to automate email-based scheduling through natural language processing. The tool reads and responds to email requests, simplifying appointment bookings. This autonomous process reduces workloads for small to midsize logistics firms, saving brokers and carriers time and improving customer satisfaction.

AI further enhances procurement processes. A South Korean system uses machine learning models to match companies with international bidding opportunities. By parsing vast amounts of procurement data, it precisely evaluates company profiles against bid requirements, offering real-time recommendations that also improve bid success rates.

Even in supply chain resilience, the Two-Stage Deep Decision Rules method uses deep learning to manage uncertainties like fluctuating demand and supplier disruptions. This optimizes resource allocation and aids in adapting to market shifts.

WHY IT MATTERS

These processes have the potential to enhance accuracy, speed, and resilience of supply chains. Traditional logistics often rely on manual data entry, but that's asking for errors and delays. AI can process large volumes of data in real time, reducing errors, cutting costs, and accelerating logistics operations for quicker deliveries and improved customer experiences. Automating workflows like truck tracking or appointment scheduling transitions tasks toward autonomous processes, enhancing precision and service quality. This shift reduces the need for human intervention in routine tasks, giving workers more time to pay attention to more complex activities.

Geopolitical uncertainties and persistent market fluctuations are forcing supply chains to become more robust and adaptive. AI tools that make decision-making more informed and efficient—even under uncertain conditions—empower businesses to stay competitive and meet demand despite disruptions. Automation also plays a crucial role in sustainability by reducing operational waste and optimizing resource allocation. All of these factors position AI as a vital element in building resilient, sustainable supply chains, not just for efficiency but also for future-proofing the industry against unforeseen challenges.

3RD YEAR ON THE LIST

REAL-TIME OPTIMIZATION

WHAT IT IS

The ability to optimize logistics in the moment positions companies to make the most of their container space, better allocate resources to reduce costs, and scale their supply chains.

HOW IT WORKS

Real-time optimization uses advanced algorithms to tackle complex logistics issues, such as fleet management and container utilization. A key example is research to use algorithms like the Hybrid Genetic Algorithm and solutions like the Solomon Insertion Heuristic to optimize fleet delivery routes while considering constraints like vehicle capacity and customer time windows. The algorithm mimics natural selection to evolve route solutions while using a hybrid approach to enable faster convergence to high-quality solutions, enhancing fleet efficiency. AI is also used to predict container utilization rates with long short-term memory networks and model-agnostic meta-learning, accounting for long-term dependencies in time-series data. Machine-learning algorithms like K-Means clustering segments shipping routes, to optimize container allocation and adjust resources dynamically.

The multimodal transport logistics system is another beneficial innovation for small and medium-size businesses. It combines subjective inputs (user preferences) with objective data (location, traffic) for precise, real-time logistics quotations. It optimizes both delivery and return processes by integrating multiple transportation methods and reducing manual intervention. AI-powered demand forecasting helps small businesses manage inventory in real time, minimizing stock issues. Companies like C.H. Robinson use real-time AI for scheduling, which reduces inefficiencies, while Oracle’s plans for a real-time worker oversight system ensures accuracy in manufacturing and supply chains.

WHY IT MATTERS

By optimizing routes, container usage, and workforce management in real time, companies can reduce operational costs, including those related to fuel consumption, labor, and vehicle wear. This leads to more sustainable logistics practices, such as lowered carbon emissions and improved resource allocation. With predictive models and real-time data, logistics providers can adjust dynamically to changing conditions, such as traffic patterns, fluctuating demand, or supply chain disruptions, all musts for establishing faster, more reliable deliveries. AI-driven logistics solutions are set up to scale efficiently, to manage large fleets and complex shipping routes as e-commerce and global trade expand.

Real-time optimization also improves the decision-making by providing actionable insights into future demand and resource needs. Companies can anticipate peak shipping seasons and allocate containers more effectively, reducing underutilization or congestion. This results in better customer experiences, with more on-time and complete deliveries, and keeps complaints down. The long-term effect will be a more streamlined, resilient, and environmentally friendly supply chain. Integrating these innovations is quickly becoming a necessity rather than a luxury.

“

Global supply chains are broken—too many are still being run on Excel... Operators spend countless, frustrating hours battling endless spreadsheets... It’s inefficient, chaotic, costly, suboptimal and completely unfit for the modern world.

Dave Clark, former Amazon Consumer CEO & Co-founder of Auger

3RD YEAR ON THE LIST

VISIBILITY TRACK AND TRACE

WHAT IT IS

True traceability is happening throughout supply chains, for up-to-date tracking of movements and an understanding of where materials originated. This enhanced transparency is addressing long-held sustainability and security concerns.

HOW IT WORKS

Tracing the origins of goods has become a must, not only for compliance reasons but to build customer trust. In agriculture, innovations in DNA tracking allow for rapid, on-site identification of crop traits. NanoBio Designs has developed portable DNA tests so that grain handlers can instantly verify genetic traits, while also reducing contamination risks and meeting export compliance requirements. In textiles, RFID tags are used in the production process to track fibers, bales, and equipment. This digital traceability verifies claims about origins of materials, such as premium cotton types. Blockchain technology enhances this data integrity even further by creating an immutable ledger.

Besides tracking goods, these technologies also automate the relationship between different production stages by linking inputs, processes, and outcomes in a seamless digital system. Real-time monitoring offers unmatched visibility plus improved quality control and operational efficiency. Additionally, innovations like the CICAPT-IIoT dataset, which addresses risks in Industrial Internet of Things (IIoT) environments, enhance cybersecurity. By integrating provenance data, this system improves the detection of advanced persistent threats, to maintain the integrity of interconnected supply chains and help companies develop stronger defenses against cyberthreats.

WHY IT MATTERS

Across industries, enhanced traceability and real-time data in supply chains are becoming the norm and are increasing the return on investment. Rapid genetic testing could help prevent billions in losses from rejected agricultural, textile, and other shipments by reducing contamination. This granular level of visibility also helps streamline operations by reducing manual errors, increasing efficiency, and enabling quicker responses to disruptions. Consumers can feel more confident about companies' product origin claims, ethical sourcing, and sustainability. These advances also help both governments and businesses manage their compliance with international regulations, for improved global trade operations.

The increased use of blockchain takes sustainability and visibility to an even higher level. By incorporating blockchain technology, companies can address growing concerns about data integrity in supply chains, particularly in high-value or sensitive industries such as pharmaceuticals, electronics, and food safety. The immutable ledger component of blockchain should become a priority for companies as government regulations could soon require data to be provided through such platforms. By acting on this now, companies can also shore up concerns about future cybersecurity risks.

3RD YEAR ON THE LIST

ESG TRACKING AND DECLARATIONS

WHAT IT IS

Environmental, social, and corporate governance (ESG) reporting has become a critical requirement for companies across the globe due to new regulations, particularly the EU's push for heightened transparency and accountability in supply chains.

HOW IT WORKS

Innovative platforms are helping companies meet the heightened ESG requirements for tracking and reporting across their supply chains. Shipzero, a green logistics startup, recently secured funding to assist logistics providers in monitoring and reducing transport emissions. The new funding supports the development of a "Book & Claim" solution that companies can use to get credit for supporting sustainability attributes of transportation fuels that they do not directly use.

Heavy-duty trucking is responsible for more than 3% of global emissions, and some in the industry are working to reduce trucking's impact while saving money. Like Shipzero, the climate-focused nonprofit Center for Green Market Activation also uses a Book & Claim system, but it's focusing on helping carriers fill low-emission trucks with guaranteed shipments. Carriers can use it to justify their investment in new technology by gaining stable business for their low-emission fleets. Blockchain-enabled platforms are also becoming crucial in ESG compliance by enhancing transparency and traceability, with real-time monitoring of contracts and supply chain operations to detect anomalies, predict risks, and secure sensitive data. Additionally, AI integration in supply chain solutions, like Alibaba's AI-powered sourcing engine, is making B2B procurement processes more intuitive and efficient.

WHY IT MATTERS

The shift toward more transparent, ethical, and sustainable supply chains is being driven by both regulatory requirements and market demand for environmental and social responsibility. While many companies are concerned about additional costs due to new procedures, platforms like Shipzero and blockchain-based logistics solutions are not only helping companies meet ESG targets but improving their overall operational efficiency. These innovations offer critical tools for tracking carbon emissions, ensuring regulatory compliance and improving supply chain security—and companies implementing them are better positioned to meet the growing calls for sustainable business practices.

However, the adoption of these technologies requires significant investment and operational shifts, which will be a challenge for smaller companies and those without advanced reporting systems. Companies facing high technological debt may need to find partners to address their current and future needs. One simple step companies could take would be to investigate current fuel usage by their transportation and logistics partners and services. Switching to new fuel sources or local production would require little to no technological change. Even with its challenges, this trend marks a pivotal moment in the transition to a more sustainable global economy.

SCENARIO YEAR 2027

DNA SHOPPING

It's 2027, and in Sweden, grocery shopping has leaped into the future with the integration of DNA tracking and cutting-edge technology. Klara, a resident of Gothenburg, steps into her local eco-friendly grocery store, one of many local options that now offer a fully immersive shopping experience. She pulls out her smartphone, equipped with a custom XR app, to explore the products more closely as she walks down each aisle. This has become a key part of Klara's routine; she now expects to know the full lifecycle of her groceries, from farm to table. She holds her phone over a bag of flour, and instantly, the app scans the product, revealing its digital twin. Klara can see the exact origins of the wheat, harvested from an organic farm in the Skåne region. As Klara continues her shopping, scanning items like pasta and oats, she receives personalized recommendations for products with DNA scores that align with her physiological wellness directives. For Klara, and many like her, this level of transparency and technological sophistication is more than a convenience—it's an expectation in a country that consistently leads the world in health and innovation.

3RD YEAR ON THE LIST

OMNICHANNEL MANAGEMENT PLATFORMS

WHAT IT IS

While management platforms have traditionally been siloed, omnichannel management platforms combine various tools to serve as an end-to-end solution across industries.

HOW IT WORKS

Startups like Didero are advancing omnichannel platforms for midsize companies, to ease supply chain tasks like finding suppliers, negotiating contracts, and analyzing costs. In cross-border logistics, omnichannel platforms such as Cargado simplify US-Mexico freight movement by addressing regulatory complexities. These platforms are increasingly focusing on cybersecurity: one example is SPatch's patch management services. These services secure omnichannel systems by using differential symbolic execution to ensure software updates fix vulnerabilities without disrupting functionality.

Blockchain is another key component because it's improving supply chain traceability. Advanced systems now allow for multi-condition queries across blockchain data, filtering by transaction details or timestamps. Adaptive Bloom filters and Trie trees facilitate faster searches, offering real-time validation and feedback. This significantly enhances logistics managers' ability to quickly identify and resolve issues like shipment delays or tampering. AI-powered features, like those in C.H. Robinson's Digital Dispatch, use real-time data to optimize load matching for carriers, accelerating freight booking and reducing manual tasks.

WHY IT MATTERS

Whether it's in logistics, retail, or manufacturing, omnichannel management platforms offer customizable, scalable solutions that cater to diverse industry needs. In situations where flexibility to address specific tasks becomes increasingly vital, comprehensive platforms that integrate procurement, logistics, and real-time analytics provide major advantages. They reduce the need for multiple systems, lowering costs and increasing agility. They also empower companies to develop cohesive long-term strategies, optimize resource allocation, and enhance decision-making.

Platforms capable of managing global trade complexities are critical for seamless cross-border operations. So is the need for robust cybersecurity, especially with the rise in digital platform complexity. Tools like SPatch demonstrate how omnichannel systems must balance efficiency and security to protect supply chains from cyberattacks. Omnichannel platforms are now key enablers for growth and resilience in a dynamic market. They must be adaptable across sectors and tasks, to help companies meet immediate goals and plan strategically for future challenges. Investing in flexible, sector-agnostic platforms positions businesses to manage market shifts, regulatory changes, and technological advances.

3RD YEAR ON THE LIST

DIVERSIFYING THE PROCUREMENT PROCESS

WHAT IT IS

Procurement processes are increasingly affected by global disruptions. To mitigate these risks, companies are turning to advanced technologies that offer diversity, flexibility, and resilience in their supply chains.

HOW IT WORKS

When it comes to diversifying the procurement processes, new AI-powered systems are driving the trend, by creating what's known as flexible, liquid networks that can adapt in real time to shifting demands and challenges. One major innovation is dual-sourcing combined with penalty constraints. The first aspect mandates using multiple suppliers for the same product, reducing reliance on a single supplier and mitigating the risk of supply chain breakdowns. With penalty constraints, companies ensure that suppliers meet their performance standards. Modern procurement systems are also tracking suppliers across multiple tiers and integrating direct and indirect suppliers in the decision-making process.

With liquid networks, procurement processes continuously adapt to changes in material flow and supplier capabilities. AI-driven systems monitor procurement timelines and optimize purchases based on current demand. AI systems can further diversify procurement by continuously analyzing data and adjusting workflows; they track every step in the process, identifying inefficiencies and making automatic adjustments to improve speed and accuracy. Additionally, through community benchmarking, companies compare their performance against industry peers so they can make data-driven decisions based on cost-efficiency and improve how they collaborate with their suppliers.

WHY IT MATTERS

The pandemic, geopolitical tensions, and environmental crises have revealed the limitations of traditional procurement strategies that rely on single suppliers or rigid systems. The shift toward liquid procurement networks will make companies more adaptable to sudden changes. Real-time AI systems provide unprecedented transparency, giving companies the ability to swiftly respond to changes in supplier availability, pricing, and material needs. This also creates a more fluid relationship between companies and suppliers, as businesses can dynamically adjust their procurement strategies to achieve optimal prices without compromising supply chain stability. This flexibility is crucial for industries, like manufacturing and consumer goods, that have frequently changing material needs.

AI-driven procurement also reduces reliance on manual interventions. Automated decision-making systems can adjust purchase orders, reallocate tasks, and suggest improvements as needed, streamlining operations and reducing administrative overhead. Companies adopting these technologies will build resilient, scalable supply chains that can withstand future disruptions and provide greater worker autonomy and time. As more autonomous systems are implemented, the refinement process of worker routines could become a challenge if daily tweaks to operations become an annoyance to workers.

SCENARIO YEAR 2032

SELF-HEALING NETWORKS

By 2032, the Liquid Logistics Network (LLN) has evolved into a fully self-healing, autonomous system capable of resolving disruptions without human intervention. These networks are now equipped with advanced predictive analytics and AI that monitor countless data streams—weather patterns, geopolitical shifts, market conditions, and even cyberthreats—enabling them to plan for disruptions before they occur. For instance, if a hurricane is forecasted to hit a major port, the system will reroute shipments days in advance, redirecting goods to alternate hubs and rebalancing inventory across warehouses to avoid delays. Autonomous drones and electric trucks are dispatched from nearby cities to handle overflow, ensuring that the entire supply chain continues to function seamlessly, even in the face of major logistical bottlenecks.

When unexpected disruptions do occur, such as a cyberattack aimed at bringing down a key supplier's infrastructure, the LLN's blockchain-backed security protocols spring into action. Blockchain ensures that no critical data is lost or compromised, while smart contracts instantly trigger backup processes, like switching to secondary suppliers or rerouting shipments through safer channels. These networks have grown so advanced that they not only resolve issues in real time but also "learn" from each incident, adjusting algorithms to prevent future occurrences of the same nature. In a world where supply chains are increasingly complex and globalized, these self-healing capabilities provide companies with constant continuity, even during crises, while minimizing human intervention and optimizing for cost and sustainability. The era of reactive logistics management is over, replaced by a proactive, intelligent system that keeps the global economy flowing smoothly no matter the challenges it faces.

3RD YEAR ON THE LIST

LAST-MILE SOLUTIONS

WHAT IT IS

Last-mile solutions optimize the final stretch of the delivery process to get products to customers quickly and efficiently.

HOW IT WORKS

New platforms use real-time data to dynamically adjust routes and delivery windows. For example, drivers and supervisors at Solar Coca-Cola in Brazil rely on Descartes' route execution and fleet performance management solution to manage delivery routes as they're happening. Accounting for traffic, weather, and delivery windows, the mobile-based platform also captures customer information at delivery points along with driver progress, so routes can be continuously re-sequenced as needed.

AI research, especially in reinforcement learning for large language models (LLMs), is contributing to progress in last-mile optimization. New systems can fine-tune LLMs to produce relevant outputs without human input, for better delivery communications and operations. Companies like Best Buy use AI for customer support and delivery tracking to reduce customer frustration and enhance the delivery experience. Wiliot, an IoT company, leverages generative AI for natural-language interactions with IoT-connected products so that customers can communicate directly with packages during transit. Innovations in smart storage solutions are also advancing last-mile delivery. Companies like Arrive AI provide a "mailbox-as-a-service" platform, offering secure, smart storage for deliveries when recipients aren't available. The solution includes self-powered IoT Pixels and AI for real-time data analysis.

WHY IT MATTERS

The transformation of last-mile delivery is crucial for meeting consumer expectations of rapid and convenient delivery, especially in e-commerce. The upsides of AI, IoT, and real-time data optimization are enhanced delivery efficiency, reduced costs, and improved customer experiences. But there's also the potential for increases in urban traffic congestion. More delivery vehicles on the road could exacerbate existing traffic issues. While AI-enabled routing can choose the best paths to avoid congestion, the cumulative effect of increased deliveries may still be slowed traffic and increased road wear.

Sustainability and carbon emissions are also significant concerns. The frequency of last-mile deliveries raises questions about carbon emissions and energy use. Companies that adopt sustainable practices like investing in electric fleets, drones, and cargo bikes could reduce environmental impact.

Infrastructure will have to evolve to support these solutions. Urban areas may need to redesign spaces for delivery vehicles, drones, and smart mailboxes, such as dedicated lanes or parking zones, to minimize disruption to communities. Investing in new technologies and smart city solutions is essential to balance efficiency, customer satisfaction, environmental impact, and infrastructure demands.

3RD YEAR ON THE LIST

SMART PORTS

WHAT IT IS

Smart ports leverage advanced technologies to enhance operational efficiency, supply chain integration, and environmental sustainability.

HOW IT WORKS

Around the world, ports are modernizing through digitization, real-time data analytics, AI integration, and electrification. The Port of Halifax is creating a digital data hub that integrates information from trucking, marine, and rail operations. Its real-time dashboards monitor vessel turnaround times, container movements, and truck scheduling. The Port of Bellingham in Washington is installing electrical plugs so that docked ships can connect to the electrical grid, reducing their reliance on diesel engines and cutting emissions. Another advancement in port management is the use of automatic information system data for predictive modeling. This data helps estimate port congestion while providing accurate ETAs for ships and better forecasting of where goods will be at any point in time.

Ports are also using innovative machine learning models like DBSCAN and XGBoost to identify and manage congestion points. Advanced predictive models combining linear regression with machine-learning algorithms such as random forest can more accurately forecast incoming commodity volumes. The emerging Physical Internet paradigm could create a hyperconnected logistics system by standardizing protocols and treating goods movement similar to how data transfers on the internet. Additionally, extended reality and digital twins are enhancing precision and safety in remote operations by allowing operators to control machinery from a realistic representation of the physical environment.

WHY IT MATTERS

Turning ports into smart, interconnected hubs will enhance global supply chain resilience and efficiency. By adopting real-time data analytics, AI, and automation, ports can reduce bottlenecks and improve cargo flow. AI and machine learning enable predictive analysis for better congestion management and resource allocation, leading to more accurate ETA predictions and streamlined goods movement. Electrification and a focus on environmental sustainability are necessary for reducing the maritime industry's carbon footprint. New advancements support the development of hyperconnected logistics networks, to further improve the performance of individual ports and the overall global supply network, and ultimately revolutionize how goods are managed and delivered.

XR technologies and digital twins will make it so operators can precisely control heavy machinery from afar, reducing the risks in challenging environments they face today. This not only improves safety but also allows for better resource allocation and predictive maintenance, minimizing downtime. Ports play a crucial role in the future of global trade and are poised to set new standards for efficiency, sustainability, and operational excellence in the supply chain.

SCENARIO YEAR 2040

GESTURE PORTS

It's 2040 at Mumbai's Smart Port, and Arjun, an immersive port operator, begins his day by activating a small wearable pin on his shirt. With a simple flick of his hand, the entire port springs to life in front of him, displaying real-time data on every ship, container, and vehicle in the port's bustling ecosystem. The digital twin projected by Arjun's wearable gives him full control of the port operations without the need for cumbersome equipment or physical terminals. When he swipes to the right, an autonomous crane begins lifting a container from a recently docked ship, and with a pinch-and-zoom motion, he zooms into the container details.

As one of the AI-powered ships connects to the port's electrification grid, Arjun gestures to check the status of the energy draw and cargo synchronization. The XR interface seamlessly overlays critical information, allowing him to use simple motions to make adjustments, such as rerouting cargo pickups or shifting the order of containers being unloaded to avoid congestion. Drones assist in monitoring, and smart containers adjust themselves in real-time, ensuring smooth transitions and deliveries. His wearable pin keeps the digital twin active wherever he goes, allowing him to stay connected to the port's operations even while on the move. At the end of his shift, Arjun taps his wearable to sign off, and it automatically logs his work time.

MANUFACTURING & DISTRIBUTION ENHANCEMENTS

3RD YEAR ON THE LIST

CONTINUOUS ADDITIVE MANUFACTURING

WHAT IT IS

Increasingly refined and reliable, continuous additive manufacturing is living up to its name with seamless, nonstop production of items even as errors are monitored in real time.

HOW IT WORKS

The production process known as continuous additive manufacturing enables nonstop 3D printing, eliminating traditional pauses between layers. Innovations like real-time error detection systems, such as the AlexNet-SVM model, monitor common defects like “spaghetti” and “stringing” with high accuracy, reducing material waste and downtime. This technology ensures stability and quality during the continuous operations. Additionally, magnetically responsive inks offer precise control over material alignment during extrusion, and they don’t require pauses for curing or drying. They enable the rapid production of complex microstructured composites.

Recent advancements include a vertical conveyor system with build plates that unfold during printing and fold back to release the finished product, allowing for the immediate start of the next item. This eliminates downtime and facilitates the production of taller, larger objects in high-volume settings. Another breakthrough is the development of flexible multifunctional energetic fibers. These can be precisely laid on complex surfaces and ignited using low-voltage input, offering improved fire suppression capabilities by allowing rapid, controlled ignition in critical environments.

In metalworking, using chitinous biomolecules allows for producing metallic composites at ambient temperatures, which require less energy consumption, and enables making custom parts on site. Finally, all-in-one printers like Markforged’s FX10 offer seamless switching between metal and composite printing, enhancing productivity and reducing downtime.

WHY IT MATTERS

Continuous additive manufacturing is allowing for nonstop, efficient manufacturing processes that significantly reduce waste and enhance the quality of products. For businesses, the ability to produce high-quality, customized items more quickly and at a lower cost will provide a competitive edge in industries like aerospace, electronics, and advanced manufacturing. The adoption of this technology is particularly crucial for sectors requiring precision and durability, as it offers enhanced control over a final product’s properties and performance. Advancements in this field have the potential to improve safety measures in various applications, and could directly impact companies’ operational security and risk management.

By reducing energy consumption and environmental impact, continuous additive manufacturing also aligns with sustainable business practices, which is increasingly important for regulatory compliance and corporate responsibility. As this capability becomes more widespread, it will transform supply chains by enabling on-demand production and reducing dependency on traditional manufacturing methods. Companies may need to rethink the value of production time and cycles if 24/7 production becomes more of the norm, which should be incorporated into systems that leverage AI-driven demand forecasting.

3RD YEAR ON THE LIST

SMART WAREHOUSES

WHAT IT IS

Smart warehouses are optimizing efficiency in supply chains, reducing human intervention, and introducing innovations like quantum computing and gesture-based control.

HOW IT WORKS

In China, companies like Shein and Xiaomi are leading this transformation with advanced logistics hubs and fully autonomous factories. Shein is working on a smart supply chain hub in Guangzhou that will combine its stocking, picking, and distribution activities into one seamlessly run logistics park. Xiaomi's autonomous factory in Beijing showcases the future of manufacturing by producing smartphones with minimal human intervention by using AI-driven production software and advanced robotics.

Intelligent warehouse management systems put goods where they need to be for fast access and cost savings based on real-time factors like product demand and environmental conditions. Advanced analytics provide insights into frequently purchased product combinations, enabling strategic bundling and promotions while ensuring efficient operations throughout the storage lifecycle.

Quantum-enhanced generative adversarial networks are also being explored to further enhance warehouse automation, with more precise supply chain optimization models. Autonomous forklifts and gesture-based control using digital twins keep these smart environments running and keep them well maintained. Advanced predictive maintenance models using technologies like dynamic time warping and variational autoencoders, will improve the detection and prognosis of faults in industrial components.

WHY IT MATTERS

By integrating AI, robotics, and advanced analytics, companies can automate tasks like stocking, picking, and distribution, significantly reducing operational costs and improving response times. This is vital in today's market, where customer expectations for rapid, on-time deliveries are higher than ever. It is also an important shift due to decreasing labor.

The application of quantum computing in logistics amplifies these benefits, by helping businesses more quickly solve complex optimization problems, ultimately leading to more efficient routing and inventory management. With gesture-based controls and digital twins providing real-time monitoring and remote management capabilities, companies can adapt to market fluctuations and maintain smooth operations under the most challenging conditions.

Additionally, smart warehouses help mitigate workforce shortages by automating repetitive tasks to free up employees to focus on higher-value activities. Predictive maintenance models enhance equipment reliability, minimizing downtime and extending the lifespan of assets. This means businesses can achieve consistent productivity, lower maintenance costs, and ultimately enhance customer satisfaction by ensuring reliable, efficient delivery of goods.

“

Automated robots never get tired, can work 24/7, and have no aversion to taking on the laborious, hazardous, and heavy-lifting work that can tire humans... Robots can, and have, literally stepped in and saved the day.

Richard Gilliard, CEO of Renovotec

SCENARIO YEAR 2028

PRINTED FIRE SUPPRESSION

In 2028, on the outskirts of Stockholm, a drone swarm hovers over a river gorge to construct a lightweight, carbon-fiber bridge. The cluster of drones is part of a cutting-edge infrastructure project that is utilizing continuous additive manufacturing technology to 3D print the bridge. Each drone carries both a spool of carbon fiber and flexible energetic fibers, weaving together the intricate structure mid-air. As the drones work in synchrony, assembling the bridge section by section, an unexpected short circuit in a drone's battery pack causes a fire to erupt in the newly laid bridge fibers. Smoke begins to rise, and the potential for catastrophic damage becomes apparent. The swarm's energetic fibers detect the fire through embedded temperature sensors. Within seconds, they release a fire-retardant chemical embedded within their structure, snuffing out the flames before they can spread further.

The drones pause their work momentarily as the fire suppression completes, ensuring no further threats remain. The flexible energetic fibers, initially developed for military purposes, now prevent the destruction of critical infrastructure, showcasing their versatility. Once the fire is extinguished, the drone swarm resumes its task, picking up where it left off. The continuous 3D printing process remains uninterrupted, thanks to the real-time adjustments and automated safety systems in place.

By the end of the day, the bridge's skeleton is complete, with only minor delays, demonstrating the powerful combination of continuous additive manufacturing and advanced safety technologies that have transformed modern construction. The project continues, now more resilient than ever, with the confidence that any future threats can be swiftly neutralized by this innovative system.

3RD YEAR ON THE LIST

NANO-FULFILLMENT CENTERS

WHAT IT IS

Nano-fulfillment centers are redefining local manufacturing and logistics by combining 3D printing and underground automated networks to enable quick, on-demand production and efficient delivery.

HOW IT WORKS

Nano-fulfillment centers represent a new approach to manufacturing and logistics, with a focus on hyperlocal production and delivery. The "Made in Old Town" project in Portland, Oregon, serves as a pioneering example. Transforming a historic neighborhood into a hub for sustainable footwear and apparel manufacturing, the 30,000-square-foot green manufacturing facility will be equipped with advanced additive manufacturing technologies for brands to produce small batches and prototypes locally.

Looking in the opposite direction of drones, companies are also exploring underground automated networks for efficient product delivery. Leading the way are projects like Magway in the UK and Japan's 310-mile automated underground transportation system: They're designed to mitigate issues such as traffic congestion and greenhouse gas emissions by shifting deliveries to underground channels. The Japanese system aims to handle the cargo equivalent of 25,000 trucks daily, significantly reducing the strain on surface transportation.

In addition, the integration of digital twins, like inVia Robotics' Twin IQ, is enhancing the efficiency and performance of fulfillment centers. By simulating warehouse environments and workflows, businesses can optimize their layouts and processes, to ensure real-life operations run smoothly and meet tight deadlines. The combination of advanced manufacturing, underground logistics, and digital twin technology creates a robust framework for nano-fulfillment centers.

WHY IT MATTERS

Nano-fulfillment centers should be a high priority for companies looking to protect themselves from disruption. By localizing production and using advanced manufacturing techniques, nano-fulfillment centers reduce the carbon footprint associated with long-distance shipping and mitigate the risks of disruptions in the global supply chain. The use of underground automated networks for delivery will help address urban challenges like traffic congestion and pollution. This trend has the potential to revitalize local economies by bringing manufacturing jobs back to communities, promoting sustainability, and fostering innovation in product design and delivery methods. This could also lead to better product distribution to rural areas.

Additionally, these centers enhance the consumer experience by enabling rapid production and delivery of customized products, meeting the growing demand for personalization and speed. The use of digital twin technology keeps operations efficient and adaptable, giving businesses agility to respond to shifting market demands. As the logistics and manufacturing industries continue to embrace these innovations, expect to see a significant transformation in how goods are produced, distributed, and consumed.

3RD YEAR ON THE LIST

ACTIVE & INTELLIGENT PACKAGING

WHAT IT IS

Active and intelligent packaging integrates advanced materials and technologies to preserve products, monitor their conditions, and reduce waste.

HOW IT WORKS

Among the significant advancements in packaging is nanoclay-based bio-packaging, which utilizes various types of clay to enhance mechanical strength and barrier properties. These nanocomposites are embedded into bio-based polymers, improving thermal stability and reducing permeability to gases and moisture, thus extending a product's shelf life. Some composites even incorporate antimicrobial agents like copper oxide to inhibit microbial growth, further ensuring food safety. Another breakthrough is UV-blocking films, which use UV-absorbing agents to protect food from the photochemical reactions that can degrade quality. By absorbing, reflecting, or scattering UV radiation, these films significantly extend how long a food product can last. Additionally, oxygen-scavenging films with coatings like pyrogallic acid help reduce oxygen levels in packaging, to slow down microbial growth and maintain freshness, particularly in sensitive products.

Reusable packaging solutions aim to reduce waste by using replaceable components. Innovations like self-heating blister packaging incorporate mechanisms that activate heating zones upon contact with water, allowing for customizable heating without external sources. These reusable systems reduce waste by enabling multiple uses with replaceable components. Scientists are also developing self-healing electronics for labels and sensors, so they can repair minor damages and continue functioning without intervention.

WHY IT MATTERS

The evolution of active and intelligent packaging is significant for the manufacturers, consumers, and the environment. Nanoclay-enhanced bio-based materials reduce reliance on plastics, supporting companies' sustainability goals through biodegradability and reduced waste. Improved packaging performance directly translates to an extended shelf life, reducing food waste—a critical global challenge. The enhanced strength and barrier properties keep food products fresher for longer while reducing the need for preservatives. Other advancements can enhance user experience, by making packaging more than just a container but an active participant in food safety and quality control.

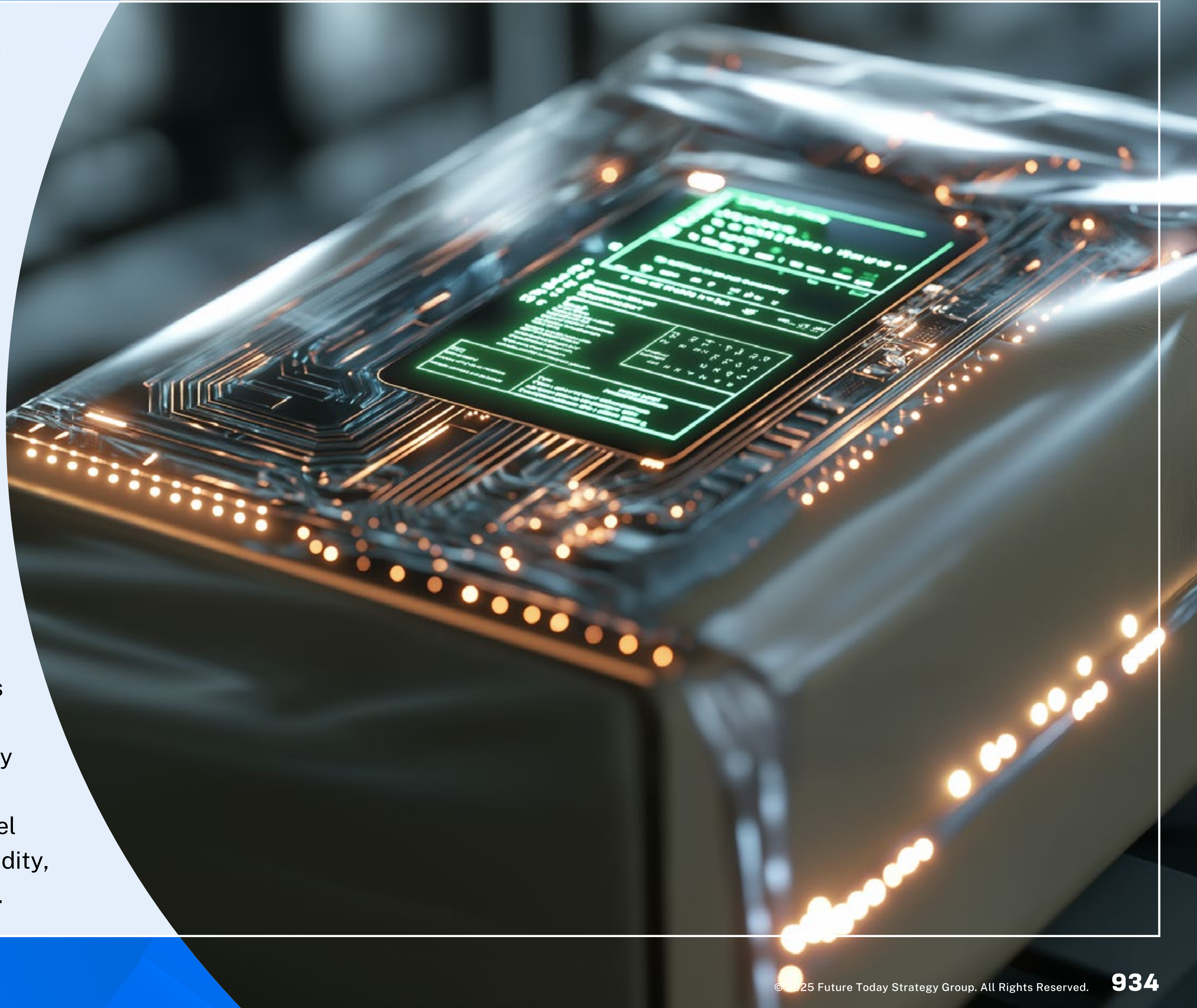
However, these innovations come with potential cost implications. As packaging becomes more intelligent and active, the cost of production and investment in these technologies may drive up shipping and product costs. A solution could be having consumers opt in to pay an additional fee for enhanced packaging features, especially for products where safety and quality are paramount. So, while active and intelligent packaging presents a step forward in sustainability, efficiency, and user engagement, it also opens discussions on cost distribution and consumer choice.

SCENARIO YEAR 2030

LABELS SAVE THE DAY

It's 2030 and in the control room of a pharmaceutical smart warehouse, Johan notices an uptick in alerts coming through his screen. The rise in same-day drone deliveries has led to a new wave of criminal activity: hacked drones that drop off packages in unauthorized locations. With the high value of pharmaceutical shipments, the supply chain has become a prime target for these attacks. As Johan scans the incoming data, a notification pops up. One of the drones carrying critical medication was tampered with mid-flight.

The hacker had successfully redirected the drone, causing it to drop the package at a suspicious location. However, the warehouse's real-time monitoring system, powered by smart labels, was already in action. The moment the package's seal was broken, the label sent out a cascade of alerts: first to Johan's screen and then directly to the authorities. The smart label's GPS tracking provided the exact location of the breach, so local law enforcement could swiftly respond. The label's innovation didn't end with the alert. As the hacker tampered with the package, its stretchable self-healing electronics in the label automatically repaired any damage, keeping the internal tracking systems fully operational. Even as the package sits at the wrong drop-off point, the label continues to monitor environmental conditions like temperature and humidity, ensuring that the integrity of the pharmaceuticals won't be compromised.



3RD YEAR ON THE LIST

AUTONOMOUS COBOTS FOR OPTIMIZATION

WHAT IT IS

Autonomous collaborative robots (cobots) are revolutionizing warehousing and delivery by improving operational efficiency, stock accuracy, and workflow management.

HOW IT WORKS

Warehouses that use cobots are noticing upticks in efficiency and accuracy of inventory. FLX Logistics employs DexoryView, merging autonomous mobile robots with digital twin technology for real-time stock monitoring and workflow optimization. Cobots like BMW's Figure 02 humanoid robots demonstrate high dexterity when they assist in tasks like precise fitting in car chassis assembly.

AI integration enables cobots to perform tasks needing human-like skills. Amazon and Rockwell Automation use AI models like Covariant Brain and Nvidia's Isaac in cobots for improved efficiency. Innovations include wearables like the "Third Thumb," an additional limb that a study found 98% of participants could use successfully within a minute. In collaborative manipulation tasks, cobots handle delicate items alongside humans to avoid damaging torques while increasing safety and reducing worker strain.

Drones are already deployed in environments like Ikea's fulfillment centers for stock management. A2Z Drone Delivery's "drone-network-as-a-service" allows autonomous drone docking for recharging and package handling. Companies like DroneUp provide enhanced drone capacity, with autonomous drones traveling at 60 mph and carrying up to 10 pounds. Autonomous delivery vehicles like the Vayu One, using a transformer-based mobility model, can transport up to 100 pounds at 20 mph without lidar, making them ideal for diverse environments.

WHY IT MATTERS

Cobots enhance safety and productivity by enabling sophisticated logistics solutions. They address the challenge of labor shortages and the demand for higher efficiency in logistics as they work alongside humans, allowing businesses to maintain operations even with reduced workforces. By providing real-time data and predictive insights, cobots help companies optimize their workflows, making the entire supply chain more resilient and adaptable.

The impact extends beyond warehouse operations; AI-driven cobots and drones are also having an impact on stock management to delivery tasks. This transformation benefits various sectors, from retail and manufacturing to health care and food services, where timely and accurate delivery is critical. Drones are particularly instrumental in reshaping last-mile delivery, offering solutions that are faster and more flexible, and that meet the demands of the growing e-commerce sector.

Humanoid cobots and wearables represent a future where human-robot collaboration will be seamless and significantly enhances productivity while reducing physical strain on workers. This not only improves employees' well-being but also reduces the associated costs involved with worker injuries and makes operations more sustainable.

SCENARIO YEAR 2027

PACKAGE COMMUNICATION

It's a typical Wednesday evening in the Dallas-Fort Worth suburbs in 2027, and Sarah is stuck in the evening rush hour. Luckily, her favorite pizza from Donatos Pizza is on its way, delivered by SkySlice, a new drone-as-a-service provider. She's been using this service for the last few weeks, and each delivery has been perfect. Tonight is no different—except she's about to experience a new level of interaction.

Around 6:20 p.m., Sarah gets a notification: "Your pizza has left Donatos Pizza, and SkySlice Drone 542 is on its way to your ThermoBox™ Smart Mailbox." Curious, Sarah decides to chat with her order through SkySlice's blockchain chatbot.

"Hi, can you tell me how hot my pizza is right now?" Sarah speaks to her wearable pin as she sits in traffic.

The chatbot responds instantly: "Sure! Your pizza is currently at 154°F and maintaining temperature. Would you like me to show the full temperature log?"

"Yeah, show me that," she replies. The chatbot displays a detailed, blockchain-verified temperature log starting from the moment her pizza was prepared, showing that it hasn't dropped below 150°F. "Nice, no cold pizza for me tonight!" Sarah says with a smile.

Moments later, she gets another message: "Drone 542 has delivered your pizza to your ThermoBox™. It will stay warm for the next 90 minutes at 140°F."

Sarah decides to try something new. “Hey, ThermoBox™. How’s my pizza doing?” This time, a cheery AI voice responds from the ThermoBox app: “Hi Sarah! Your pizza is safe and warm. It’s currently being kept at a cozy 140°F for you. Shall I keep it warm, or would you like me to adjust the temperature?”

Sarah laughs. “Keep it warm for now. I’ll be home in about 30 minutes.“

“No problem, Sarah! I’ll keep your pizza warm and delicious until you get home. Have a safe drive!”

By the time Sarah gets home, her pizza is waiting patiently in the smart mailbox. She walks up to it, unlocking it with her phone as the ThermoBox greets her again. “Welcome home, Sarah! Your pizza is ready.” She opens the mailbox, retrieving the piping hot box, feeling satisfied that she didn’t have to worry about a thing.

As she sits down to eat, Sarah reflects on how the entire experience felt more personalized and interactive than ever. Not only did SkySlice’s drone ensure that her pizza arrived promptly, but her ThermoBox Smart Mailbox actively kept her food warm and ready to eat—right down to a casual conversation about its temperature.

“This is what the future should be like,” she thinks as she takes her first bite. Perfectly warm, just as promised.

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FTSG

2025 TECH TRENDS REPORT • 18TH EDITION

ENTERTAINMENT

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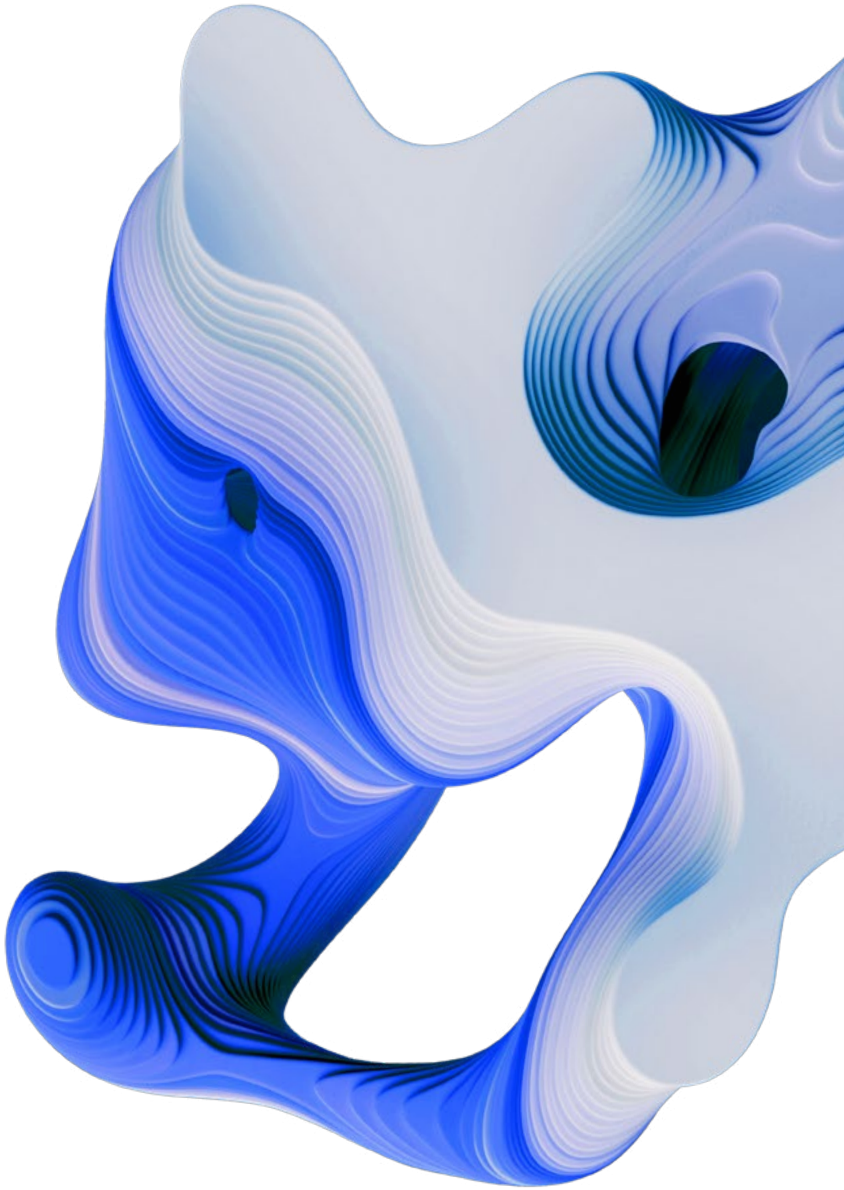


Victoria Chaitoff
Director of Marketing and Communications

Entertainment today is a boundless, tech-fueled ecosystem.

In her 2013 Golden Globes opening monologue, Amy Poehler joked that only there “do the beautiful people of film rub shoulders with the rat-faced people of television.” A decade later, that quip doesn’t ring so true. Meryl Streep is on Hulu, for crying out loud! Technology has leveled the entertainment playing field in such a way that the many once-distinct industries—film, television, music, gaming, sports, and performing arts, among others—have become nebulous. When all content has the potential to be high-quality and intellectual property reigns supreme, crossover is more appealing than ever to companies, creators, and consumers.

As we organized this year’s book, it was clear that viewing these industries as silos no longer makes sense. To better understand the forces shaping the future of entertainment, we have to look beyond. In doing so, a larger structural pattern emerges. Instead of falling neatly into traditional industry categories, trends tend to cluster around two key areas: the individual and the collective. The same technologies—augmented reality, extended reality, blockchain, wearables, and more—are driving both, but they’re deployed in unique ways to achieve different goals.

Trends centered on the individual focus on enhancing creativity, safeguarding artistic expression, and optimizing the user experience. On the other hand, collective trends emphasize community-building, shared experiences, and societal change. This duality raises an important question: If technology can be deeply personal or inherently social, how do companies choose where to play? These two clusters may seem diametrically opposed, but in reality they’re intimately linked. Companies that successfully navigate this intersection will understand that enhancing individual experiences inevitably impacts the collective, and vice versa.

Industry adopts AI applications, consumers engage while demanding regulations.

1

Daily routines become entertainment

Technology, from state-of-the-art portable gaming to improved 5G connectivity, has poised entertainment to become a bedrock of daily life. It can be integrated into any moment, including those that were previously occupied, and personalized to the consumer.

2

AI implemented at scale

Though AI continues to undergo experiments for public-facing use cases, it is becoming fundamental to back-end processes. It is both expediting and, at times, shaping development, production, and distribution of professional and amateur creative works.

3

Consumers reject isolation

Audiences are demanding immersive, community-driven experiences, from live events to interactive digital content, perhaps in response to decades of individually focused entertainment and recent pandemic isolation.

4

Growing demand for AI regulation

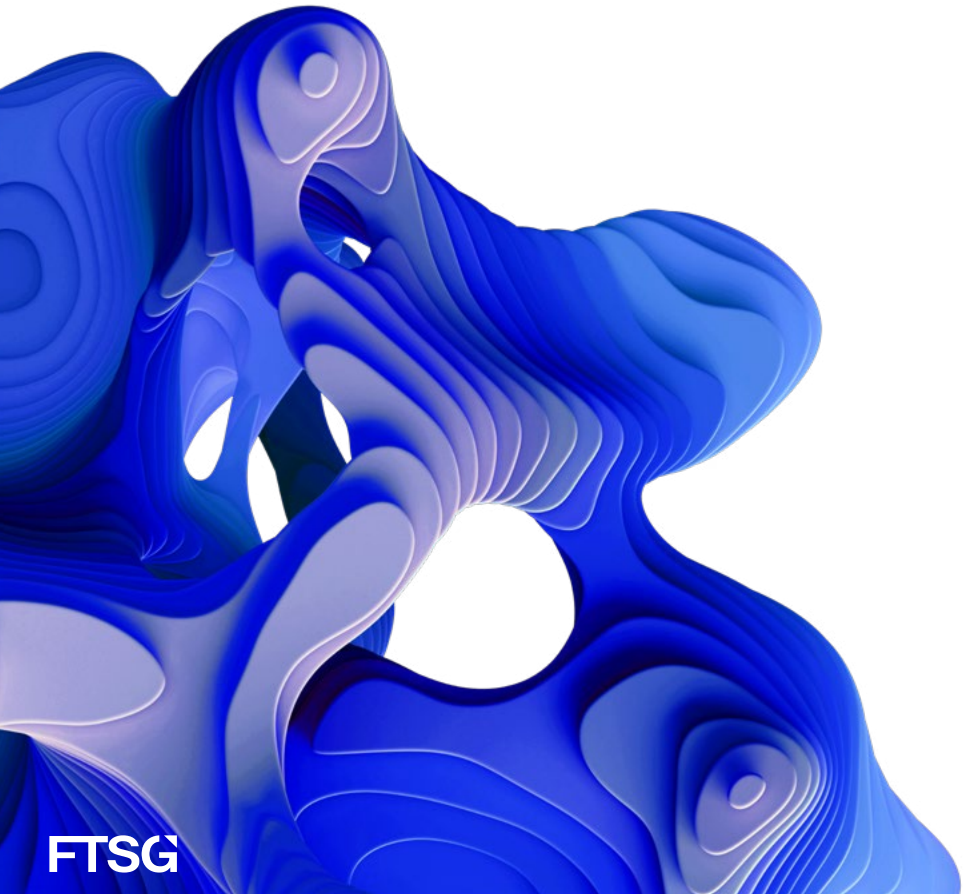
As the entertainment industry grapples with a surge of deepfake controversies, the proliferation of unmarked AI-generated content, and the exploitation of unlicensed material for AI training, creators and audiences alike are speaking out.

5

Personalized content redefines engagement

Advanced algorithms, user-driven platforms, and AI personalization are enabling hyper-specific content, reshaping how creators connect with consumers and fostering deeper, more interactive engagement.

The entertainment industry is lean... and a little lost.



More than a year has passed since the WGA and SAG-AFTRA strikes ended, but their effects continue to ripple through the industry. AI, once a theoretical concern, has now become a central focus in contract negotiations; it played a role in 2024's video game industry strike and could be a factor when the American Guild of Musical Artists renegotiates its contract with the Metropolitan Opera in 2025. Expect to see more collective action as individuals unite to demand better protections.

Meanwhile, companies across entertainment continue to make major staff reductions. Gaming took the brunt of the reorganizations, with Microsoft laying off 1,900 gaming employees in January 2024 and another 650 in September; Twitch, Discord, Sony, Electronic Arts, and others followed suit throughout the year. Blame it, in part, on the rise of generative AI coinciding with the effects of a global pandemic—the latter spurred hiring that has been rendered superfluous as AI makes processes more efficient.

Companies are taking big swings on how to use AI in public-facing capacities because they don't want to be left behind, but few have succeeded in laying the foundation for its long-term value add; its larger impact has been in back-end optimization. The hype around AI echoes the hype around other recent "of-the-moment" areas of tech like blockchain or the metaverse. Once the buzz dies down, the hard work to realize the transformational potential of the underlying technologies begins. In the case of AI, however, that realization may be more rapid, and the potential more staggering and enduring than society expects.

Overall, 2024 was about regaining balance. Strikes caused months-long delays in production, while layoffs prompted periods of realignment—all against the backdrop of the US presidential election. This year, the experimental phase of AI seems poised to give way to more purposeful integration and more structured regulatory frameworks. As entertainment companies emerge leaner and more focused, success will hinge on their ability to win back internal and external confidence.

Amid industry upheaval, tech shaped both spectacle and controversy.

JANUARY 2024

Microsoft Cuts 1,900 Gaming Workers

Industry-wide cuts at major tech and media companies continue in gaming, music, and more.

APRIL 2024

Taylor Swift Album Release

“The Tortured Poets Department” notches a record-breaking one-day tally of 300+ million streams on Spotify.

MAY 2024

Met Gala Spurs Deepfakes

AI-generated images of absent celebrities, including Katy Perry, circulate.

JULY 2024

Paris 2024 Olympics Begin

The Games showcase cutting-edge tech, from AI commentators to solar-powered arenas.

NOVEMBER 2024

“Wicked” Hits Theaters

The record-breaking movie musical ran a full-press, immersive advertising effort that could make even “Barbie” green with envy.

« PAST

Tech will drive mergers and milestones in 2025.

FUTURE »

MAY 2025

Paramount, Skydance Finalize Merger

Will a capital investment and new strategic direction breathe new life into a legacy media company?

JUNE 2026

SXSW Debuts in London

Austin's premier entertainment and technology festival will cross the ocean for its first event in Europe.

OCTOBER 2025

Comcast Completes Cable Spinoff

Untethered from a waning cable business, NBCUniversal will focus on growth areas such as its theme parks.

NOVEMBER 2025

"Grand Theft Auto VI" Comes Out

The follow-up to one of the world's best-selling video games will showcase Rockstar's proprietary RAGE engine.

JUNE 2026

North America Hosts FIFA World Cup

Quadrennial events are as much about technology as they are sports; Lenovo has signed on as tech partner.

These trends are reshaping audiences, advertising, and the future of work.

Entertainment Is Ubiquitous

Entertainment is everywhere, all the time—and everyone wants a piece. Northwell Health, New York's largest hospital system, is even launching a studio division to develop film and TV content. Companies that fail to explore how entertainment relates to their product or service risk falling behind.

Audiences Are Growing

Companies have unprecedented opportunities to reach diverse global audiences. More than two-thirds of the world's population has internet access, compared to one-third just a decade ago. AI-driven tools are breaking language barriers, while accessibility features open doors to a previously untapped set of consumers. The expansion of automation means that time previously spent on tasks like driving can convert to entertainment hours.

Advertising Strategy Will Shift

Entertainment is completely transforming the advertising industry. The mediums have changed: Instead of cable TV and physical billboards, it's FAST channels and interactive virtual worlds. Brands are now content creators with the capacity to deliver narratives directly to audiences, and advanced AI tools, such as gaze tracking, offer novel consumer insights.

Consumers Are Mobilizing

Emerging technology, in combination with social media, is rendering fandoms increasingly capable of influencing cultural and social movements (think: #FreeBritney)—but it's not always for good. Organizations need to recognize the impact of fandoms on consumer behavior and market dynamics, taking the appropriate steps to both nurture and moderate them.

Stakeholders Need Upskilling

The evolving entertainment landscape demands that both creators and consumers adapt to emerging technologies like AI. Companies can mitigate the fear of job loss by retraining their workforce; they must simultaneously educate consumers on how to navigate and interact with their products, processes, and platforms.

Work Processes Need Contemporizing

As entertainment integrates more into our daily lives, it may find a home in the workplace. It's more than having video games in the break room; it's about using tech to create engaging experiences within work processes. Incorporating elements of gamification and immersive storytelling, for example, can boost both productivity and overall well-being.

These innovators are driving new technologies in and around the entertainment industry.

- **Michelle Sanchez, Matty Ayers, Natalie Bruss, and Lillian Marsh, co-founders of MITH,** for fostering fan-artist relationships through a secure block-chain-based platform.

- **Tim Anderson, Scotty Coats, and Reyna Bryan, co-founders of Good Neighbor,** for creating an eco-friendly, high-fidelity alternative to vinyl records.

- **TJ Driver and Zach Nasgowitz, co-founders of Brick,** for developing a device that promotes more intentional smartphone use.

- **Jeb Terry Jr., president and CEO of Cosm,** for launching two immersive, "shared reality" venues for fans to experience sports and entertainment in a new way.

- **Dani Valevski, Yaniv Leviathan, Moab Arar, and Shlomi Fruchter at Google Research and Google DeepMind for developing GameNGen,** the first game engine powered entirely by a neural model.

- **Aleksandar Gecevski, Marco Colaco, and Neal Peters, co-founders of N3MUS,** for exploring a cost-effective and accessible entry into Web3 gaming.

- **Minyoung Kim, Vice President, Content for Asia (ex-India) at Netflix,** for bridging cultures by delivering groundbreaking Eastern stories to global audiences.

- **Karri Zaremba, Senior Vice President of Ballpark Experience and Ticketing for the MLB,** for her role in launching Go-Ahead Entry in baseball stadiums across the U.S.

- **Dr. Kimberly Voll, Natasha Miller, and Weszt Hart, the editorial team at the Digital Thriving Playbook,** for promoting trust, safety, and prosocial behavior in game development.

- **Andrew Hawkins and Troy Jones, co-founders of StatusPRO,** for ushering in a new chapter of VR sports gaming with the third installment of NFL Pro Era.

- **Daesik Kim, Head of AI and Data at Webtoon,** for enhancing the production, consumption, and monitoring of web comics using AI and machine learning.

- **Sarah Ellis, Director of Creative Innovation at the Royal Shakespeare Company,** whose technology-led projects push the boundaries of traditional theater.

Entertainment innovations are streamlining operations and fueling new creative possibilities...

OPPORTUNITIES

New Talent Makes a Breakthrough

Promoting creativity-enhancing AI tools, blockchain-driven platforms, and other democratizing technologies can break down traditional barriers to entry in entertainment, fostering new talent and innovative ideas from around the world.

More Efficient Content Creation

Integrating AI into production workflows can streamline traditionally time-consuming tasks, allowing creators to produce high-quality content faster and at reduced costs.

Improved Fan Engagement

Developing immersive entertainment with extended reality technology can drive long-term loyalty and engagement for fan communities, who can actively participate in and shape the content they love.

ESG for Entertainment

Investing in sustainability and regulatory initiatives, from reducing energy consumption in gaming to watermarking AI-generated content, can start to rebuild trust with a general public that is wary of emerging technologies.

...but long-term success hinges on building foundational safeguards.

THREATS

Ethical and Regulatory Standards are Required

Continuing to skirt regulatory and ethical rules—such as training AI on unlicensed materials or engaging in nonconsensual tracking—is likely to increase already intense backlash from consumers and creatives alike.

Technology-Borne Vulnerabilities

Depending on technology for large-scale world-building can create vulnerabilities, such as software malfunctions or data breaches, that disrupt the consumer experience and erode trust.

Potential New Competitors

Emerging technologies may invite not just individuals but established competitors from other industries to enter the market, potentially challenging incumbents.

Fan-Led Brand Disruption

Encouraging fan-led storytelling can help foster community and drive loyalty, but it may also challenge brand consistency and dilute the integrity of established franchises.

Companies must be purposeful in how they explore and ultimately integrate AI into their value chain.

Create and enforce a public-facing transparency policy around the use of AI-generated content, including deepfakes and synthetic media. Be a leader in educating your audience about the ethical use of such technology and clearly labeling AI-generated content. Upholding this policy will build trust with your audience and protect your brand from legal or reputational damage.

Explore innovations that are one step removed from entertainment, because they will indirectly shape the industry's future. This could include autonomous vehicles, as entertainment companies stand to capture the attention that was once spent on driving, or efficient AI algorithms, which could help mitigate the rising energy costs of generating complex content like graphics and videos.

Invest in comprehensive AI education and training for your workforce. Equip your creative and technical teams with the skills to leverage AI in content creation, post-production, and audience engagement. The benefits are twofold: Learning how to use such tools can both increase efficiency in day-to-day operations and, equally as important, alleviate concerns about job displacement.

Define your long-term goals to drive short-term AI integration. The past five years saw entertainment companies investing in non-fungible tokens and half-baked metaverse projects, partially for fear of falling behind. Experimentation isn't all bad, but aligning emerging technologies with your organization's overarching strategy will help make sure you don't spend resources on fleeting "trends."

Examine communities around your product or service, and come up with a plan to nurture them. If fandoms typically form around fictional characters or beloved celebrities, how does the average company make their offering feel worthy of a fandom? Curate personalized interactions, deliver exclusive content, host special experiences. A loyal community is about identity, belonging, and empowerment.

Research how to effectively integrate into new regions and engage with global audiences. While tools like real-time translation can reduce geographic barriers, it is vital to maintain authenticity. Invest in understanding and reflecting regional nuances, from culture to preferences in storytelling and humor, in order to build a deeper connection with audiences and enhance long-term engagement.

Technology Deployment
Capital Expenditure
Talent Development
Regulatory Influence

ENTERTAINMENT TRENDS

THE INDIVIDUAL

6TH YEAR ON THE LIST

AI-ASSISTED CREATIVITY

WHAT IT IS

AI is enhancing human potential throughout the entertainment industry, pushing boundaries and offering tools that streamline and elevate the creative process.

HOW IT WORKS

Entertainment sectors from filmmaking to music are integrating AI, enhancing human creativity, and simplifying complex tasks. Artists who use AI tools find they can increase efficiency and experiment in previously unimaginable ways. One standout example is the 2024 release of “Our T2 Remake,” a full-length parody of “Terminator 2: Judgment Day.” Despite using AI programs like Midjourney and Runway, the film was far from a “push-button” operation: It took 50 creators months to meticulously craft the film, demonstrating that AI still requires significant human input.

Flawless, an AI-driven studio, has revolutionized dubbing with its TrueSync technology, mapping actors’ faces to deliver precise lip-synching for foreign-language films. Robert Zemeckis’ film “Here” used AI to de-age characters over several decades, combining makeup and AI tools like Metaphysic Live. In music, Randy Travis, who lost much of his ability to speak after a stroke, released a song with the help of AI. His longtime producer used a custom program to combine his voice from old recordings with that of another, consenting singer.

AI can also streamline traditionally cost-and labor-intensive behind-the-scenes processes, like hair and makeup. The LUUM Lash robot’s automated eyelash extensions are designed to be more precise, safer, and faster than traditional methods. LUUM still relies on a lash artist for the finishing touch, demonstrating how AI can supplement rather than replace human work.

WHY IT MATTERS

The incorporation of AI across entertainment is inevitable. It offers tools that save time, expand creative possibilities, and enable previously impossible projects. Artists who adopt AI will likely become more efficient and productive than those who avoid it; however, a niche market may emerge for “uncontaminated” works—live, acoustic, or improvised performances—offering a premium experience in an industry saturated with AI-driven content.

As AI becomes increasingly fundamental to creative processes, concerns about ownership and the legality of training AI on unlicensed material continue to grow. There is an urgent need for increased regulations for technology that is philosophically complex and thus difficult to regulate. In addition, workers across the industry are worried about job displacement. While many of these technologies are intended to enhance human artistry rather than replace it, intentions aren’t always honored.

Importantly, though, AI is not yet a perfect substitute for human intuition. A 2023 study found that generative AI models, like ChatGPT, outperformed humans on a creativity test; however, the best human responses still surpassed AI’s top answers. The results raise questions about whether AI’s performance equates to genuine creativity, as AI generates ideas based on its training data rather than original thought.

AI threatens to upend just about every aspect of cinematic production... But therein lies the opportunity. AI is likely to make high-quality filmmaking much less expensive and less logistically arduous, empowering smaller, nimbler productions by outsiders with few or no connections to the studio system.

Peter Suderman, Features Editor at *Reason*

1ST YEAR ON THE LIST

DEMOCRATIZING CREATIVITY

WHAT IT IS

Advances in technology, particularly AI and blockchain, are making creative tools more accessible, lowering the barrier to entry for individuals who lack traditional skills or resources.

HOW IT WORKS

Startups like Bitmagic offer AI-driven platforms that enable users to generate fully interactive 3D games with simple prompts. By automating coding and design, Bitmagic allows individuals without programming skills to create complex games that are distributed on platforms like Steam. Similarly, RoEx's Automix automates music mixing and mastering, helping artists prepare tracks for streaming faster and at lower costs. RoEx's government-backed research project in the UK trains AI to replicate the unique production styles of mix engineers while ensuring they receive compensation. Discord, with its tech-savvy communities and robust content moderation tools, is increasingly acting as a testing ground for AI tools. With AI generators such as Midjourney (text-to-image) and Viggle (text-to-video), millions of users can create high-quality visuals and videos quickly and easily. Platforms like Decentralized Pictures (DCP) provide independent filmmakers with a new way to fund and distribute their projects. DCP's community of users evaluate and rank project submissions; filmmakers pay for these peer reviews through blockchain-based smart contracts, ensuring fair and auditable results. The Rights, a sync licensing clearance platform launched in 2024, simplifies the process of clearing music rights for small productions. Partnering with blockchain platform Dequency, The Rights enables multiple rights holders to be cleared in a single transaction, improving efficiency and making it easier for creators to secure music for their projects.

WHY IT MATTERS

As AI and blockchain lower the barriers to entry, more individuals can participate in the creative economy. This shift has the potential to disrupt established business models and alter the landscape for content creation and distribution. For businesses, this democratization presents both opportunities and challenges. On one hand, it enables new business models that support creators, such as subscription-based access to creative tools or platforms that share revenue with community evaluators. On the other hand, it threatens traditional industry structures, where major players have been in control. In gaming, for instance, companies may need to adjust their focus from producing and distributing a small number of high-budget games to fostering platforms that allow users to create and share their own.

Contradictorily, AI-generated content raises concerns about authenticity and intellectual property theft while blockchain, with its ability to create transparent and immutable records, offers a solution for proving the origin and ownership of creative works. This duality means that as AI enables more widespread creation, blockchain could serve as the safeguard ensuring that artists and creators retain control over their work. The issue of authenticity is critical, as seen in recent incidents involving AI-manipulated images. Companies and creators will need to invest in tools that guarantee the provenance of their content, particularly as AI-generated media becomes harder to distinguish from human-led work.

4TH YEAR ON THE LIST

RIGHTS AND REGULATIONS

WHAT IT IS

As emerging technologies continue to permeate the entertainment industry, there is an increasing call to protect both public figures and private citizens from exploitation, misuse, and manipulation in digital environments.

HOW IT WORKS

The SAG-AFTRA and WGA strikes highlighted growing concerns over AI's role in creative industries, underscoring the need for stronger protections for individuals whose likenesses, voices, and work could be replicated by AI. In 2024, Scarlett Johansson sued OpenAI, claiming a voice similar to hers was used in a ChatGPT update despite her refusal to authorize such use. Lawmakers are pushing efforts to combat these issues. The bipartisan No Fakes Act, currently under consideration in the US Senate, would allow individuals to sue companies or platforms that create or host deepfakes or digital replicas without permission.

Industry self-regulation is also gaining traction. Many tech companies now support the C2PA standard for certifying the source of media content. OpenAI added watermarks to images generated by DALL-E 3, while Meta labels AI-generated images across its platforms. New players are also emphasizing ethical AI use. Tech startup Futureverse has developed Jen, a text-to-music model trained on licensed music catalogs that uses tools like the "Jenuine" indicator to authenticate AI-generated content.

Another notable market under scrutiny is live entertainment and ticketing. In 2024, the US Department of Justice and 30 state attorneys general filed an antitrust lawsuit against Live Nation Entertainment/Ticketmaster. The lawsuit alleges monopolization that stifles competition and harms artists, venues, and consumers.

WHY IT MATTERS

The growing prevalence of AI tools capable of mimicking voices, images, and creative output without explicit permission could lead to a significant loss of control for artists and consumers alike. AI is still relatively unexplored territory, and regulations are still in development; however, businesses in entertainment and tech must adapt to an environment that is experiencing increased governmental intervention. For media companies, aligning with proposed legislation will be essential to maintain trust with consumers.

From a business perspective, the rise of ethical AI companies and platforms could offer new market opportunities. As consumers become more aware of the risks posed by unregulated AI, companies that emphasize transparency, fairness, and compensation for creators could build competitive advantages. Meanwhile, for companies like Live Nation/Ticketmaster, legal challenges may spur a reassessment of their market dominance, potentially opening the door for competitors to enter the space.

Tech and media companies should invest in developing tools that not only comply with legal standards but also foster innovation that respects creative ownership. Partnerships with ethics-led startups could help established players navigate the complex landscape of AI-driven entertainment, ensuring they remain both competitive and responsible.

1ST YEAR ON THE LIST

BEHIND-THE-SCENES OPTIMIZATION

WHAT IT IS

Emerging technologies are making subtle but powerful behind-the-scenes changes that streamline back-end processes, enhance content quality, and improve user experience.

HOW IT WORKS

Despite flashy news stories, some of the most frequent use cases of emerging technologies are invisible—automating behind-the-scenes processes that the average consumer might not even notice. Colourlab Ai, for example, uses AI to streamline the color grading process for film and television, making it more efficient without directly altering the visible product. A team of 1,500 artists used Autodesk Flow Capture, a fully cloud-based workflow system, to collaborate virtually on "The Lord of the Rings: The Rings of Power."

In 2024, Netflix patented a method for selecting optimal thumbnails using AI to analyze facial expressions and character prominence. Electronic Arts has filed a patent for "curiosity agents" to use in playtesting; these models use reinforcement learning to explore games more thoroughly than human testers or traditional AI could. Disney Music Group announced its partnership with AudioShake to isolate individual instrumental tracks on older recordings that are missing their original stems, which will allow them to remix and remaster classic songs for new applications.

These "invisible" upgrades are particularly noteworthy in marketing. As traditional advertising methods decline, AI companies like BENlabs are embedding marketing directly within content to create more natural brand interactions. Their AI rapidly processes massive amounts of data in order to predict and optimize the entire sales funnel.

WHY IT MATTERS

Invisible upgrades are significant because they allow businesses to make substantial improvements in productivity and efficiency without disrupting consumer experiences. These advancements reduce costs, shorten production timelines, and improve the quality of outputs. Companies leveraging these technologies can allocate more time and resources to creative tasks, enabling innovation without sacrificing operational efficiency. Tools like Cinelytic, which is one of several AI-enabled platforms that provides data and analytics to support decisions across a film's lifecycle, are helping studios make more informed decisions about projects—though too heavily automating such processes can eliminate the human "grit" and intuition that once drove creative risk-taking.

These upgrades also raise questions about the future of certain jobs. As automation takes on more roles traditionally held by humans, such as quality assurance in gaming, there may be a need to retrain or upskill workers to keep pace with the changing landscape. Additionally, while the invisibility of these upgrades is convenient for consumers, it does pose ethical concerns around transparency. How much should audiences know about the algorithms shaping their experiences? The most successful companies will strike a balance that ensures they can continue innovating while maintaining public confidence.

1ST YEAR ON THE LIST

INTANGIBLES-LED PERSONALIZATION

WHAT IT IS

The entertainment industry is moving beyond traditional personalization methods, leveraging AI to tailor experiences based on intangible factors such as emotions and memories. While new systems may offer deeper engagement, they raise ethical concerns around manipulation and privacy.

HOW IT WORKS

Personalization in entertainment, historically driven by demographics and behavior, is evolving into a new phase where artificial intelligence tailors experiences based on intangibles like emotions, intent, and memories. In 2024, Disney patented a system that uses AI to create personalized content by analyzing users' memories and predicting emotional states. The technology leverages machine learning to predict and match emotional features from stored memory data, ensuring that the content feels uniquely relevant to each user. This move shifts personalization from merely being about what users have done or liked in the past to understanding how they feel in real time.

Similarly, Hulu may be moving beyond basic keyword search by introducing semantics-based search systems. Its patented design interprets users' intent through natural language processing, delivering more meaningful search results by understanding not just what users are looking for but why they're looking for it.

The gaming industry is also embracing intangibles-based personalization, particularly in creating "flow states" for players. Recent research from the University of California, Riverside highlights how video games can induce this deep focus by balancing difficulty and immediate feedback, leading to enhanced mental well-being. AI systems are learning to dynamically adjust gaming experiences based on real-time emotional feedback, ensuring players remain challenged yet engaged.

WHY IT MATTERS

The shift toward personalization based on intangibles marks a profound evolution in how entertainment is crafted and consumed. AI-driven engagement promises to create experiences uniquely tailored to each user, fostering strong emotional connections.

For companies, this unlocks unparalleled loyalty and engagement; however, it also raises several ethical questions. As AI systems learn more about users' emotional landscapes, there is a growing concern about the potential misuse of this information—either for profit or unintended psychological influence. The more AI knows about personal memories and emotions, the more control it has over the content it delivers. This could lead to manipulation in subtle ways, influencing decisions from purchasing to political views, without the user's awareness.

As AI advances, the line between helpful personalization and invasive profiling may blur, triggering calls for regulations to protect users' mental autonomy. Video games' induced flow states, for example, may improve mental well-being, but as these tools grow more sophisticated, the risk of creating addictive or harmful experiences increases. The growing power of AI to guide emotional responses and behavior will likely prompt regulatory scrutiny.

1ST YEAR ON THE LIST

ON-THE-GO ENTERTAINMENT

WHAT IT IS

Entertainment is increasingly integrated into every aspect of daily life, as companies respond to consumer demand for constant, portable amusement. People expect high-quality entertainment options on-the-go, facilitated by advances in technology, connectivity, and AI.

HOW IT WORKS

Entertainment is more accessible than ever, with companies meeting the growing demand for constant engagement. The Entertainment Software Association reported that 78% of players engage in mobile games. In 2023, about 19.3 million handheld gaming devices were sold globally. The rise of portable consoles like Valve's Steam Deck, Asus' ROG Ally, and Lenovo's Legion Go highlights the demand for ultra high-performance, on-the-go gaming. Even Sony recently reentered the portables market with its PlayStation Portal. These devices feature powerful processors, high-resolution screens, and robust cooling systems, making them capable of running demanding games smoothly.

In-flight entertainment is also advancing as internet connectivity improves. Companies like Panasonic Avionics and SpaceX's Starlink are increasing satellite capacity, while low-Earth orbit satellites promise faster, more reliable internet, narrowing the gap between on-ground and in-flight experiences. It's not just limited to planes—companies like Gameway are setting up gaming lounges in airports like LAX and DFW, giving travelers more ways to stay entertained in traditionally transient spaces.

Entertainment on the road is evolving too. In 2024, LG Display unveiled a 57-inch automotive LCD, offering both vehicle information and entertainment like movies and games. As AI automates more tasks like driving, entertainment can become a constant companion across all facets of travel.

WHY IT MATTERS

The demand for high-quality, accessible entertainment is poised to continue growing. The introduction of more powerful mobile devices and tech-enabled transit will continue to blur the lines between at-home and on-the-go entertainment, creating new opportunities for content creators and brands. To stand out in an increasingly saturated market, companies must balance innovation with personalization while exploring new frontiers for engagement. How can entertainment be more effectively woven into everyday activities like household chores, personal hygiene, or even sleep? Examining this untapped "real estate" may unlock the potential for deeper and more frequent engagement.

Meanwhile, as AI increasingly automates both the creation and delivery of content, this shift also raises questions about the growing passivity of entertainment consumption. The constant stimulation hand-delivered by digital devices poses potential risks. Psychologists have raised concerns about device addiction and overstimulation, especially the impact on mental health. Constant access to entertainment can prevent moments of quiet reflection or even boredom, which is critical for children in particular. Psychologists agree that boredom plays an important role in development, fostering creativity and critical thinking skills. Without these unstructured moments, children may miss out on opportunities to develop resilience, patience, and the crucial ability to self-entertain.

1ST YEAR ON THE LIST

INNOVATIONS IN ACCESSIBILITY

WHAT IT IS

Accessible entertainment is opening doors for people with physical limitations while also gaining popularity among broader audiences. These innovations are setting new industry standards, making entertainment more inclusive while enhancing the user experience for all.

HOW IT WORKS

Entertainment companies are increasingly recognizing the value of accessibility features that cater to both disabled and nondisabled audiences. For example, according to a survey by Preply, half of Americans now use subtitles most of the time. This shift is due to poor sound mixing, the growth of foreign media, and the need to watch content in noisy public spaces. In a more specialized application designed for people who are deaf or hard of hearing, XRAI Glass pairs with augmented reality smart glasses to subtitle real-world conversations in 76 languages and 140 dialects.

Gaming has also made significant strides toward inclusivity. "The Last of Us Part II" set a new industry benchmark by offering more than 60 accessibility options, including customizable controls, visual cues, and audio aids. Microsoft introduced its adaptive controller in 2018; in 2025, it plans to release the Xbox Adaptive Joystick, which will allow players to operate a controller with one hand.

Cutting-edge technologies like brain-computer interfaces (BCIs) are emerging as the next frontier in accessibility. In 2023, Blackrock Neurotech and Caltech researchers showcased BCIs that allow users to control computers with their thoughts. The technology was featured in the first-ever thought-generated art gallery, where individuals with physical limitations created digital art using BCIs.

WHY IT MATTERS

Accessibility in entertainment is no longer just about meeting the needs of disabled audiences; it's about enhancing the experience for everyone. Subtitles, originally intended for hearing-impaired viewers, are now widely appreciated by all due to increased media diversity and noisy environments. Similarly, adaptive gaming options are not just about inclusivity but are setting a higher standard for game design. Companies can better reach a wider variety of new consumers—the disability gaming community, making up 13% of the population, represents a significant market—and foster deeper relationships with existing consumers through meaningful personalization.

These days, personalization isn't just a buzzword or vanity tool; it's about connecting to the core of how someone experiences and interacts with the world around them. Features like voice commands, eye tracking, and the rise of BCIs mark a bold leap into the future of accessibility. These technologies demonstrate how hands-free interactions may reshape the ways in which users engage with the entire entertainment landscape.

1ST YEAR ON THE LIST

SPORTS-LED STREAMING

WHAT IT IS

The streaming ecosystem is expanding with a major shift in sports content distribution. As exclusive sports contracts move from cable to streaming, both on-demand platforms and FAST (free ad-supported streaming television) channels are reshaping how and where viewers access live sports.

HOW IT WORKS

Last year's report focused on the increase of on-demand streaming platforms; this year, it's all about sports. NFL games accounted for 93 of the top 100 broadcasts in 2023, up from 82 in 2022. Cable is losing more subscribers as streamers pick up exclusive sports contracts: Amazon now holds exclusive rights to "Thursday Night Football," while YouTube, the top streaming platform with a 10.6% share of TV usage, has exclusive rights to "NFL Sunday Ticket."

FAST channels, which offer the familiar experience of linear TV and are free to watch, are also growing rapidly. Since they don't typically require original content, they're a cost-effective option for companies. In 2024, Major League Baseball became the first US sports league to air live games on a FAST platform (The Roku Channel), engaging both new and existing audiences while monetizing them through AI-enhanced targeted advertising. Projections indicate that FAST channel ad revenue will nearly double by 2028. CBS Sports also entered the FAST market with a 24-hour Champions League channel on Pluto TV, showcasing UEFA soccer matches.

ESPN, FOX, and Warner Bros. Discovery (WBD) announced Venu, an all-in-one sports platform offering live sports content from 15 linear networks—until it was blocked by a federal judge. WBD meanwhile, lost NBA rights to Disney, Comcast, and Amazon, as the league sought to maximize its reach across broadcast, cable, and streaming.

WHY IT MATTERS

The shift of live sports to streaming platforms is fundamentally reshaping the media landscape. As streaming becomes the go-to platform for exclusive sports contracts, traditional cable loses one of its last advantages. The growth of FAST channels in particular offers an appealing, low-cost alternative for both consumers and content providers. With live sports content increasingly available across multiple platforms, media companies have a significant opportunity to engage a wider, more global audience.

This diversification is particularly impactful for sports like soccer, which has seen explosive growth in the US. More than half of soccer fans are under age 45, and 40% are fans of color. Major League Soccer and the National Women's Soccer League (NWSL) both set attendance records in 2022, with NWSL's championship game viewership rising by 71%. As sports distribution expands across streaming ecosystems, companies like Amazon and YouTube are poised to capitalize on this growing market.

As of 2024, 95% of US adults report using the internet—just a fraction of the 5.5 billion users across the globe. More people than ever can stream live sports from virtually anywhere. With such wide availability, streaming platforms can use data-driven, tech-enabled advertising to deliver personalized ads to a worldwide audience. Brands have more options than ever to engage fans with hyper-relevant, timely promotions.

1ST YEAR ON THE LIST

ADVERTISING AS ENTERTAINMENT

WHAT IT IS

As traditional product placements lose effectiveness and technology enables unique integrations, brands are starting to function as entertainment providers. From interactive TV ads to branded gaming experiences, companies are blurring the line between content and commerce.

HOW IT WORKS

Brands are shifting away from traditional ads and product placements to make advertising a form of entertainment, creating experiences that merge storytelling and shopping. Nike partnered with Superconnector Studios to launch Waffle Iron Entertainment, a content studio that has produced feature-length documentaries of Nike-sponsored athletes such as “Sue Bird: In the Clutch.” Similarly, LVMH has established its own media company, 22 Montaigne, to develop film, TV, and audio content across its 75+ luxury brands.

Paramount has partnered with Shopsense AI to launch a shoppable TV feature; viewers watching the 2024 CMT Music Awards could scan a QR code to purchase items similar to those worn by celebrities. Home Depot produced its own holiday miniseries that allowed viewers to buy featured home makeover products using embedded QR codes. Next up: brand-run platforms. In August 2024, Deadline reported that Chick-fil-A has a plan to launch its own streaming platform with a slate of original programming.

With the largest gaming market in history and platforms like Roblox that allow free-to-play, user-generated content, companies like McDonald’s and Hyundai are regularly creating their own games. Ikea’s “The Co-Worker Game” lets players virtually “work” at a digital store, blending recruitment, entertainment, and promotion. Also this year, Hasbro and London-based Path Entertainment Group brought their tech-infused “Monopoly Lifesized” live-action experience to the US.

WHY IT MATTERS

As consumers become more discerning about advertising, brands are embedding themselves into the very fabric of entertainment. Younger audiences in particular are demanding transparency; brands must either integrate in a way that feels natural and authentic or be explicitly upfront about their involvement. Clunky, obvious product placements can be counterproductive. Brands are adopting either ultra-subtle or boldly honest approaches.

The shift goes beyond just using third-party entertainment. Brands are no longer merely showing up in TV shows or video games; they are the shows and the games. While that’s not an entirely new phenomenon—Coca-Cola and Nike launched their own branded games as early as the Atari 2600 era—advancements in technology now allow companies to produce high-quality content that can reach global audiences instantly, enhancing brand recognition across diverse markets.

Ultimately, interactive and brand-produced content gives consumers more agency in how they engage with products. By integrating entertainment and commerce in innovative ways, brands can foster deeper engagement and emotional connections. As this trend continues to grow, the brands that succeed will be those offering authentic, immersive content that enhances the consumer’s experience rather than interrupting it, blending entertainment with value-driven interactions.

1ST YEAR ON THE LIST

COUNTERING OVERSTIMULATION

WHAT IT IS

As consumers grow fatigued from digital devices and constant notifications, there's a rising demand for simpler, more mindful tech use. Companies are responding with products that limit overstimulation and encourage intentional engagement.

HOW IT WORKS

In 2024, a viral meme about taking long flights without any entertainment highlighted an underlying trend: the growing desire to unplug. For years, the tech industry focused on adding features and streamlining usability, but now, as people feel overwhelmed by constant connectivity, there's a shift toward products that promote disconnection.

TinyPod turns an Apple Watch into a mini iPod-like device, allowing users to access essential features like messaging, calls, and music without the distraction of a smartphone. HMD (Nokia) partnered with Mattel to release a Barbie-branded flip phone without internet access, appealing to Gen Z's desire for a "digital detox." Retro-modding, where old devices are upgraded to improve functionality, is also experiencing a revival. People are turning to older technology not just for nostalgia but for a scaled-back, more intentional entertainment experience.

Analog entertainment is seeing a resurgence as well. The board game industry, which boomed during the COVID-19 pandemic, is projected to grow from $13.06 billion in 2023 to more than $32 billion by 2032. Board games offer a way to unplug from digital life and engage in meaningful, face-to-face interactions. Social media influencers have helped promote these benefits, driving further interest. Companies like Hasbro aim to balance the appeal of classic games with new offerings that cater to shifting consumer preferences.

WHY IT MATTERS

The trend toward countering overstimulation represents a significant cultural shift in how people engage with technology. For years, devices were designed with a "more features, the better" mindset. Now, consumers are increasingly aware of the side effects of digital overuse, such as low self-esteem, anxiety, depression, and sleep issues. Research from Virgin Mobile indicates that smartphone users now receive 427% more notifications and send 278% more texts than a decade ago.

As these concerns rise, consumers are seeking alternatives that allow them to disconnect while retaining essential functionality. These tools reflect a growing demand for more mindful engagement with digital content, providing users with a sense of agency. For a long time, companies wanted to make everything as easy for the consumer as possible and friction was seen as a pain point that needed to be eliminated—but "good friction" can actually help by making the user feel involved in the process.

Big tech is still focused on optimizing performance and maximizing convenience, opting to add features to counter overstimulation over new product lines; however, companies paying attention to these concerns may find success in niche markets with consumers who are eager for mindful tech solutions.

SCENARIO YEAR 2035

ENTERTAINMENT TAKES THE WHEEL

As vehicles become increasingly autonomous, traditional manufacturers find themselves struggling to remain relevant in an industry where entertainment has replaced driving as the primary in-vehicle focus. Disney becomes one of the first media companies to enter the automotive space, with its purchase of longtime partner Hyundai marking a pivotal moment in the shift from cars as tools that enable travel to personalized, mobile entertainment hubs.

In this future, the car is no longer a means to an end. It's more like an immersive clubhouse, with every drive transforming into an AI-tailored experience. Gone are the days of needing separate devices. The car itself is the system. Dashboard screens, equipped for extended reality experiences, stretch from door to door and spill onto the windows. Content-aware haptic seats rotate 360 degrees. These vehicles are accessible to people across a spectrum of ages and abilities, thanks not only to self-driving technology but also their modular interiors and digital customization options.

Unfortunately, it's not all fun and games: this reality raises questions about overstimulation and perhaps even isolation. Moreover, the car is not just a vehicle—it's also a data-collecting machine, and the content that passengers consume is deeply commercial. Where on-road advertising was once limited to radio spots and billboards, it's now woven directly into the experience. AI generatively inserts Disney products into scenes, whether it's subtle placements within a game or characters in films sporting "Toy Story 8" merchandise.

The data Disney is collecting—everything from a passenger's media preferences to their emotional responses to specific content—begins to inform far more than just entertainment. Car insurance companies start to factor content consumption habits into their risk assessments. A passenger who regularly indulges in high-adrenaline action movies or survival video games, for example, may find themselves paying higher premiums, their habits considered risk factors for potential accidents even in primarily autonomous vehicles.

THE COLLECTIVE

1ST YEAR ON THE LIST

WORLD BUILDING

WHAT IT IS

Consumers are seeking deeper emotional engagement with stories and experience. World building lets people feel like part of something larger than life yet tangible, creating immersive environments that foster a sense of belonging.

HOW IT WORKS

Companies are creating location-based immersive worlds that consumers can physically and emotionally inhabit. Warner Bros. Discovery and NEON debuted “Harry Potter: Visions of Magic” in 2023 and expanded it to Singapore in 2024. The multisensory art exhibit blends video content, original soundscapes, and interactive elements. Immersive Gamebox utilizes tech like touch-sensitive walls and motion tracking to create in-person experiences based on “Squid Game,” “Ghostbusters,” and more.

Amusement parks such as “Super Nintendo World” and “Minion Land” (Universal Studios) are evolving from “themed” attractions to fully immersive environments. They make the guests a “character” in a given world, offering layers of interactivity with leaderboards, customization, and evolving content. Last year, Universal filed a patent for virtual reality (VR) rides that incorporate riders’ physical reactions, like facial expressions, into the virtual world. Previously, Disney published a patent for a new technique that uses machine learning to automatically generate augmented reality (AR) content by combining the layout of a physical space with digital elements, making it easier to create immersive experiences on the go.

World building also extends beyond IP-based content. Moment Factory is a multimedia entertainment studio that creates immersive experiences like Astra Lumina, a series of night walks set in botanical gardens that combine projections, lighting, and music.

WHY IT MATTERS

World building reflects a need for immersive, emotionally engaging experiences that go beyond passive viewing or participation. It taps into the need for meaningful connections with stories, communities, and environments. People want to belong to worlds where they can explore, interact, and connect on a deeper level. Physical spaces like amusement parks are an ideal medium to make fiction reality, since they can combine real infrastructure and cutting-edge technology to create a tactile world. That said, world building doesn’t have to be confined to in-person experiences. Even with passive entertainment, companies should keep this desire for world building in mind. After all, world building is fundamentally about richness of storytelling, depth of imagination, and strength of community—all elements that can be combined digitally.

Ultimately, though technology facilitates these experiences, the core of the trend lies in the emotional investment consumers make when they engage deeply with a narrative or environment. As companies expand their IP into real-world, location-based experiences, they open new revenue streams and foster long-term relationships with consumers. IP provides established fan bases and can drive initial interest and engagement; however, overreliance on it can lead to high costs, creative constraints, and the risk of losing relevance as the popularity of the IP wanes. Balancing IP-based projects with original content is crucial for staying creative and adaptable to changing preferences.

1ST YEAR ON THE LIST

FAN-CENTRIC TECH

WHAT IT IS

As fandoms become powerful hubs for identity and community, brands are leveraging AI, blockchain, and extended reality (XR) to cultivate deeper connections and drive new business opportunities.

HOW IT WORKS

As media companies struggle with the high costs of producing large-scale, IP-based shows, startups like Fable Studio are fostering interactive storytelling experiences. Fable's Showrunner platform allows fans to engage with the universes they love by using AI to write, voice, and animate original episodes of their favorite shows. Fable will pay studios to license the content and collaborate on appropriate restrictions.

Web3 platforms MITH and Medallion host decentralized fan communities, offering exclusive content and interactions while bypassing traditional distributors. Blockchain provides a tamper-proof ledger of fans' interactions, creating new ways for musicians to reward loyalty through unique digital collectibles, tickets, and more.

Sports have traditionally enjoyed strong fandoms, but a 2024 survey found that only 23% of US respondents aged 18-29 identify as die-hard sports fans—while 35% said they aren't fans at all. Leagues, teams, and venues are now leaning into digital interactions geared toward younger audiences. Nickelodeon and CBS Sports partnered for a Super Bowl alternate telecast, which included AR-enhanced visuals, virtual filters, and original on-field graphics. The NBA worked with Meta to bring live NBA League Pass games to Xtadium on Meta Quest; digital avatars, decked out in official team apparel, could experience games together via Watch Party.

WHY IT MATTERS

Superfans have long been valuable, but recent examples emphasize their power in driving revenue and loyalty. Just look at Taylor Swift—an NFL game that she attended in 2023 saw a 63% increase of female viewers from the previous week; meanwhile, boyfriend Travis Kelce saw his jersey sales skyrocket 400%. According to one study, "70% of fans say their fandom... [is] part of their everyday life." They are drawn to these communities for escapism, empowerment, identity, and a sense of belonging.

Today's fans want to be part of the narrative, which is increasingly possible through immersive technologies like AI, blockchain, and XR; however, it's not just about the gimmick—it's about understanding fan communities and purposefully integrating into the worlds they care about. The same study indicated that 54% of fans recognize authentic brand integration. For companies, this means understanding what drives fan loyalty and building experiences that feel personalized.

Notably, younger fans engage with entertainment differently than previous generations. Much of Gen Z consumes sports, for example, through social media, where they feel more connected to individual athletes than to teams. Several viral moments from the Olympics focused on personalities rather than performances—like a Norwegian swimmer's love for chocolate muffins. Brands that invest in understanding these evolving fan behaviors will be well-positioned to foster their fandoms.

1ST YEAR ON THE LIST

COMMUNITY AUDIO

WHAT IT IS

Audio is evolving beyond passive consumption and becoming a key tool for community building. Consumers are seeking more than just sound—they crave purposeful audio experiences that foster connection and interaction.

HOW IT WORKS

Audio has emerged as a preferred medium for multitasking, ease of access, and emotional engagement. Voice messaging—a text message alternative that instead uses short audio clips—has become a key form of communication, providing a more personal connection than text that is less demanding than video. A 2023 poll found that 62% of Americans have sent a voice message, with 43% of 18 to 29-year-olds using them at least weekly. WhatsApp reports more than 7 billion voice messages are sent daily on its platform.

Social audio platforms like Clubhouse saw a brief boom during the COVID-19 pandemic; though these faded as influencers and celebrities moved away, signals show the format remains relevant. Rune, a San Francisco-based gaming startup, raised $8 million in 2024 for a platform that integrates multiplayer gaming with voice chat. Stationhead offers artists like Megan Thee Stallion and BTS a way to connect with superfans through live audio sessions. With upward of 15 million users, the average listener spends more than two hours a day on the platform.

Discord, known for its voice channels, continues to grow rapidly, increasing from 45 million users in 2017 to 563 million by 2023. In 2024, Discord partnered with TuneIn to bring live radio to its platform, expanding its audio offerings with live broadcasts and curated music collections. Similarly, Spotify is leaning into real-time shared audio experiences with features like its Jam sessions.

WHY IT MATTERS

While traditional platforms like terrestrial radio are losing relevance, purpose-driven audio platforms are tapping into the growing demand for interactive and meaningful engagement. This shift represents a broader transformation in how people consume and interact with entertainment. Audio, which offers a unique balance between personal connection and flexibility, is driving a more collective, community-driven model of entertainment consumption.

This trend will likely lead to more tailored content creation and innovations like voice-based AI interfaces, where users have greater control over their audio experiences. As younger generations increasingly adopt voice-and audio-centric formats, companies may need to adjust their communication methods in order to remain relevant and accessible.

Meanwhile, brands will have new opportunities for integration within these ecosystems. As audio platforms evolve and generative AI tools become more practical, sonic branding is reemerging as a crucial tool for reinforcing brand identity through sound. By developing distinctive jingles or sound signatures, brands can create memorable auditory experiences that resonate with users on an emotional level. This also presents an opportunity for brands to explore voice-driven advertising that feels more natural and integrated into the user's audio environment.

3RD YEAR ON THE LIST

PERFORMING ARTS EMBRACE TECHNOLOGY

WHAT IT IS

Technologies like 5G, AI, VR, and wearables are expanding the creative possibilities of the performing arts, improving accessibility, diversity, and audience interaction.

HOW IT WORKS

The performing arts, traditionally slow to evolve, are increasingly integrating technology into performances and venues. In 2024, pianist Lang Lang performed a concert featuring his holographic digital twin, created using 4K cameras that captured his performance in real time. The data was transmitted via 5G, ensuring synchronization. His jacket was equipped with sensors that visualized his heartbeat through LED lights, and the audience used cellphones to form chords.

The Doris Duke Foundation offers grants and support to explore innovative uses of digital tools in jazz, contemporary dance, and theater; last year, it announced its inaugural Performing Arts Technology Lab. The foundation received more than 700 applications from across the US, with projects spanning AI, virtual reality, accessibility for disabled artists, and more.

Accessibility is a common theme. The Lyric Opera of Chicago became the first opera company in the world to offer wearable technology during live performances when it introduced the SoundShirt, which uses haptic actuation to translate music and voices into touch sensations on the wearer's upper body. "Sensorium Ex," an opera slated for a 2025 debut, aims to democratize voice-recognition AI for people with voice-related disabilities and speech impairments. Sensorium AI will be used within the opera and as part of an interactive art installation.

WHY IT MATTERS

The increased use of technology is positioning the performing arts to compete with other entertainment industries, offering experiences that appeal to tech-savvy audiences. Immersive tech in particular helps performing arts compete with digital-native entertainment platforms. Hybrid productions that incorporate elements such as holographic actors or virtual set extensions will reshape the audience experience and expand what is possible in live performance.

The convergence of tech and the arts is also creating opportunities for cross-industry collaborations. Entertainment giants like Netflix are bringing popular screen content to the stage with high-tech Broadway productions ("Stranger Things: The First Shadow" is due in 2025). These collaborations reflect a shift toward performances that will appeal to a generation that has grown up with video games, social media, and interactive content. In embracing this evolution, performing arts organizations will remain relevant to contemporary audiences.

Such enhancements transform not only how performances are created and experienced but also who can access them. The industry is moving beyond traditional boundaries to create more immersive, interactive, and inclusive experiences. This democratization of the arts opens the door for broader participation, helping the sector reach underserved communities.

3RD YEAR ON THE LIST

MULTI-USE SPACES

WHAT IT IS

Advances in technology are transforming multi-use spaces into dynamic entertainment environments that can adapt to various needs, boosting efficiency, creativity, and sustainability.

HOW IT WORKS

Adaptable spaces are leveraging technologies such as LED displays, AI-powered camera tracking, and intelligent audio systems to maximize flexibility without requiring extensive physical modifications. The Toranomon Hills Station Tower in Tokyo is a 266-meter, 49-floor tower that integrates business, cultural, and entertainment facilities, including the Tokyo Node Hall. The hall is designed for hybrid events, supporting XR technologies and offering features like a lift for large exhibits and moveable steps to accommodate varying audience configurations. The Tokyo Node Lab includes a volumetric studio for XR live distribution.

In Paris, Aura Invalides showcases how historic sites are embracing multi-use functionality. The nighttime experience inside the Dôme des Invalides, created by Moment Factory in collaboration with Cultival, employs 28 projectors to display more than 45 million pixels and 568,000 lumens of light. The setup provides a 360-degree immersive experience while preserving the building's architecture.

Dozens more mixed-use projects are progressing, from a $1 billion proposed entertainment district in Norman, Oklahoma, to the Grand Stade Hassan II stadium complex in Casablanca, Morocco. Sunset Pier 94 Studios, expected to open in 2025, will be Manhattan's first purpose-built movie studio. Featuring six multifunctional soundstages and 145,000 square feet of support space, the building will be equipped with virtual production infrastructure and is designed to run on renewable energy.

WHY IT MATTERS

Multi-use spaces bring a level of flexibility to industries that have traditionally been confined by physical limitations. As urban environments become more crowded and real estate prices rise, making efficient use of space is increasingly important. The rise of flexible environments that can easily adapt to different needs maximizes both utility and profitability. Multi-use spaces are particularly valuable in the entertainment industry, as they provide venues that can accommodate multiple types of performances, screenings, or exhibitions with minimal turnover time. State-of-the-art sound systems, adjustable lighting, modular staging elements, and other advanced technologies allow for quick changes in setup.

These spaces also offer sustainability benefits, as smart technologies like energy-efficient lighting and dynamic HVAC systems reduce energy consumption. Plus, facilities designed with multi-use adaptability in mind are more efficient and can host diverse types of events without the environmental cost of building new spaces for each function. On a broader scale, multi-use spaces are able to merge historical architecture with modern immersive experiences, ensuring that existing infrastructure and cultural sites remain relevant—and economically attractive—in today's digital landscape.

1ST YEAR ON THE LIST

GLOBALIZATION

WHAT IT IS

Streaming and social media, as well as AI tools, are fueling the globalization of the entertainment industry, making diverse content more accessible worldwide.

HOW IT WORKS

High-speed internet and social media platforms allow for real-time sharing and viral trends that transcend geographic borders, while streaming platforms make entertainment accessible to audiences everywhere. Luminate reported that multilingual music listeners are more likely to discover music via movie soundtracks, TV shows, and video games than the average US listener, underlining how the availability of multiple platforms can boost international reach. Globalization is evident in the success of genres like Afrobeats in the Nordics, K-pop in South America, and Dance/Electronic in Asia.

Sports are also becoming more international thanks to digital streaming services. Global sports revenue reached $159 billion in 2023, with soccer accounting for nearly a third. The NBA reported record-breaking fan engagement in Europe and the Middle East during its 2024 season, with a 220% year-over-year increase in watch time on the NBA Europe YouTube channel. Younger fans prefer highlights, which they can watch online, over full games; social media then encourages them to form attachments to individual players over teams.

AI is playing a pivotal role in breaking down barriers, like language, that have limited the globalization of entertainment. Meta's Seamless Communication AI model, for example, provides real-time translation while preserving the speaker's vocal tone and emotion, making cross-cultural content consumption more immersive.

WHY IT MATTERS

The globalization of entertainment is reshaping how content is created, distributed, and consumed. Streaming has become crucial for introducing audiences to new sounds and stories. For the music industry, the success of multilingual genres signals a shift in consumer preferences and opens new opportunities for collaboration across cultures. Algorithms on streaming platforms can curate personalized experiences based on a user's preferences, blending global content into their recommendations.

Major TV and film platforms are increasingly focused on local and regional content, including sports. This shift is broadening the reach of international leagues and tournaments, making global fan engagement a critical growth strategy for franchises. The meteoric rise of sports betting is further driving international interest in various leagues. In addition to sports, Eastern media has had a particularly notable influence in the US. Crunchyroll has passed 15 million paid monthly subscribers, while companies like Netflix continue to invest in anime, K-drama, and more.

The economic implications are vast. As the entertainment industry becomes more interconnected globally, there are new opportunities for revenue growth through licensing, distribution, advertising, and merchandising. AI will further reduce production and localization costs, allowing more content to reach global audiences without sacrificing quality or cultural nuances.

1ST YEAR ON THE LIST

SUSTAINABILITY TECH

WHAT IT IS

Sustainability is now central to the entertainment industry, as companies adopt green initiatives and innovations to meet consumer demand, comply with regulations, and reduce costs.

HOW IT WORKS

Sustainability tech in entertainment applies to both the physical and digital worlds. The Aquatics Centre, the only permanent sports facility built for the Paris 2024 Olympic games, features 11,000 spectator seats made from 100 tons of recycled plastic, as well as one of France's largest urban solar-energy farms with 5,000 square meters of photovoltaic panels. Lollapalooza's 2024 event in Chicago was entirely powered by a hybrid battery stem; it deployed more than 1.5MWh of battery storage capacity, minimizing the run time of biodiesel generators, providing fuel and emissions savings.

Meanwhile, the UN launched the Playing for the Planet Alliance in 2019 in order to encourage the gaming industry and community to "Promote, Protect, and Play for the Planet." As of November 2024, it consisted of 32 major gaming companies, 12 trade associations, and several support organizations. Though digital platforms like Steam reduce the need for physical media, lowering production and shipping emissions, gaming hardware remains energy-intensive. Epic Games, through its Fortnite optimization initiative, found a method that would save approximately 200MWh per day of savings across its total player base. Microsoft's Xbox Developer Sustainability Toolkit provides developers with real-time analytical and visual tools to measure and reduce energy consumption and carbon emissions of their games.

WHY IT MATTERS

A sustainability-first mindset is no longer optional but a critical concern for entertainment companies, especially as climate change intensifies and consumers become more eco-conscious. Events like the Olympics and other major live events serve as showcases for green innovation, signaling a future where sustainability will shape both physical infrastructure and digital experiences.

Despite progress throughout the entertainment industry, the rise of energy-hungry technologies like AI and blockchain present a significant challenge. Training AI models, such as OpenAI's GPT-3, can generate substantial carbon emissions—in GPT-3's case, the equivalent of 500 tons of carbon dioxide. Blockchain technology, particularly cryptocurrency mining, also has a massive environmental footprint. As of 2023, Bitcoin alone consumed around 110TWh annually, comparable to the electricity consumption of small nations like Sweden.

These technologies offer transformative benefits but come with considerable environmental costs that must be addressed. Solutions to mitigate these impacts, from regulation to innovation, will define the future of the entertainment industry. Without concerted efforts to reduce their environmental footprints, technologies like AI and blockchain risk exacerbating the very issues they could help solve.

1ST YEAR ON THE LIST

APPLIED GAMING

WHAT IT IS

Gaming mechanics, software, and hardware are being used to solve real-world challenges across industries, unlocking new avenues for innovation and collaboration.

HOW IT WORKS

Everything from exercise to banking to insurance has been gamified. The oversaturated trend will likely continue, because it makes mundane activities engaging and rewarding. Applied gaming focuses less on driving consumer behavior and more on leveraging game mechanics and software for meaningful outcomes.

McGill University's "Borderlands Science" project has engaged 4.5 million "Borderlands 3" players to map the human microbiome through minigames, generating data that surpasses computational algorithms. Researchers at Lancaster University developed a modified version of "Cities: Skylines" to involve citizens in urban planning. By integrating real-world data into the game, users can design and manage urban spaces, helping planners generate data-driven insights.

Both game engines and peripherals are being used for non-gaming purposes across industries. NASA employs Epic Games' Unreal Engine to simulate lunar environments for planning space missions. BMW partnered with Unity to create an in-vehicle AR experience that displays navigation cues, road hazards, and parking assistance directly in the driver's field of view. Companies are also using engines to enhance digital twins, simulating everything from smart cities to manufacturing processes using detailed, interactive virtual replicas. Meanwhile, the US Department of Defense has introduced a familiar form factor for certain advanced weapons systems: a modified video game controller.

WHY IT MATTERS

The rise of applied gaming demonstrates the potential of game mechanics to transcend entertainment and impact diverse sectors. In urban planning, for example, applied gaming bridges the gap between public engagement and policy-making. It could lead to more inclusive and informed urban design, fostering community participation and ensuring that infrastructure developments better reflect public needs and preferences.

In health care, applied gaming might mean more scalable and cost-effective solutions to mental health care, rehabilitation challenges, and even chronic disease management. The success of projects like "Borderlands Science" may open pathways for research collaboration, where the public becomes an active participant in solving scientific challenges. The integration of gaming with AI and machine learning may accelerate breakthroughs in life and climate sciences, among other areas.

Furthermore, industries from aerospace to manufacturing may increasingly rely on these tools such as game engines to simulate, optimize, and visualize their processes, leading to more efficient designs, better decision-making, and the acceleration of innovation cycles. Ultimately, gaming mechanics, software and hardware may provide businesses with new avenues for innovation and engagement.

“

A lot of games are released with high budgets, and they’re not selling nearly as well as expected, whereas other games are going incredibly strong. What we’re seeing is a real trend where players are gravitating toward the really big games where they can play with more of their friends.

Tim Sweeney, CEO of Epic Games

SCENARIO YEAR 2040

BEST SEAT IN THE HOUSE

What happens when every seat is a front-row seat? Rising real estate prices and advanced immersion technologies have intersected to create digital-first entertainment experiences. Major concerts, political rallies, sporting events, and more are staged for largely virtual audiences. Real-time translation and increased 5G connectivity mean that culture is no longer bound by geography. A fan in Seoul can experience a live-streamed Taylor Swift concert in New York with the same clarity and emotional intensity as someone down the street.

The in-person experience, on the other hand, becomes an extravagant luxury, accessible only to the highest-end consumer. As companies shed their physical footprints, the few remaining production facilities are relocated to strategically remote areas. Only a handful of flagship venues, often hidden away in scenic or exotic locations, remain. Attending a live event is now a monumental, often unattainable, occasion. Modular in design to allow for maximal flexibility, these venues are enhanced with haptic and interactive mixed-reality technologies.

Like audiences, performers and athletes begin to travel less. The environmental impact of constant travel and maintaining large-scale physical infrastructures fades as the digital world becomes the primary arena for entertainment. But this shift comes with an interesting paradox: Companies that reduced their physical footprints now rely on enormous amounts of energy to power immersive environments and AI-driven personalized content. Companies that lead in reducing digital energy consumption and carbon emissions skyrocket in value.

Soaring property values may also push people toward communal living, where they share both space and virtual experiences with like-minded individuals. Ultimately, these curated spaces have the potential to become ideological echo chambers. Despite the hyperconnectivity, people start to feel more isolated—and while the world is closer in some ways, it's more divided in others.

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Recognized as the global leader in strategic foresight, Amy Webb advises leaders through disruptive change, enabling them to navigate an unpredictable future with confidence and take actions that address global challenges, create sustainable value, and ensure a company's long term growth.

As Founder and CEO of the Future Today Strategy Group (FTSG), Amy pioneered a unique quantitative modeling approach and data-driven foresight methodology that identifies signals of change and emerging patterns very early. Using that information, Amy and her colleagues identify white spaces, opportunities and threats early enough for action. They develop predictive scenarios, along with executable strategy, for their global client base.

In 2023, Amy was recognized as the #4 most influential management thinker in the world by Thinkers50, a biannual ranking of global business thinkers. She was also featured on the 2021 Thinkers 50 list, was shortlisted for the 2021 Digital Thinking Award, and received the 2017 Thinkers50 Radar Award. Forbes called Amy "one of the five women changing the world" and she was honored as one of the BBC's 100 Women of 2020.

Amy is regularly asked to advise policymakers in the White House, Congress, US regulatory agencies, the European Union and United Nations. She is an inaugural member of the World Economic Forum's Strategic Foresight Advisory Board, a member of the WEF's Global Risks Board, and is an AI Governance Alliance partner. Amy was elected a life member of the Council on Foreign Relations and is a member of the Bretton Woods Committee. She served as a Delegate in the former U.S.-Russia Bilateral Presidential Commission, where she advised on the future of technology and international diplomacy.

For the past decade, Amy has served as a professor at New York University's Stern School of Business, where she developed and teaches the MBA-level strategic foresight course with live case studies. She is a Visiting Fellow at Oxford University's Säid School of Business, a former Visiting Nieman Fellow at Harvard University, a Fellow in the United States-Japan Leadership Program and a Foresight Fellow in the U.S. Government Accountability Office Center for Strategic Foresight.

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Amy attended the Jacobs School of Music to study classical clarinet. She holds a B.A. in political science, game theory and economics from Indiana University and an M.S. from the Columbia University Graduate School of Journalism. She is a competitive endurance cyclist.

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Melanie Subin is Managing Director at Future Today Strategy Group, serving on our management committee and leading our consulting division. Renowned for her pragmatic, forward-thinking approach, Melanie has successfully steered numerous clients toward future-ready strategies, harnessing emerging trends and technologies to identify risk and opportunity early enough for action. Her leadership has significantly impacted how industries envision and execute their long-term strategies.

Melanie specializes in strategic transformation, quantitative and qualitative research, and scenario development. With deep expertise in the development and establishment of foresight capabilities within large organizations, Melanie regularly counsels C-staff on strategy and execution. Melanie is also a recognized expert in fostering psychological safety within teams, a crucial element for operationalizing strategic foresight effectively.

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Prior to FTSG, he held positions in corporate strategy and insights generation roles, serving as a partner to senior leadership at multiple Fortune 100 financial services companies. Throughout his career, he has specialized in framework design, corporate innovation, strategic management, and insurance.

Nick has an extensive background in developing strategic insights across a variety of industries (e.g., manufacturing, transportation, construction, energy) and subject matter areas (e.g., small business, mobility, robotics, platforms & ecosystems), in addition to the shifting nature of business and consumer preferences. He has deep experience in developing and implementing both trend sensing, as well as signal identification for large organizations. Nick has also led the design and establishment of internal foresight and scenario development capabilities across multiple institutions.

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ABOUT US

Future Today Strategy Group is a consulting firm specializing in strategic foresight, a data-driven practice for developing plausible future scenarios to inform today's decisions. As organizations across the globe grapple with an increasingly volatile and uncertain business climate, FTSG provides clarity through long-term strategic planning. Its team of subject matter experts combines best-in-class trends and technology research with actionable strategies to generate business impact. In the two decades since its founding, FTSG has become the preeminent foresight advisory to Fortune 500 companies, world governments, and other major organizations—empowering leaders to make better decisions about the future, today.

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Future Today Strategy Group employs a rigorous, research-driven methodology to identify and assess emerging trends. Our approach integrates qualitative and quantitative analysis, drawing from a diverse set of data sources, including patent and trademark filings, scientific literature, investment flows, macroeconomic indicators, regulatory developments, media discourse, and digital engagement patterns. We leverage our proprietary system to detect and map weak and strong signals, clustering them into thematic nodes and evaluating them against standardized criteria. Once trends are qualified, each trend is further assessed for trajectory, momentum, and timing, ensuring a structured and forward-looking perspective.

To enhance analytical depth, we engage a network of subject matter experts, industry leaders, and researchers, refining insights that provide actionable intelligence.

Since 2007, FTSG's annual report has provided a structured lens on industry and technology trends, offering executives a strategic view of how emerging developments are reshaping sectors and value chains. Industry trends explore systemic shifts impacting businesses and markets, while technology trends focus on the evolution of specific innovations. Our research spans multiple industries, ensuring a holistic view of transformation and disruption.

We systematically track and update these trends to help organizations anticipate risks, seize opportunities, and develop resilient strategies. By providing clarity amid uncertainty, we equip leaders with the foresight necessary to navigate an era of accelerating change.

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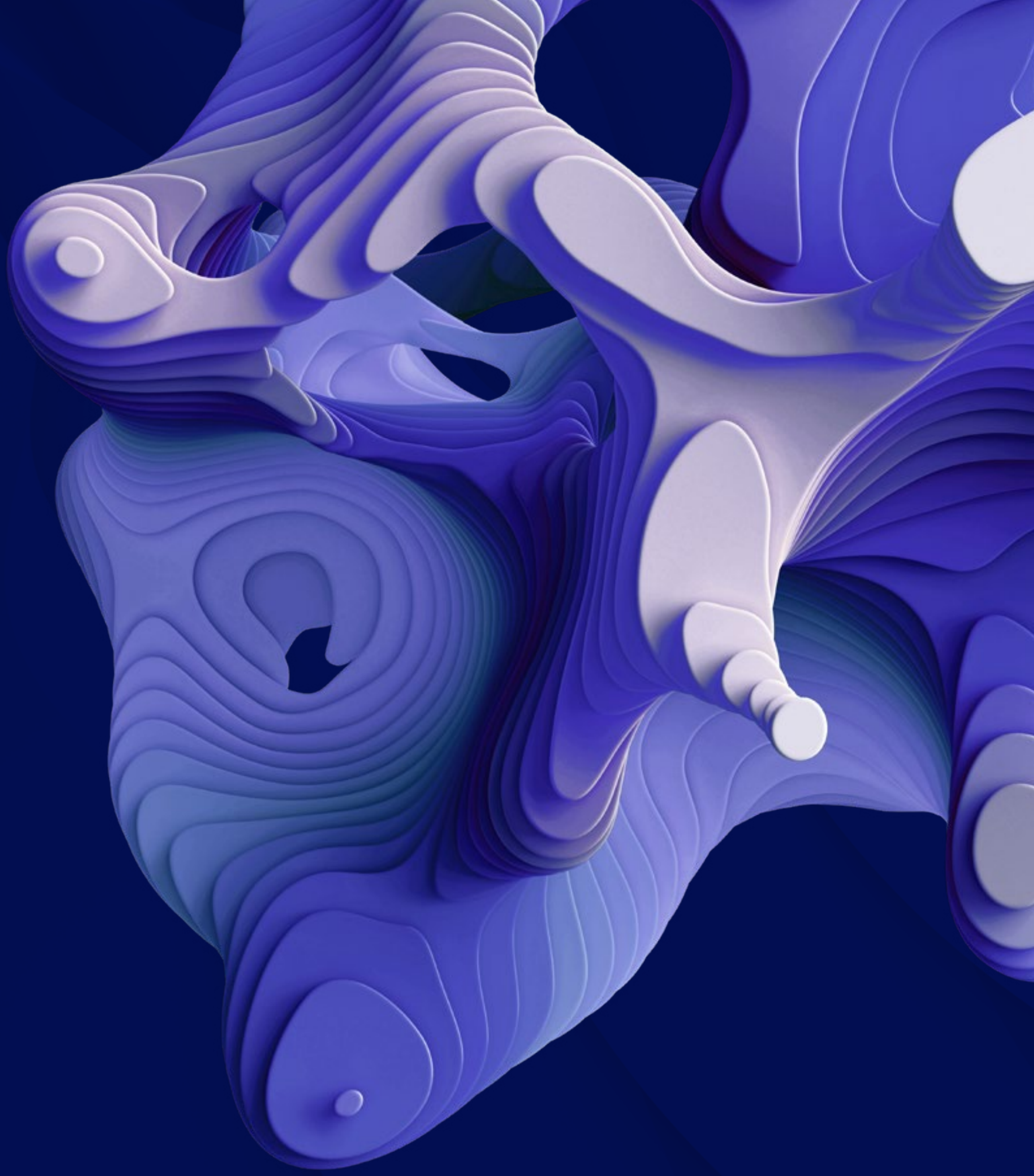

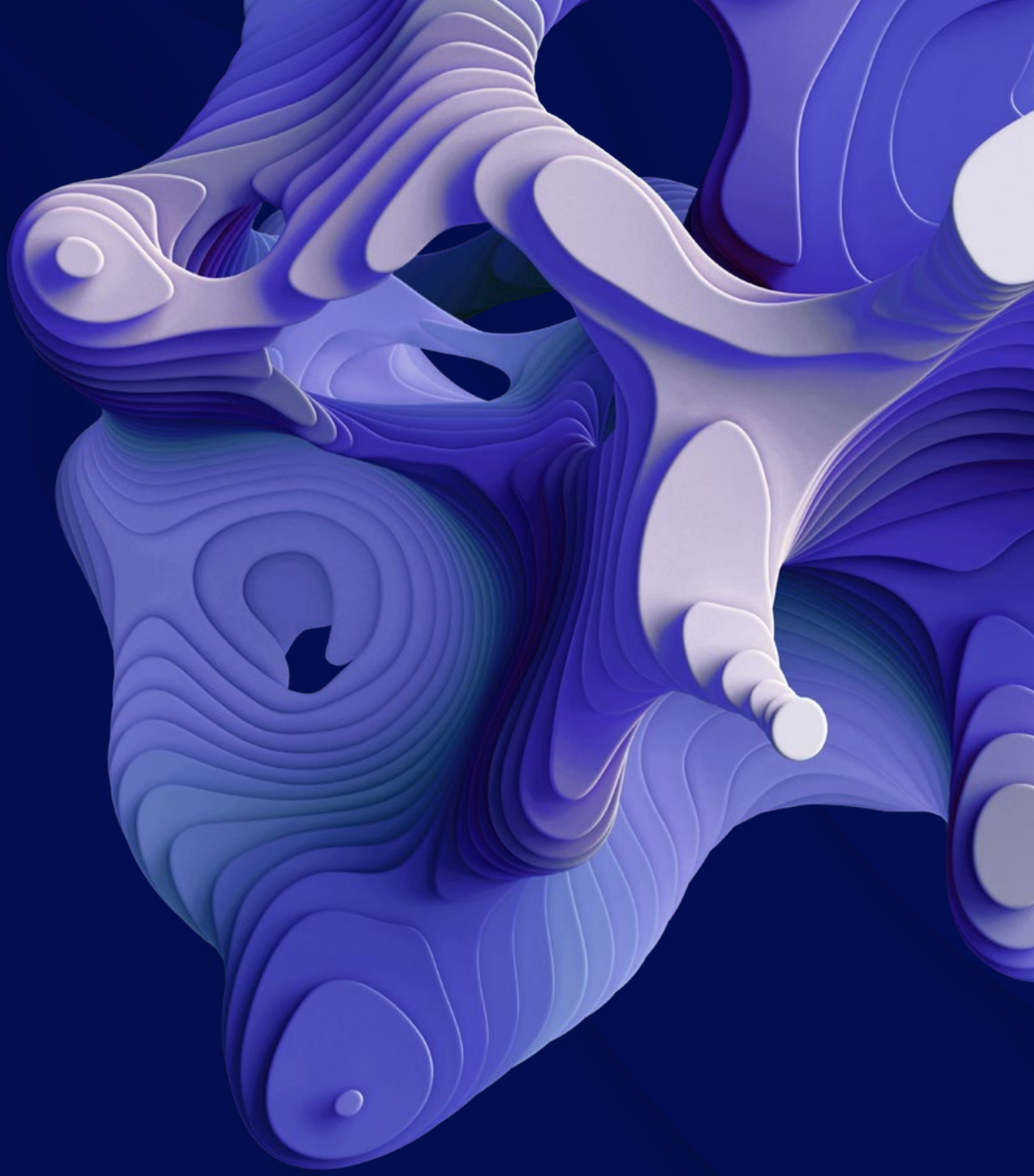

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