2025 TECH TRENDS REPORT • 18TH EDITION

SPACE

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Future Today Strategy Group's 2025 Tech Trend Report

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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...

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.

...but as it becomes more accessible, new threats and challenges emerge.

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.

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.

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.

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.

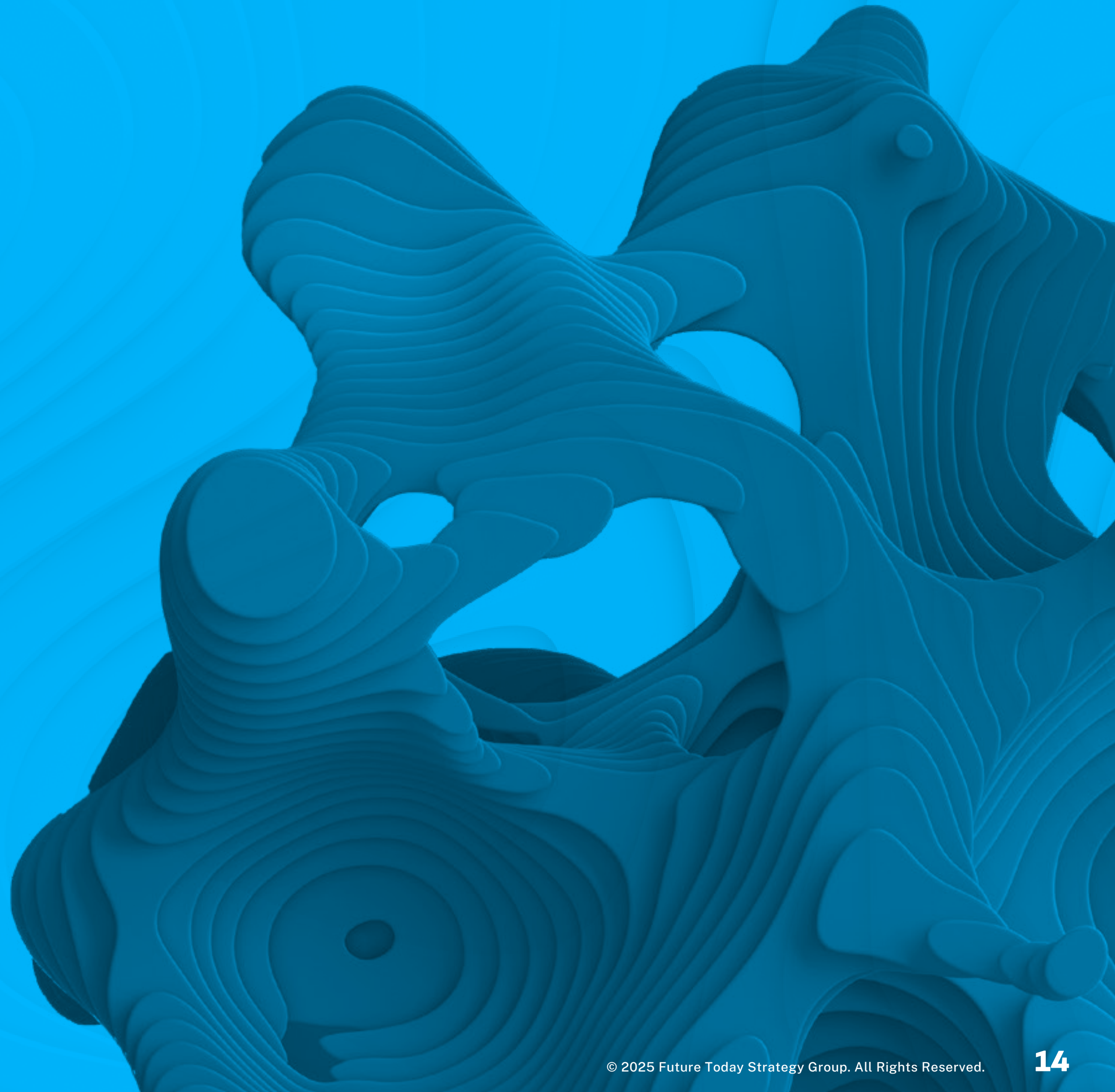
SPACE-BASED SOLAR POWER (SBSP)
The concept of harnessing solar energy in space and transmitting it to Earth, offering a clean energy solution with global environmental benefits.

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.

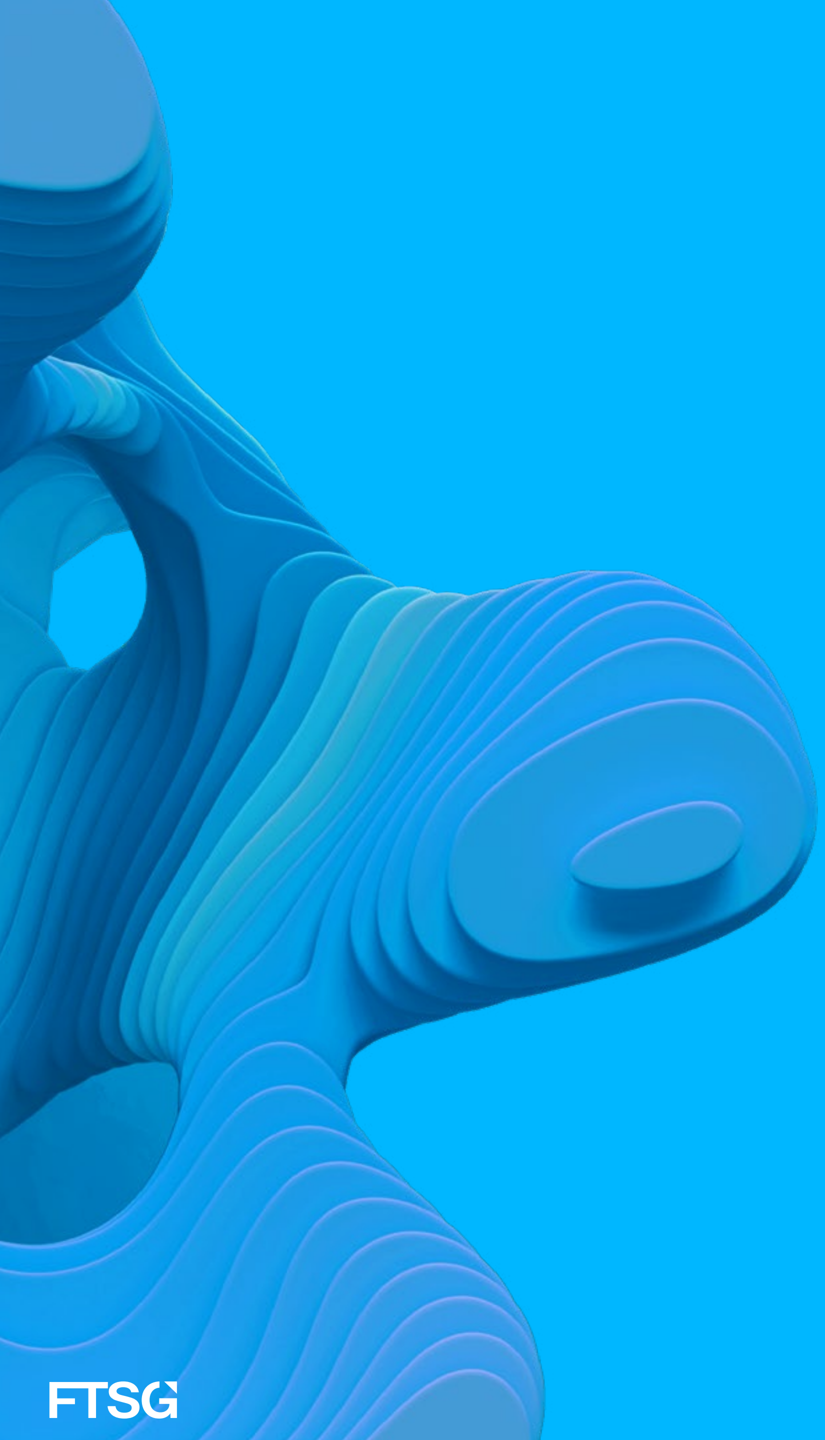
SCENARIO YEAR 2035

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.

AUTHORS & CONTRIBUTORS

Sam Jordan

Space Lead

Sam Jordan is a Senior Manager and the Technology and Computing Lead at FTSG. Her research focuses on the future of computing, spanning large-scale systems, personal devices, AI, and telecommunications. She also covers the space industry, analyzing advancements in satellite technology, communications infrastructure, and emerging aerospace innovations. She has worked with some of the world's largest technology companies to advance human-computer interaction, develop AI strategies, and drive innovation in device evolution.

Before joining FTSG, Sam was the CEO and co-founder of TrovBase, a secure platform for data discovery and analysis sharing. She also worked at IBM, where she helped large enterprises modernize their IT infrastructure, specializing in mainframes and integrating modern software and methodologies into legacy systems.

Sam currently serves as a coach in the Strategic Foresight MBA Course at NYU Stern School of Business and is an Emergent Ventures Fellow at the Mercatus Center. She holds a B.S. in Economics and Data Analysis from George Mason University and an MBA from NYU's Stern School of Business.

Chief Executive Officer
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inquiries@ftsg.com

ftsg.com

+1 267 342 4300

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