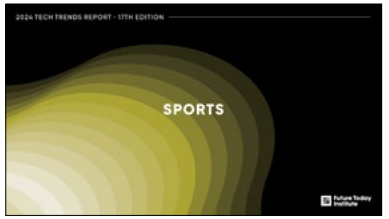
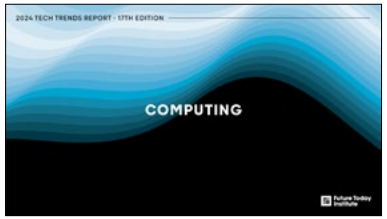
SPACE

FUTURE TODAY INSTITUTE'S 2024 TECH TREND REPORT

Our 2024 edition includes nearly 700 trends, which are published individually in 16 volumes and as one comprehensive report with all trends included.

Download all sections of Future Today Institute's 2024 Tech Trends report at **http://www.futuretodayinstitute.com/trends.**





THE YEAR AHEAD: TECH SUPERCYCLE

The theme for our 2024 report is Supercycle. In economics, a "supercycle" refers to an extended period of booming demand, elevating the prices of commodities and assets to unprecedented heights. It stretches across years, even decades, and is driven by substantial and sustained structural changes in the economy.

We believe we have entered a technology supercycle. This wave of innovation is so potent and pervasive that it promises to reshape the very fabric of our existence, from the intricacies of global supply chains to the minutiae of daily habits, from the corridors of power in global politics to the unspoken norms that govern our social interactions.

Driving this seismic shift are the titans of technology and three of their inventions: artificial intelligence, biotechnology, and a burgeoning ecosystem of interconnected wearable devices for people, pets, and objects. As they converge, these three macro tech segments will redefine our relationship with everything, from our pharmacists to our animals, from banks to our own bodies. Future Today Institute's analysis shows that every technology—AR/ VR/ XR, autonomous vehicles, low Earth orbit satellites, to name a few—connects to the supercycle in some way.

The ramifications are stark and undeniable. As this tech supercycle unfurls, there will be victors and vanquished, those who seize the reins of this epochal change, and those who are swallowed whole. For business leaders, investors, and policymakers, understanding this tech supercycle is paramount.

In this 17th edition of FTI's annual Tech Trends report, we've connected the supercycle to the nearly 700 trends we've developed. Our research is presented across 16 technology and industry-specific reports that reveal the current state of play and lists of influencers to watch, along with detailed examples and recommendations designed to help executives and their teams develop their strategic positioning. The trends span evolutionary advancements in well-established technologies to groundbreaking developments at the forefront of technological and scientific exploration. You'll see emerging epicenters of innovation and risk, along with a preview into their transformative effects across various industries.

We've visually represented the tech supercycle on the report's cover, which is an undulating image reminiscent of a storm radar. Vertical and horizontal lines mark the edges of each section's cover. When all 16 section covers converge, the trends reveal a compounding effect as reverberating aftershocks influence every other area of technology and science, as well as all industries.

It's the convergence that matters. In isolation, trends offer limited foresight into the future. Instead, the interplay of these trends is what reveals long-term change. For that reason, organizations must not only remain vigilant in monitoring these evolving trends but also in cultivating strategic foresight—the ability to anticipate future changes and plan for various scenarios.

Our world is changing at an unprecedented rate, and this supercycle has only just begun.

Amy Webb
Chief Executive Officer
Future Today Institute

TABLE OF CONTENTS

05 **Top Headlines**
06 **State of Play**
07 **Key Events**
08 **Likely Near Term Developments**
09 **Why Space Trends Matter to Your Organization**
10 **Opportunities and Threats**
11 **Investments and Actions To Consider**
12 **Central Themes**
14 **Ones To Watch**
15 **Important Terms**
16 **Space Politics**
17 Geopolitical Tensions in Space
18 Emerging Space-Faring Countries
19 Governing Space
20 Space Defense
21 Scenario: Tax Tensions on Mars
22 Domestic Competition
23 Space Blocs
24 Geopolitical Tensions over Space Junk
25 Scenario: Interplanetary Park System
26 **Space Industry**
27 Space Factories
28 Biomanufacturing in Space
29 Off-Planet Resource Production
30 The Satellite Boom
31 Constellation Management
32 Mining
33 **Space Infrastructure**
34 Telecoms
35 Maintenance Missions: Satellite Servicing
36 Monitoring Earth
37 Self-Assembly Tech
38 Green Propulsion
39 Monitoring Orbital Debris
40 Deorbiting Debris
41 **Commercialization of Space**
42 Off-Planet Tourism: Getting to Space
43 Off-Planet Tourism: Staying in Space
44 Space Entertainment and Events
45 Private Missions
46 Smaller Companies in Space
47 Scenario: Preparing for Game Day on the Moon
48 **Origins of a Multi-Planetary Species**
49 Search for Far-Off Life
50 The Search for Nearby Life
51 Moon, Then Mars
52 Scenario: The Moondust Mariner
53 The Search for Cosmic Resources
54 Universe Mapping
55 Space Habitats
56 Scenario: The Martens' Month on the Moon
57 Simulated Space Environments
58 Biological Adaptations for Space
59 Official Investigations of UAPs
60 **Authors**
62 **Selected Sources**
66 **About Future Today Institute**
68 **Methodology**
69 **Disclaimer**
70 **Using and Sharing the Report**

TOP HEADLINES

Access to space is expanding, but challenges persist due to investment constraints, geopolitical tensions, and threats from a crowded orbit.

01 The race to the moon is heating up

Who can establish a base on the moon first? The highlight of recent successes and failures include India's landing on the moon's south pole.

02 Space junk is still a threat

SpaceX's Starlink satellites performed 25,000 collision avoidance maneuvers in six months, showing the continued need for innovative solutions.

03 Distrust among the US and China extends into space

China has accused the US of militarizing space, while the US fears that China will use electronic warfare jammers to target US satellites.

04 Countries and companies rush to develop and bolster space capabilities

Saudi Arabia, Scotland, and New Zealand are all increasing space capabilities while NASA's partnership with startups will further its moon pursuits.

05 SpaceX's busiest year yet

In 2023, SpaceX conducted over 90 orbital launches, breaking last year's record by 29. The company also made strides on its Starship program, with the first two test flights ending in explosions but achieving partial success.

STATE OF PLAY

The space economy is a series of contradictions.

Space exploration is entering a new era defined by fresh geopolitical rifts alongside the rise of new spacefaring nations. While the US and Russia unwind once-productive cooperation on projects like the International Space Station, this space race 2.0 sparks rapid capabilities development. Past rivalries yielded innovations in integrated circuits, memory foam, solar technologies, and more. New friction may now drive the next wave of space-enabled advances. This contemporary competition, however, is not just a replay of past dynamics. It brings into play a broader constellation of actors, including smaller nations and private enterprises, all enabled by the decreasing cost of space access. As space access becomes cheaper, more countries can realistically launch their own missions. India and Japan recently landed lunar rovers, joining an exclusive club. With more diverse space blocs taking shape, we may see new models of collaboration between secondary space powers.

Parallel to the geopolitical shifts is a burgeoning commercial space ecosystem now feasible given reduced launch costs. Microgravity research and development, space tourism, and asteroid mining represent trillion-dollar opportunities. As these space industries mature, we can expect related economic and technological ripple effects.

The enduring debate over humanity's future direction—whether to prioritize our ventures into space or focus on Earth's pressing needs—continues. Billionaire explorers like Jeff Bezos and Elon Musk champion the cause of space exploration, not merely as a pursuit of curiosity but as a necessary step for human survival. They argue for the establishment of human presence beyond Earth, envisioning space as a sanctuary that could ensure humanity's continuity against existential threats. As Carl Sagan observed, "Since, in the long run, every planetary civilization will be endangered by impacts from space, every surviving civilization is obliged to become spacefaring—not because of exploratory or romantic zeal, but for the most practical reason imaginable: staying alive." Sagan's words remind us that the journey to space transcends mere adventure or ambition. Investing in space exploration and planetary science is not just about the pursuit of knowledge or the expansion of human presence into the cosmos; it's a critical step in ensuring the long-term sustainability and survival of humanity.

KEY EVENTS

APRIL 14, 2023

Mission Sets Off to Probe Jupiter's Icy Moons
Europe's JUICE spacecraft begins its eight-year odyssey to Jupiter, targeting moons like Europa in the quest for extraterrestrial life clues.

MAY 1, 2023

James Webb detects water vapor
JWST discovers water vapor on an exoplanet 26 light-years away from Earth.

JUNE 28, 2023

Universe Permeated with Gravitational Waves
New measurements reveal a cosmic background hum of low-frequency gravitational waves, confirming Einstein's century-old prediction and expanding our understanding of the universe's fabric.

JUNE 29, 2023

Virgin Galactic launches
Virgin Galactic successfully launches Galactic 01, its first commercial space flight.

AUGUST 2023

Lunar Highs and Lows
India's Chandrayaan-3 lands on the moon's south pole as Russia's Luna 25 crashes.

LIKELY NEAR TERM DEVELOPMENTS

UNLOCKING POTENTIAL IN SPACE

When it comes to space exploration, there are never any guarantees. Missions are often delayed, and the complex nature of space travel often results in the failed execution of even properly laid plans. A wave of transformative developments will make our space-based futures look brighter, however. Based on near term developments and milestones, we will have more certainty on the viability of certain technologies such as asteroid mining, in-situ resource utilization, and space-based manufacturing. We will achieve new breakthroughs, placing humans in new environments. Additionally, we will unlock new mysteries and potentially learn more about our origins.

Space Manufacturing Takes Off

With significant interest from government organizations such as NASA, combined with the engineering know-how of startups like Redwire and Varda, the industry will soon know the viability of manufacturing in space and the true benefits of working in microgravity.

Asteroid Mining Viability

Asteroid mining in and of itself will not be a near term development. However, we should know more about its viability as startups like AstroForge have reestablished their interest in the activity and have insightful missions planned.

ISRU on the Moon

As a demonstration of oxygen production on Mars by NASA's MOXIE has shown, in-situ resource utilization (ISRU) is crucial for space exploration. In due time, a demonstration of oxygen or water production will take place on the moon.

Humans on the Moon

NASA's Artemis program has its sights on sending humans back to the moon and plans to do so by 2025. This along with the recent flurry of lunar activity, including India's unmanned Chandrayaan-3 landing, expect humans to be there again soon.

New Discoveries by the JWST

Since its successful deployment in space, the James Webb Space Telescope has continued to uncover new revelations and inspiration. The JWST will continue to discover more about space, potentially giving us new clues about our origins.

Affordable re-entry

Expect a rise in companies focused on cost-effective return vehicles and methods to retrieve goods manufactured in space. If viable, this point-to-point space delivery and off-Earth industry promises immense expansion for commercial interests.

11 MACRO SOURCES OF DISRUPTION

WHY SPACE TRENDS MATTER TO YOUR ORGANIZATION

Support for disaster preparedness and management

Space-based technologies play a critical role across the entire disaster management cycle. This includes prevention, preparedness, early warnings, response plans, and reconstruction. Predictive modeling can warn of potential threats, and provide information that's critical for assessing risks of entering new markets or providing new services.

More resilient and revolutionary supply chains

Space can impact supply chains in two fundamental, yet dramatically different, ways. First, satellites used for Earth observation can help pinpoint the location of goods throughout supply chains, and help by proactively protecting key parts. Also, in the future, a company's supply chain could extend to space, as space factories become more viable.

Spillover technologies are there for the taking

Technology used in the Hubble Telescope has improved technology for cancer detection in women. Eye doctors are now using technology from the James Webb Space Telescope to help improve human eyesight. Other spillover technologies from space exploration could already exist and provide innovations for other adjacent industries.

Capitalize on the interests of the public sector

The new space race shows no signs of slowing down. Governments will continue to invest more of their budgets in the space industry to maintain competitive advantages. There could be opportunities to win government contracts that aren't necessarily grandiose in nature—such as new applications for project management, not just engineering new rockets.

Responsible orbital activity impacts everyone

At first, our crowded and increasingly unsafe orbits could seem to just be a threat to organizations operating in the space economy. However, this is a risk for everyone, as so much of our connectivity and navigation systems rely on space. Advocating for responsible orbital activity should be something we all invest in.

Existential threats create business opportunities

There is an enormous economic opportunity to clean up Earth's orbit. Unfortunately, we are the culprits responsible for creating this mess. Our space junk dilemma mirrors our current climate crisis. The stability of safe space travel is decreasing, and we must rely on the market to reverse this trend.

OPPORTUNITIES & THREATS

Threats

As long as regulations remain outdated, there's a risk of countries operating kinetic-based anti-satellite weapons. These should be a worry for not just governments but companies whose satellites could get caught in the crossfire.

As ground-based lasers become more sophisticated, there is an increased risk of being on the receiving end of a cyberattack. These nonphysical attacks can use lasers to jam or even blind satellites.

With the tense geopolitical environment of space, it could be easy for a country or competing business to mistake a mishap in space as a purposeful attack against them. Some groups might be quick to retaliate.

Space debris poses the most significant space-related threat. In the event of the Kessler Syndrome, not only would satellites be destroyed but we would not be able to leave Earth, preventing us from being a multi-planetary species.

The democratization of space poses the threat to traditional players of not only smaller and more nimble businesses but also less space-established nations. This could upend incumbents' resourcefulness in the face of constraints.

Opportunities

As more people and things travel to space, there's a heightened need for insurance packages. These could cover the traveling individuals, their possessions, or the satellites in orbit.

Counterintuitively, existential threats in space are leading to business opportunities. The industry for deorbiting space junk and reservicing satellites will remain a growth market for the foreseeable future.

As SpaceX gets closer to reaching the limit of meaningful cost improvements for sending rockets to space, a new player could enter the satellite ride-sharing domain and gain some market share.

As sending payloads to space becomes more affordable, new business models have formed, and other alternative business models are yet to be discovered.

As space tourism unfolds, first-mover advantages open up for companies that offer entertainment services to guests. This will be a very niche market and might only benefit actual first movers.

INVESTMENTS AND ACTIONS TO CONSIDER

1

Earth observation technology will continue to improve and reveal new types of data from advanced instruments. As machine learning and artificial intelligence also improve, companies can make the most of these data sets by uncovering new insights for urban planning, insurance, disaster preparedness, and agriculture for urban planning, insurance, disaster preparedness, and agriculture.

2

The space economy will contribute to the burgeoning biomedical revolution. To ensure that our bodies are conditioned and optimized for space, researchers are exploring ways to edit humans' biology. Research breakthroughs will optimize the human body for space travel and improve human experience on Earth. Research breakthroughs will optimize the human body for space travel and improve human experience on Earth.

3

New pharmaceutical regimens will be needed for individuals spending prolonged periods in space, upending the pharmaceutical industry. The environment of space will also transform the manufacturing process for drugs. This presents a domain outside of the space economy where investments ultimately will impact space.

4

In space, gravity is not a constraint like it is on Earth. As space factories and manufacturing become more viable, businesses should explore products that would benefit most from these micro- and zero- gravity environments. Taking inventory of such products today will enable quick action in the future.

5

Mining will be essential for future space missions and a worthwhile investment consideration. While many associate space mining with asteroids, whose possibility is further in the future, the prospect of mining services on the moon looms much sooner. Mining will be imperative for all aspects of space travel and colonization.

6

As the industry of precision agriculture grows, investing during its infancy could pay off greatly. As it becomes more widely adopted, more companies will follow John Deere's lead and partner and collaborate with space-based organizations that specialize in navigation systems.

CENTRAL THEMES

Space Is Essential for Earth

Critics say we should protect our interests on Earth before entertaining the idea of exploring other worlds. However, this is not a zero-sum game. In fact, the benefits of space exploration and research manifest here, too. Much of our communication and navigation systems and architectures are made possible because of satellites and their constellations out in space. Earth observation services are providing us with a level of data we could not achieve on the ground—data that will prove invaluable as we navigate uncertain climate futures. Many of the technologies essential for space travel also have spillover effects, and will serve extremely useful purposes to our everyday lives.

Microgravity's Macro Potential

Microgravity creates an environment for research impossible on Earth, potentially leading to breakthroughs and new inventions. Drug companies and materials scientists see huge potential in conducting experiments aboard orbiting laboratories. Without gravity, they can develop new kinds of pharmaceuticals and advanced materials not possible on Earth. These breakthroughs might transform medicine, telecommunications, electronics, and more. Many companies are already starting small-scale production of space-made materials. As launch costs continue to decline, space research is poised to skyrocket. We expect a flood of experiments as access expands. But what goes up must come down. Secure transportation methods will be needed to return these precious space-produced goods to Earth. Solving this challenge will help commercialize outer space and unlock profits from zero gravity.

Optimized Resource Utilization

While space exploration is a noble and commendable endeavor, it comes with many perils. For one, getting to space is challenging and costly. Once there, the conditions are unforgiving and not very favorable for human life. With all this in mind, space becomes the epitome of human resourcefulness and ingenuity, and these characteristics are absolutely essential for achieving success beyond our planet. Space exploration is essentially a closed system: all resources within it are valuable and their use must be optimized. This manifests itself in a number of technologies or theoretical solutions including reusable rockets, In-Situ Resource Utilization, additive manufacturing that takes advantage of zero- and micro- gravity environments, resources for mining and harnessing materials for building habitats and spacecrafts, water for jet fuels and radiation protection, and oxygen for supporting life. These optimized processes and technology engender components necessary to ensure continued vitality.

CENTRAL THEMES

Democratizing Space

Entering the space industry can be daunting. Creating the systems and technology required for space travel and exploration requires sophisticated engineering and a comprehensive understanding of math and science. Despite the barriers, space is continuing to become more accessible for unexpected countries launching space programs, fledgling startups raising capital to enter the race, and universities and academic programs with no previous experience. Today, you don't have to create technologies or engineer complex solutions to enter the space economy. Turnkey satellite solutions and satellite-as-a-service business models allow small companies, developing countries, or individuals the chance to live out their space interests. Additionally, the increase in private missions and commercial flights to space is encouraging for the democratization of space. In time, these options will become available to a broader audience.

Collaboration Is Key But Murky

Throughout the history of space exploration, collaborations have made impressive feats possible. Private companies might collaborate to create innovative technologies, or work with public-facing institutions that seek their ingenuity and scrappiness. For nations, the matter is more complicated despite instances of countries with shared interests accomplishing shared objectives in space. Sometimes, space collaboration lags behind the geopolitical situations on Earth. For now, Russia is still a member of the International Space Station. But the country's actions on Earth could eventually put a strain on its space activities. Then there's the US and China: If space collaboration could ever be possible for the two countries frequently at odds, this would reap immeasurable benefits for space exploration. However, China seems to be focusing on expanding its own space station, by doubling the size, as an alternative to the NASA-led ISS, indicating limited interest in increasing cooperation. As the race to space intensifies, the line between collaboration and competition becomes increasingly blurred, reflecting the intricate dance of diplomacy and strategic interests in the final frontier.

ONES TO WATCH

Dr. Amy Williams, astrobiologist at the University of Florida, for her insights into Mars' history and potential for supporting life.

Dr. Christopher Mason, professor of genomics, physiology, and biophysics at Weill Cornell Medicine, for his book "The Next 500 Years" and his work on bioengineering humans for space.

Jane Greaves, professor at Cardiff University, for her discovery of phosphine, a potential biomarker, in the clouds of Venus.

Ivo Labbé, research professor at Swinburne University of Technology, for his Nature publication on the six massive galaxies discovered in the early universe.

Dr. Robin Hanson, economist at George Mason University and research associate at Oxford University's Future of Humanity Institute, for his theories on the "Great Filter" and "Grabby Aliens."

Delian Asparouhov, co-founder of Varda, for his work to create a platform for in-space manufacturing, especially related to the development of in-space pharmaceutical production.

Sara Seager, physics professor at MIT, for her research on exoplanet atmospheres, interiors, and signs of life by way of exoplanet atmospheric biosignature gases.

S. Somanath, chairman of the Indian Space Research Organisation, for his leadership and expertise in guiding the Chandrayaan-3 mission.

Dr. Jane Rigby, astrophysicist at NASA's Goddard Space Flight Center, for being named the new senior project scientist for the James Webb Space Telescope mission.

Dr. Ariel Ekblaw, founder of the MIT Space Exploration Initiative, for leading a portfolio of more than 40 research projects focusing on future life in space.

Dr. Nathan Lundblad, physics professor at Bates College, for his research aboard the Cold Atom Lab on the International Space Station.

Dr. Sarah Burke-Spolaor, associate professor of astronomy at West Virginia University, for proving the existence of low-frequency gravitational waves in space.

Dr. Alexandra Navrotsky, director at Arizona State University's Center for Materials of the Universe, for her contributions to thermodynamics and materials science.

Martin Nisser, Ph.D. candidate in the HCI Engineering Group at the MIT Computer Science and Artificial Intelligence Laboratory, for his research in reconfigurable robots.

Gui Haichao, professor at the School of Astronautics, for becoming the first Chinese civilian to fly in space.

Jared Isaacman, CEO of Shift4 Payments, for his commitment to private space missions through the Polaris program.

Bill Diamond, president and CEO of the SETI Institute, for his leadership in the continual search for extraterrestrial intelligence.

Yuri Milner, Israeli entrepreneur, investor, physicist, and scientist, for his contributions to the Breakthrough Listen project and search for alien life.

Dr. Catriona Jamieson, director of the Sanford Stem Cell Institute at the University of California, San Diego, for overseeing stem cell research in space.

Rayyanah Barnawi, mission specialist on the Ax-2 mission, for becoming Saudi Arabia's first female astronaut in space.

Dr. Lisa Carnell, program scientist for Translational Research in NASA's Biological and Physical Sciences Division, for her work related to 3D tissues and microphysiological systems.

Dr. Stafford Sheehan, co-founder and CTO of Air Co., for his research developing a kerosene-based rocket fuel.

Matt Gialich, CEO of AstroForge, for his commitment to exploring the viability of mining asteroids.

Dr. William Blackwell, laboratory fellow in the Applied Space Systems Group at MIT Lincoln Laboratory, for his leadership of NASA's TROPICS project.

IMPORTANT TERMS

CubeSats
This small, square-shaped satellite measures 10-by-10-by-10 centimeters, and typically weighs around 1 kilogram. CubeSats can be utilized individually as single units or in a constellation. They have a wide range of applications, including testing instruments, conducting scientific experiments, facilitating commercial endeavors, and supporting educational initiatives.

The Drake Equation
This probabilistic argument is used to estimate the quantity of active and communicative extraterrestrial civilizations within the Milky Way galaxy.

Fermi Paradox
The confounding situation of lacking definitive proof for advanced extraterrestrial life, despite the seemingly strong probability of its existence.

Great filter
The term introduced by economist Robin Hanson suggests that, regardless of the widespread emergence of life within our galaxy, every extraterrestrial civilization inevitably encounters an obstacle that threatens its own continued existence.

In-situ resource utilization
The extraction, processing, and use of resources found on other celestial bodies like the moon or Mars.

The Kármán line
Established by the international record-keeping organization World Air Sports Federation, this demarcation point distinguishes Earth's atmosphere from outer space. It is defined to be at an altitude of 100 kilometers above the mean sea level.

Kessler Syndrome
This concept, introduced by NASA scientist Donald J. Kessler in 1978, envisions a situation in low Earth orbit where there are so many objects from space pollution that collisions between them trigger a chain reaction. Each collision generates more space debris, raising the risk of additional collisions.

Low Earth orbit (LEO)
A geocentric orbit spanning from approximately 160 kilometers (100 miles) to 2,000 kilometers (1,240 miles) above the Earth's surface. This is typically where human-crewed artificial satellites operate, where their orbital path completes roughly every 90 minutes.

Medium-Earth orbit (MEO)
A geocentric orbit extending from approximately 2,000 kilometers (1,243 miles) to 36,000 kilometers (23,000 miles) above the Earth's surface. Satellites positioned within MEO face an increased susceptibility to potential damage as they are exposed to intense solar radiation. This orbital region hosts a variety of satellites, including global positioning systems and communications satellites. Satellites situated in MEO typically complete an orbit around the Earth in approximately two hours.

On-orbit satellite servicing
The process of refueling, repairing, or maintaining space satellites while they are in orbit.

Orbital space flight
When a spacecraft reaches a trajectory where it can remain in space for at least one orbit.

Space junk
Defunct satellites and other man-made debris in orbit around the Earth.

Suborbital spaceflight
This occurs when a spacecraft travels to space but does not achieve an altitude and velocity resulting in a ballistic trajectory circling the Earth at least once.

SPACE POLITICS

3RD YEAR ON THE LIST

GEOPOLITICAL TENSIONS IN SPACE

WHAT IT IS

Geopolitical tensions on Earth are spilling over into space-based relations among various nations and complicating aspirations to explore beyond our globe. Conversely, as space becomes more active, the events taking place there will undoubtedly impact relations here.

HOW IT WORKS

The International Space Station once personified nation-to-nation cooperation, but that came into question in 2022 when Russia announced it would abandon the ISS by 2024. Since then, Russia softened this declaration and said it will support the station through 2028, but the country will likely still abandon its commitment in the future. As the war in Ukraine continues, space represents a rare avenue where Russia and Western nations still cooperate and collaborate; however, these relations are tenuous at best.

In space, a shifting geopolitical landscape is unfolding. In August 2023, Russia's Luna-25 spacecraft crashed into the surface of the moon's south pole, just a few days before India's Chandrayaan-3 became the first mission to successfully land a craft there. While Russia and India have been partners on Earth, India's display of strength could come at the embarrassment of Russia. In isolation, India's achievement is significant for solidifying its position in a new space race as various groups rush to the moon to take advantage of its resources.

Other notable groups vying for access to lunar resources are the US and China, which have had a colorful past when it comes to geopolitics on Earth and in space. To further complicate matters, both countries have essentially declared space to be a military domain, leaving little hope that the two nations will cooperate on future related space endeavors.

WHY IT MATTERS

Traditionally, collaborative space projects have not always been a clear indicator of geopolitical relations on Earth. But now, it's becoming even more challenging to disentangle countries' relations in space with what's happening on our home planet. Over the years, space pursuits by various countries have mostly had positive implications for research and technology development, but fear persists that space could be used by various world powers for military purposes. Recently, China accused the US of accelerating the militarization of space. Conversely, the US is wary of potential Chinese electronic warfare technology that could potentially deny US space-based communications. Whether or not there is merit to either country's claims, the threat of a new cold war taking place in space is becoming more pronounced. While it could prove to be foolish to actually use space-based technologies to wage war on other nations, different countries could still engage in an arms race to preemptively render their opponents defenseless, mirroring the dynamics of the previous Cold War. This ongoing threat highlights the pressing need for unified and binding international commitments to ensure the safe, peaceful, and equitable use of space.

2ND YEAR ON THE LIST

EMERGING SPACE-FARING COUNTRIES

WHAT IT IS

Multiple factors, such as reduced payload costs, advances in launch technology, and overall lowered barriers to entry, are making the prospect of space exploration more accessible to new figures in the public sector.

HOW IT WORKS

In May 2023, two astronauts became the first Saudi Arabians to visit the International Space Station. This crew included Rayyanah Barnawi, who became the first Saudi woman in space. The Axiom Space's Ax-2 mission signifies the increasing influence that Gulf nations are having on the space economy. Prior to this milestone, another Gulf nation had already left its mark in space: The United Arab Emirates has sent its own astronauts to space, launched spacecraft to both Mars and the moon, and deployed satellites. As for future missions, in 2028, the UAE plans to send a spacecraft to our solar system's asteroid belt to study seven asteroids with the intent of learning more about our origins on Earth. Looking beyond Gulf countries, other new faces are entering the mix. In mid-2023, South Korea's Nuri Rocket completed its third launch, but for the first time carried commercial payloads into space. Scientists from the Indian Space Research Organisation launched next-generation navigation satellite NVS-01, adding to India's fleet of navigation spacecraft and providing interoperability with other countries' global networks. Recognizing the heightened geopolitical risks surrounding space, New Zealand has developed its own space policy, including objectives for growing an innovative and inclusive space sector centered around promoting and protecting its national security and economic interests. The policy serves as an important landmark in New Zealand becoming a space-faring nation.

WHY IT MATTERS

Of the over 70 documented space agencies, as of 2024, 16 possess the ability to launch, while only seven exhibit complete launch capabilities—meaning they can launch and also recover satellites and operate extraterrestrial landing capabilities. South Korea is the most recent country to join this exclusive list but Scotland could also join soon, as construction of Sutherland Spaceport is underway on its north coast. The only continent lacking launch capabilities is Africa, but even this could change soon, as plans exist to build a spaceport in Djibouti over the next five years with $1 billion invested by Chinese company Hong Kong Aerospace Technology. This operation, along with existing space projects, could propel the African space industry to a value of $23 billion by 2026. There is significant economic incentive for new space-faring countries, and as prospects of sending payloads to space become more accessible and less costly, it should come as no surprise to see this trend continue. By expanding their presence in space, these countries will increase their autonomy, allowing them to stand up for themselves and their own interests—whether they want increased monitoring for agriculture programs or more control over telecommunications systems.

3RD YEAR ON THE LIST

GOVERNING SPACE

WHAT IT IS

Both governments and intergovernmental organizations are advocating for responsible space behaviors to avoid a major catastrophe in space. As the space industry becomes more lucrative and enticing, new guidelines are needed to ensure safe and equitable exploration, exploitation, and utilization of space and its resources.

HOW IT WORKS

In 2022, the United States banned direct-ascent anti-satellite (ASAT) missile tests, which can potentially create orbital debris—an action intended to create an international push for more responsible space behavior. At the end of that year, the United Nations General Assembly overwhelmingly approved a resolution to suspend ASAT testing. Despite the nonbinding resolution's immense support, only 13 nations have committed to its precepts. More countries are actively being encouraged to also commit.

When it comes to governing space, many existing initiatives—such as the one mentioned above—are driven by nations' independent interests and concerns. Currently, there is no agreed upon international framework for space resource exploration, exploitation, and utilization—as noted by the UN brief "For All Humanity—The Future of Outer Space Governance"—and no mechanism to even support the implementation of such a framework. The UN hopes that the dialogue and activity surrounding its brief will lead to the development of international norms, rules, and principles to address threats to space and its associated programs and systems. A combination of binding and nonbinding norms have also been proposed to address emerging risks to outer space security, safety, and sustainability.

WHY IT MATTERS

Individual nations, including the United States, have enacted their own resolutions to address activity in space, but such resolutions primarily serve the interests of the nation that proposed them and are only binding for the signing countries. Subsequently, this gives privileges to non-signing parties. The current actions of the United Nations are promising, as they move to implement a set of unified norms for space travel and use, but because some of the norms will still be nonbinding, obstinate countries could continue to make things complicated.

Organizations such as the UN pursuing safer guidelines for space travel need to strike the appropriate balance between properly regulating activities and spurring innovation. As space exploration remains unchecked, there is the increasing threat of debris or a geopolitical quagmire among competing nations. However, a hasty implementation of strict and stringent rules could drastically hamper the progress of bold and daring endeavors to access more of space. Both private and public organizations must prepare for a more regulated industry while also ensuring that the spirit of exploration and discovery that drives humanity's fascination with space is not extinguished.

2ND YEAR ON THE LIST

SPACE DEFENSE

WHAT IT IS

Nations around the globe have a vested interest in protecting themselves from space-related activities. As space systems become more prevalent, countries will naturally become more suspicious of other competing nations, heightening the risk of space-based turmoil.

HOW IT WORKS

President Joe Biden's 2024 budget request increases funding for the US Space Force to $30 billion to meet evolving threats and protect the country's interests in space. The institution has cited the importance of space to everyday life, including GPS navigation and communications. Ultimately, this budget increase marks the US' attempt to keep pace with other countries, namely Russia and China. The US has identified the latter's ground-based lasers as a threat to satellites and plans to transition to proliferated networks of smaller satellites in Earth's orbit to combat the issue. The Space Force has also opened the Commercial Space Marketplace for Innovation and Collaboration to partner with the private sector in acquiring defense technology.

In a historic first, Israel's Arrow 2 missile defense system intercepted and neutralized a ballistic missile beyond the Earth's atmosphere, marking a potential inaugural instance of space-based combat. The system obliterated a suborbital missile launched by Houthi rebels in Yemen, achieving interception above the Kármán line—the internationally acknowledged space boundary situated 62 miles above sea level. This demonstration indicates that conflicts on Earth may begin to extend beyond our atmosphere as well.

Aside from space defense against other countries, planetary defense involves initiatives to monitor and protect Earth from asteroids and other objects that could threaten our planet. Even though NASA's Double Asteroid Redirection Test (DART) happened almost two years ago, we are still learning more about this mission. DART's successful impact with the asteroid Dimorphos altered the asteroid's orbit but led to the creation of a crater that flung debris from the asteroid. ESA's Hera mission, launching in October 2024, aims to study the Didymos binary asteroid and assess DART's impact, providing key insights for future asteroid deflection strategies.

WHY IT MATTERS

As space presents itself as a new Wild West, it will continue to be perceived as a risk to national security, whether those threats come from rising geopolitical tensions and conflicts on our home planet, or from the impending threat of celestial objects that we have even less control over.

When it comes to national defense, space has become critical for myriad reasons. So many space systems have become necessary components of our daily lives. Simple miscommunication among disparate nations can have outsized impacts, potentially leading to the destruction of important communication devices. More overtly nefarious threats exist as evidenced by Russia's cyberattack in February 2022 that left Viasat's KA-SAT modems inoperable in Ukraine. This incident led to other next order impacts, resulting in the malfunction of 5,800 Enercon wind turbines in Germany and other major disruptions to major European organizations. The US Defense Department has vowed to openly communicate US military space activities in an effort to prevent misunderstandings and miscalculations. However, China's decision to not be as transparent complicates matters. Without unified standards and norms, we are just a minor mishap away from nations taking retaliatory measures on perceived space-based threats.

SCENARIOS

SCENARIO YEAR 2043

Tax Tensions on Mars

The Colonized Habitat Optimization and Mining Co. (CHOAM), operating primarily on Mars and its surrounding Lagrange Orbit Equilibrium stations, mined Martian water ice to support other Mars-based ventures, scientific explorations, and low orbit Earth habitats. Initially incorporated as a Delaware C corp, CHOAM contemplated a paradigm shift in its corporate structure amid the complex milieu of US corporate tax policy. Attracted by the increasingly business-friendly climate of Singapore, and its progressive stance toward space commerce, CHOAM considered reincorporation. Singapore's introduction of tailored tax incentives for space-faring entities promised an advantageous arena compared to the US jurisdiction.

However, CHOAM's interplanetary ambitions are being tethered by the restrictions of US export controls. Navigating through the maze of the International Traffic in Arms Regulations (ITAR) and the Export Administration Regulations (EAR) was no minor feat. To circumvent the challenges of US export controls, CHOAM is ramping up in-situ inputs: By leveraging Martian regolith and other locally sourced materials, the company is extensively employing advanced 3D printing technologies to fabricate tools, infrastructure, and essential operational components. This drastic reduction in its Earth-based dependencies skirts many export control complications. CHOAM's strategic move to Singapore didn't go unnoticed. Other extraterrestrial corporations, grappling with the intricacies of off-world operations under their respective Earth jurisdictions, have begun evaluating potential reincorporation in tax-favorable countries.

1ST YEAR ON THE LIST

DOMESTIC COMPETITION

WHAT IT IS

Having recognized the economic impact the new space economy will have on local economies, select US states and markets are trying to establish themselves as major hubs for domestic operations. Through economic incentives and relaxed regulations, these states will attempt to edge out others to gain a competitive advantage.

HOW IT WORKS

In 2023, Texas Gov. Greg Abott signed HB3447 into law, establishing the Texas Space Commission. This group will allocate $350 million to develop the space industry in the Lone Star State, and will oversee planning, funding distribution, research, and education efforts in the Texas space industry. In a similar vein, Florida Gov. Ron DeSantis signed a bill into law aimed at reducing liability for commercial spaceflight companies, with an ultimate goal of attracting more launch providers to Florida's Space Coast. Under the law's provisions, companies will be granted immunity from liability associated with flight-related injuries or deaths, as long as crew members sign a waiver. Other states have shown they want a foothold in the space industry. President Joe Biden's decision to leave the US Space Command headquarters in Colorado evoked ire from Alabama officials. It was a reversal of a Trump administration decision to relocate the headquarters to Alabama. State officials claim abortion politics played a role in the change, as Alabama Republican Sen. Tommy Tuberville had been blocking military promotions over the Pentagon's abortion policies.

WHY IT MATTERS

In January 2023, Space Florida, the state's aerospace economic development agency, announced that the total economic impact of its aerospace finance and development authority had reached $5.9 billion since 2007. It expects the industry will have an additional $5.3 billion economic impact over the next five years, with an average annual impact of $1.1 billion. Ultimately, Florida recognizes the tremendous economic impact of the space economy and is doing everything in its power to entice more organizations to move or establish operations in the state. The space industry's potential economic impact on local economies is the central driver for the Texas Legislature's committing $350 million to fund and support Texas aerospace and space projects and new economic incentives to draw space companies and space startups to the state. The reaction from the political leaders of Alabama is understandable considering the US Space Command represents the significance, influence, and status of the space industry. The activities of these states underscore one thing: Whoever dominates the space race will dominate here on Earth.

1ST YEAR ON THE LIST

SPACE BLOCS

WHAT IT IS

Despite competition arising from the quest to travel to space, there's also been extensive collaboration. Since the Cold War's end, nations have been forming space blocs—groups of countries joining forces to further their collective interests in space.

HOW IT WORKS

Many consider the European Space Agency—now consisting of 22 nations—to be the first space bloc. One of the newer collaborative blocs is the African Space Agency, which officially formed in January 2023. Despite this union, Russia has tried to entice Algeria and Egypt to join its space program. The Latin American and Caribbean Space Agency now consists of 23 member states, and while no formal agreements have been brokered, China has expressed open support of the organization. Perhaps the most prominent collaborative bloc is the Artemis Accords, drafted by NASA and the US Department of State. This nonbinding multilateral arrangement with other world governments attempts to establish common principles, guidelines, and best practices for the safe exploration of the moon and beyond. NASA's adjacent Artemis program will require significant partnerships with countries and private companies to ensure it sends astronauts back to the moon. In 2023, India, Ecuador, Argentina, and the Czech Republic became the most recent countries to sign the Artemis Accords, marking a significant uptick in space collaboration with the US.

WHY IT MATTERS

Proponents of the Artemis Accords contend that the major tenets act as an extension of the 1967 Outer Space Treaty, to set principles for a safe, peaceful, and prosperous future in space. While a series of protocols to ensure this type of future is necessary, some have a complicated view of the Accords for a few key reasons. Notably, the 1967 Outer Space Treaty is seen as insufficient for governing current space endeavors, and the industry in general could benefit from a new, refreshed set of regulations to moderate activity in space. The treaty also asserts that "outer space is not subject to national appropriation by claim of sovereignty." Forming space blocs could be seen as a strategy for skirting this major tenet: While not claiming sovereignty of the moon or other celestial bodies, these blocs may make the case that their visits to and settlement of the moon are not acts of individual state sovereignty, and thereby not in violation of the treaty.

Opponents of the Accords contend that they are too centered on American and commercial interests, leading countries such as Russia and China to not sign the agreement. Both countries have their own individual and sometimes joint efforts to establish a presence on the moon, and continually seek collaboration with new countries and agencies, fully understanding this mode of operation is necessary to be the leader of the modern space race.

1ST YEAR ON THE LIST

GEOPOLITICAL TENSIONS OVER SPACE JUNK

WHAT IT IS

Space junk refers to the tens of thousands of defunct human-made objects in space, including old rocket parts, dead satellites, and debris from collisions—both accidental and intentional. As more nations operate in space, managing this issue involves addressing concerns of national security, weaponization, and liability.

HOW IT WORKS

About 100 trillion fragments of defunct satellites and spent rockets orbit the Earth. While some of these fragments are monitored, others are too minuscule to be tracked, presenting a considerable danger. Potential collisions between them can create even more fragments. In a phenomenon known as the Kessler Syndrome, these collisions can create a cascading effect, where debris begets more debris in a runaway cycle.

The severity of space debris was highlighted in January 2023, when an old Soviet-era rocket nearly collided with defunct satellite debris, a potential worst-case scenario that could have resulted in thousands of new pieces of debris. The threat is further complicated by irresponsible actions including the deployment of anti-satellite devices. In November 2021, the Russian Ministry of Defense launched an anti-satellite (ASAT) missile, creating a cloud of debris that threatened the International Space Station. Following the incident, the UN approved a resolution against ASAT tests. Meanwhile, tensions continue to brew around North Korea's satellite capabilities, leading South Korea and the US to agree on a joint probe into North Korean space rocket debris. In May 2023, the G7 nations deemed the issue of space debris an "urgent problem" that must be addressed collectively, including research in both orbital debris mitigation and remediation technologies.

WHY IT MATTERS

The escalation of space debris is both a technical challenge and a complex geopolitical issue. Nations possessing advanced space capabilities heavily depend on satellites for core national security functions, like surveillance, communication, and navigation. But satellites extend beyond military applications; from guiding us to our destinations through Google Maps to facilitating real-time financial transactions, commercial satellites are integral to our modern existence. Space debris, consequently, doesn't merely jeopardize national security—it also threatens economic stability and daily lives.

The problem exacerbates if debris from one nation damages another's satellite, invoking questions of accountability and liability. While international space law offers a legal framework, its application can be ambiguous, potentially sparking international conflicts. Like the high seas, space is considered outside the jurisdiction of any one nation, leading to a "tragedy of the commons" scenario. Citing the mismanagement of the oceans as a cautionary tale in the journal Science, a group of scientists recently urged regulators to avoid repeating past mistakes when establishing governance for space.

SCENARIOS

SCENARIO YEAR 2031

Interplanetary Park System

After more nations started sending spacecraft to land on the moon's south pole through the end of the 2020s, the United Nations finally decided to step in with more stringent and binding resolutions to regulate space travel. The international body had to be done right or risk both private and public operations wrecking the entire space environment. The urgency to put a temporary reprieve on commercial operations on the lunar surface was precipitated when a US-based company's testing equipment interfered with a Japanese rover, which almost sparked an international lunar incident. With commercial operations indefinitely suspended, various organizations were left hanging in the balance as their moon-based initiatives lay fallow.

In a ruse to keep valuable experimentation and lunar-based research moving forward, the US is volunteering its Artemis Program to launch the Interplanetary Park System in an effort to ensure the heritage of space can "be enjoyed today and preserved for tomorrow." Under the proposal, the IPS, through the collaboration of Artemis countries, now numbering 38, will continue its in-situ resource extraction and utilization and other experimental manufacturing methods, but all collected resources will be used for the infrastructure needed to establish monuments and the necessary built environment for IPS programming. Artemis and the IPS pledge to make space accessible to all global citizens of Earth. After establishing the infrastructure that would least invasively allow individuals to visit historical and significant sites on the moon, the IPS plans to explore other potential locations in our solar system to establish additional sites of interest, using lunar resources for fuels and building materials needed for such an initiative.

SPACE INDUSTRY

2ND YEAR ON THE LIST

SPACE FACTORIES

WHAT IT IS

Low earth orbit (LEO) may be a more suitable environment for manufacturing some goods and products like semiconductors and artificial proteins. As orbital transport costs decrease, we may see more companies move specialized production to space.

HOW IT WORKS

Space-based manufacturing harbors immense potential due to the unique conditions inherently present there. For instance, semiconductor manufacturing necessitates an extremely clean, low-pressure environment to avoid contamination. Naturally, the vacuum of space offers these conditions, a fact being capitalized on by companies like Space Forge, which intends to manufacture semiconductors in space. Researchers at MIT have utilized LEO's microgravity to produce intricate "skins" for additive manufacturing. Other efforts include Apsidal's module to manufacture complex glasses and fibers in space, and Varda's successful launch of the first space factory on SpaceX's Falcon 9 to produce pharmaceuticals (discussed in more detail under "Biomanufacturing in Space").

The impact of space manufacturing extends beyond earthbound economies. It's instrumental in establishing sustainable human habitation outside of Earth. Redwire Corp., through a recent NASA contract, is turning this concept into reality with FabLab, an in-space multi-material 3D printer. This transformative tool will empower space crews to manufacture essential items on demand, bolstering the self-sufficiency of future space dwellers and marking a significant leap toward a multi-planetary existence.

WHY IT MATTERS

Space-based manufacturing has the potential to overcome the constraints of gravity and optimize production in ways not possible on Earth. By making goods like semiconductors, organoids, and metal alloys in the microgravity of space, we can customize the manufacturing environment free from gravity's limitations. As climate change disrupts supply chains on Earth, off-planet production offers a resilient backup option, diversifying sources beyond our planet. In-space manufacturing may prove a strategic solution for enhancing supply chain resilience as accelerating climate impacts threaten production on Earth.

Space factories also play a pivotal role in enabling a sustainable long-term human presence in space. They not only reduce our dependence on Earth but also make us more viable as an interplanetary species by drastically cutting costs and risks associated with launching resources from Earth. The International Space Station has been trailblazing in this respect, having 3D printed in space since 2011. This progress toward self-sufficiency shows in-space production is feasible and an essential step toward independence from Earth. It signals a new era enabling deeper space exploration and habitation as humanity transitions to a multi-planetary civilization.

1ST YEAR ON THE LIST

BIOMANUFACTURING IN SPACE

WHAT IT IS

Biomanufacturing in space leverages microgravity to enhance production of biomolecules and materials, like drugs and tissues. It deepens our understanding of biology and aids clinical applications. As we plan for long-term space missions, sustainable in-space biomanufacturing becomes crucial.

HOW IT WORKS

Organoids are tiny, lab-grown models of human organs used to study structure and function. On Earth, gravity flattens organoids into blob-like shapes. But in microgravity, cells proliferate faster and can grow in 3D and better mimic real organ behavior. Space also optimizes organoid development. The controlled environments of space stations further limit contamination risks, creating ideal biomanufacturing conditions.

In 2023, Varda Space Industries launched the first orbital factory dedicated to pharmaceutical production in space. Its inaugural project focuses on assessing the manufacturing of the HIV medication ritonavir under microgravity conditions. However, Varda encountered a regulatory setback after its June launch: While the Federal Aviation Administration approved the launch of the orbital factory, it has not authorized the descent of the recovery capsule, posing a challenge to the startup in retrieving its space-manufactured drug samples. Redwire Space was awarded a 14 million euro contract by the European Space Agency to design a comprehensive facility for tissue engineering and regenerative medicine on the International Space Station. This effort builds on Redwire's existing bioprinting work on the station, including a project to bioprint human knee meniscus tissue. Meanwhile, researchers at the China Space Station have successfully created early-stage blood cells in space for the first time, bringing us one step closer to treating diseases by producing any type of human cell. In this experiment, pluripotent stem cells, capable of developing into any major human cell type, were sent to the Wentian lab module, where they successfully matured into hematopoietic stem cells, the precursors to blood cells.

WHY IT MATTERS

After decades of single-use spacecraft, SpaceX's reusable launch systems have dramatically reduced the costs of accessing space. With biotechnology innovations accelerating in parallel, we have reached an inflection point where biomanufacturing in space is technically possible and may soon make financial sense. For example, growing human organs in microgravity could provide a cost-effective, long-term solution to organ shortages for transplants. Producing biomaterials and pharmaceutical goods in space could lead to scientific breakthroughs or better drugs. Varda's founder explained in an interview that until now, gravity has always been considered a constant. With space biomanufacturing, gravity can now be a variable to sub in and out of experiments. This could revolutionize fields like drug testing and disease modeling by engineering higher-fidelity organoids.

SpaceX enabled cheap launches, catalyzing space research. But achieving orbit is only step one. We also need companies focused on affordable ways to retrieve the results and deliver them safely back to Earth. Reusable reentry vehicles to ferry goods from cosmic factories will require regulatory greenlights. If approved, regular roundtrip transport could accelerate off-planet R&D across sectors. Furthermore, as we venture farther into space, the ability to manufacture biomaterials and pharmaceuticals in situ will become increasingly vital. Transporting all required medicines, medical devices, and even organs from Earth to off-world colonies would be enormously expensive and inefficient. Instead, establishing biomanufacturing infrastructure throughout the solar system can provide colonists with reliable on-demand access to medicines, nutrients, tissues, and organ replacements tailored to local needs.

2ND YEAR ON THE LIST

OFF-PLANET RESOURCE PRODUCTION

WHAT IT IS

Off-planet resource production, or in-situ resource utilization (ISRU), refers to the extraction, processing, and use of resources found on other celestial bodies like the moon or Mars. ISRU aims to make space missions less expensive and easier by reducing the amount of resources needed to be transported from Earth. It's the key for long-term space habitation and deep space expeditions.

HOW IT WORKS

ISRU endeavors are largely concentrated on extracting life-sustaining elements (water and oxygen) as well as providing rocket propellant for return trips to Earth. NASA's Perseverance rover is actively seeking water on Mars, and similar strategies are applied on the moon using thermal extraction. Experiments like MOXIE on Mars have successfully produced oxygen. In recent years, however, the focus of ISRU has extended beyond oxygen and water production. Companies like Air Co., a finalist in NASA's Deep Space Food Challenge, have developed a method to convert carbon dioxide, water, and yeast starter into protein-rich yeast using a process that simulates plant photosynthesis but uses astronaut breath. This yeast can then be converted into a variety of food forms, potentially supplying long-duration space missions.

Blue Origin, funded by a $34.7 million NASA contract, is "Blue Alchemist"; this ISRU project is a reactor that separates oxygen from lunar regolith, leaving behind materials for solar cell construction, while the oxygen could provide breathable air. Zeno Power and Redwire also won contracts that help missions to live off the lunar land. Zeno Power is converting heat generated from decaying radioisotopes into electricity to provide nuclear power on the moon. Meanwhile, Redwire is building roads and landing pads on the moon by utilizing a microwave emitter to transform lunar landscapes into solid surfaces.

The ESA is also experimenting with methods to create roads on the moon. In 2023, the agency successfully used a laser to melt simulated moondust. The goal was not just to pave roads for future on-moon transportation but also as a practical response to keep lunar dust at bay, which has caused issues in the past by clogging equipment during the Apollo era.

WHY IT MATTERS

Consider this analogy: If you're a New Yorker planning a vacation in Europe, you wouldn't pack all the water you'd need for drinking and bathing into your suitcase. Not only would it be exorbitantly expensive, but it's also highly impractical since water is readily available in Europe. The same principle applies to space travel. With starting costs around $6,600 per kilogram, the fiscal burden of taking anything with you is undeniable. Even as SpaceX's reusable rockets strive to bring down these costs, launch costs are still substantial. By tapping into local resources on the moon or Mars, we can significantly reduce the costs and challenges associated with space travel. Simply put, to establish self-sustaining colonies in space, we must utilize local resources. Without ISRU, practical and sustainable life on other planets remains a distant, unattainable dream. It's too costly and risky to rely solely on Earth for the constant supply of life-sustaining resources. To live beyond our planet, we will require more than just the basic survival resources like water and oxygen; we need infrastructure and shelter. Efforts from companies like Blue Origin, Zeno Power, and Redwire will help establish the infrastructure we need for scientific research, colonization, and even industrialization.

1ST YEAR ON THE LIST

THE SATELLITE BOOM

WHAT IT IS

Over the past decade, the number of satellites in space has grown almost sevenfold as costs decreased for building satellites and shipping payloads to space. Turnkey solutions and new business models are allowing smaller companies to enter the market, but to match the demand, new players will need to capture more market share.

HOW IT WORKS

In the early 2010s, only about a thousand satellites were in orbit, mainly because of their high costs. Originally, building a satellite cost $200–$300 million, and launches were around $380 million each. Today, there are over 7,000 active satellites thanks to SpaceX's efforts in reducing launch costs through reusable rockets and ridesharing services. By 2015, launch costs dropped to $275,000 per kilogram, and now range as little as $3,000/kg–$6,000/kg. This affordability has opened doors for entrepreneurs and hobbyists in satellite ventures. However, smaller satellite operators are struggling to get on SpaceX's crowded launch schedule. Despite this, smaller launch companies like ABL Systems, Relativity Space, and Astra Rocket are emerging to meet the increasing demand. For those entering the satellite industry, turnkey solutions from companies like York Space Systems, Blue Canyon Technologies, and Apex Space offer mission design, spacecraft, launch, ground, and operations services. To cater to growing military demand, Lockheed Martin is restructuring its space division and selling technology and satellite parts to align with the booming space sector. For organizations with even fewer resources to spend on this industry, satellite-as-a-service is an increasingly popular business model offered by ISISpace, Loft Orbital, and Spire Global.

WHY IT MATTERS

While rideshare options on SpaceX rockets are showing to be more of a challenge, growth for the global satellite industry is far from slowing down. With growing demand, new players can gain market share. The market for hitching rides on other company's rockets now consists of two broad categories: smallsat constellation developers looking to augment their systems, and startups, universities, and governments planning to send their first satellites to space. Additionally, regions such as Latin America and the Middle East are growing their space capabilities and also contributing to this new demand.

Besides the decrease in cost to both build and launch satellites, two other significant drivers are creating demand in this industry: the need for mobile communications and Earth observation (EO) services. Communications satellites account for the largest and fastest growing market segment. According to Grand View Research, this segment is currently valued at roughly $72 billion and anticipated to grow at a compound annual growth rate of 9.5% from now to 2030. Alternatively, Straits Research predicts the EO market will be worth $13.6 billion by 2030. New regulations will require organizations to report environmental impacts using satellite data. This mandated transparency is expected to create an Earth observation boom, driving innovation of technologies that enable independent tracking of sustainability metrics from space. This industry will have an immeasurable impact on resource and supply chain management as well as urban planning and development—it shows no signs of slowing down.

1ST YEAR ON THE LIST

CONSTELLATION MANAGEMENT

WHAT IT IS

With the meteoric rise of the satellite industry over the past several years, there is increasing need for effective and dependable satellite constellation management solutions. These systems assist satellite operators in optimizing performance while minimizing operational expenses.

HOW IT WORKS

Florida-based Sidus Space offers a full suite of satellite constellation management services. It assists in arranging the launch, ensures all necessary licenses and permits are in place, and handles all aspects of the day-to-day operations once in orbit—including monitoring the constellations' health, adjusting their positions, and making sure they continue to function properly. Engineering services company A.I. Solutions specializes in satellite flight dynamics by providing expertise in orbital mechanics, mission planning, and satellite operations. It's been involved in operating and managing satellite constellations associated with the International Space Station, GPS, Landsat, and the Geostationary Operational Environmental Satellite. Its proprietary FreeFlyer software provides flexible and scalable options for both small and large satellite constellations. It can automate routine tasks and distribute them across virtual machines or cloud instances, providing coverage for constellations consisting of thousands of satellites. FreeFlyer also supports traffic management efforts for these complex satellite clusters. Raytheon's constellation management solutions use a signal ground system and edge processing to enhance data collection speed and accuracy. They employ artificial intelligence and machine learning to extract maximum value from on-orbit assets.

WHY IT MATTERS

Companies that rely on constellations of satellites to run their everyday operations need efficient and dependable systems and services, at minimal operational cost. Advanced signal processing on satellites enables efficient use of available spectrum, with dedicated integrated circuits maximizing capability and efficiency. Phased array antenna technologies create dynamic spot beams, delivering signal power and capacity where needed on the ground. High-bandwidth optical inter-satellite links connect mega-constellations, providing secure, low-latency data backhaul across the globe. From this complex network of technologies, operators can achieve real-time monitoring and notice of issues, consequently reducing possible downtime risk. They also realize efficiencies with optimized fuel usage and decreased maintenance costs. Through analytics, these services can open up revenue opportunities by enhancing satellite coverage and expanding service areas, thereby increasing the number of customers these constellations can serve. Overall, satellite constellation management systems enhance satellite performance, reduce costs, and improve customer service.

1ST YEAR ON THE LIST

MINING

WHAT IT IS

Space mining is the process of extracting valuable resources such as minerals, metals, and water from celestial objects like asteroids, the moon, and other planets. The prospecting, excavating, and extracting of these resources can be used for various purposes including fuel production, construction of habitats, and future space exploration.

HOW IT WORKS

In 2023, the OSIRIS-REx mission successfully returned a sample to Earth from asteroid 101955 Bennu. The spacecraft continued on to a new mission to explore the asteroid Apophis. Meanwhile, scientists hope the sample will offer clues about whether asteroids brought water and other key ingredients for life to Earth billions of years ago. It could also help inform us of available materials for more commercial purposes.

California-based startup AstroForge is embarking on two missions toward becoming the first commercial company to mine asteroids. It plans to use CubeSats on its first mission to test in-situ refining in a zero-gravity environment. The second mission will send a spacecraft on an 8- to 11-month journey to prospect a near-Earth asteroid, which has yet to be publicly identified. Ultimately, AstroForge plans to extract rare minerals from these asteroids and bring them back to use on Earth. Colorado-based Karman+ is focused on creating technology to mine water from near-Earth asteroids. It has identified over a million of these asteroids that could potentially be mined using a model developed through a meta-survey of solar system objects. Asteroid Mining Corp. is also on a mission to prospect, explore, and extract resources from asteroids. It is developing Space Capable Asteroid Robotic Explorers (SCAR-E), a modular hexapedal robotics platform for drilling into asteroids and processing extracted materials in space. TransAstra plans to mine moons and planets in addition to asteroids. By using its optical mining process, TransAstra will use concentrated sunlight to excavate feedstocks for propellant from these celestial bodies.

WHY IT MATTERS

While many space startups have set their mining ambitions on extracting valuable resources from asteroids, our moon will probably serve as a more valuable asset for collecting these resources first. With the success of India's Chandrayaan-3 moon landing, the utilization of Earth's moon as a viable location for landing, living, and exploration is gaining momentum. It is important for startups to consider the challenges of traveling to and mining asteroids in space, but the moon will also be a significant source for powering space activities and for supporting future moon missions. Oxygen, water, and metals can potentially be mined from the surface of the moon and used in supporting ways, such as producing rocket fuel, enabling life-support systems, and constructing infrastructure on the moon and in space.

The moon is known to contain abundant amounts of helium-3, which is a rare isotope on Earth that can be used in the process of nuclear fusion. The current price for helium-3 is $140 million for 220 pounds, and the moon is estimated to have enough of it to generate $1.543 quadrillion. Asteroids, on the other hand, contain numerous metals including nickel, cobalt, and more valuable metals, such as gold, platinum, and rhodium. The asteroid 16 Psyche has been reported to contain $700 quintillion worth of gold.

SPACE INFRASTRUCTURE

1ST YEAR ON THE LIST

TELECOMS

WHAT IT IS

A considerable portion of the world's population shares information through mobile phones, PCs, and various electronic communication devices. While Earth-based networks have primarily facilitated this connectivity, a constellation of space-based satellites and technology will increasingly address the need while impacting new industries.

HOW IT WORKS

In 2023, AST SpaceMobile collaborated with AT&T on the first satellite-to-smartphone call over a 2G to 5G network. Verizon, T-Mobile, and others are pursuing space connectivity too. NASA achieved record 200 gigabit per second data rates from an experimental satellite using laser communications. Meanwhile, Starlink extended its customer lead, exceeding 1.5 million subscribers. In addition to this achievement, Starlink laser-based communications will be tested in space by the private Polaris Dawn mission, which will result in valuable data for future space communications systems. This year opened with John Deere teaming with SpaceX to enhance rural broadband access. An anticipated Starlink IPO could intensify investment enthusiasm.

Competitors have struggled to match SpaceX's breakaway pace. Yet, competitors like Amazon and European-based OneWeb are slowly making progress. Amazon's Project Kuiper aims to deploy a constellation of 3,236 satellites to achieve global connectivity. However, it will take several years before a sufficient number of satellites are in orbit to provide consistent and reliable commercial service. For now, Starlink's foremost rival in terms of broadband capacity is OneWeb, recently acquired by Eutelsat. Rather than direct consumer sales, OneWeb employs a business-to-business model. It sells to intermediaries, like partner Airbus, which then provide access to institutional clients, prioritizing governments and militaries in initial efforts.

WHY IT MATTERS

On Earth, space-based telecommunications are already enhancing cellular connectivity more globally: Both developed nations and developing nations, as well as urban and rural communities, can benefit from this technology, ultimately bridging the connectivity gap that currently divides cultures and populations. Additionally, other innovations in this constellation of technology will improve space science instruments. The use of new technologies such as laser communications will enable more efficient data transmission and could make both communication in space and communication from Earth to space more reliable and efficient. Additional benefits include reduced system weight, heightened security, and greater flexibility for ground-based infrastructure. Taken together, these advantages will enhance the capabilities of scientific instruments and expand the possibilities for data analysis and data transfer. Eventually, laser communications will allow increased volumes of data to be transmitted over longer distances, which will be pivotal for establishing our presence in our solar system beyond our home planet. Ultimately, space telecommunications will impact life in space but also our experiences here on Earth, whether through more efficient communications or enhanced processes to industries such as agriculture.

1ST YEAR ON THE LIST

MAINTENANCE MISSIONS: SATELLITE SERVICING

WHAT IT IS

On-orbit servicing extends the operational life of satellites by repairing, upgrading, or performing maintenance while they are in Earth's orbit. The service can be done through orbit adjustments, refueling, or upgrading instruments.

HOW IT WORKS

The European Space Agency and European industry are working together to develop in-orbit servicing (IOS) technology. Companies working toward extending the life of satellites include Astroscale, ClearSpace, D-Orbit, and Telespazio; they're making progress on IOS concepts involving maintenance, orbit adjustment, refueling, and instrument upgrades. Starfish Space, a startup founded by veterans of Blue Origin, obtained $14 million in funding to launch its own satellite-serving endeavors. After creating a prototype vehicle called Otter Pup, they will attempt to dock on another satellite in orbit before trying it with a full-size Otter spacecraft. Northrop Grumman's SpaceLogistics sold its third Mission Extension Pod (MEP), a propulsion system designed to extend the lifespan of legacy satellites in geosynchronous Earth orbit. The MEP will be placed on a satellite by a Mission Robotic Vehicle using robotic arms, and will essentially function as a jetpack for satellites. This will extend the satellite life by at least six years. The US Space Force now sees the value in servicing preexisting satellites and is investing in early-stage technologies. It's working on a strategy for refueling and servicing satellites in geostationary orbit, and hopes to have the capability by the early 2030s.

WHY IT MATTERS

According to MarketsandMarkets, the on-orbit satellites servicing market is expected to grow significantly, from $2.4 billion in 2023 to $5.1 billion by 2030 with a compound annual growth rate of 11.5%. The telecommunications industry has serious interest in life extension services for maintaining satellites' orbit and reducing fuel costs. Organizations are now viewing satellite servicing as a strategic advantage. By essentially refueling and repairing satellites in orbit, satellite operators will have increased flexibility in response to threats.

Satellite servicing is important for a multitude of other reasons. We rely on satellites for weather forecasting, communications, navigation, and scientific research. Maintaining consistent operation of these constellations will ultimately lead to longer service lives of spacecraft and increase the return on investment for companies that launch these satellites. Servicing will also minimize the risk of space debris as satellites can be repurposed rather than merely decommissioned.

1ST YEAR ON THE LIST

MONITORING EARTH

WHAT IT IS

The harshest critics of space exploration often emphasize the need to focus on the challenges here on Earth before extending our energy to explore the cosmos. As it is, a constellation of satellites and associated space technology have been providing valuable information about our world since the 1960s.

HOW IT WORKS

Much of the infrastructure we've set up in space is for monitoring Earth. Monitoring technology can be used to drive weather-tracking abilities, sustainability measures, and disaster preparedness. As a pillar of space-based research, the International Space Station has a series of platforms for monitoring climate change, including external instruments measuring ground temperature, imaging spectrometers tracking dust particles' impact on climate, and an instrument that measures atmospheric particles from events like volcanic eruptions. Additionally, CubeSats are used by the ISS to observe particle-cloud interactions and meteorological disasters. The European Space Agency also uses a fleet of satellites to monitor soil moisture, measure polar ice thickness, and conduct analysis from radar imagery. Future missions including Flex will map vegetation, and Biomass will gather information on forests. The Canadian Space Agency and Spire Global will undertake their WildFireSat mission using space-based thermal intelligence to support wildfire management. In May 2023, Rocket Lab successfully completed two launches for NASA's Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission. TROPICS will use four CubeSats to monitor the evolution of tropical storms and hurricanes to enhance storm prediction. Furthermore, the escalating regulatory focus on climate disclosure, marked by California's 2023 enactment of mandatory emissions disclosure rules, is further catalyzing the growth of the Earth observation market. Expect the regulatory moment to incentivize the development and technology that facilitate accurate and independent metrics for monitoring our planet.

WHY IT MATTERS

As is the case with all technology, in time, monitoring technology has become more sophisticated since NASA started using it more than 60 years ago and can address a broader range of applications. By establishing a constellation of satellites in space, we can make more observations about a broad swath of phenomena that would require an exorbitant amount of ground-based observers to operate with similar accuracy. Earth observation satellites can assist in tracking gradual environmental shifts including deforestation, rising sea levels, and increasing wildfires. This data can assist in predicting crop yields as weather patterns become more erratic, helping to ward off food insecurities. Governments can use data collected from these satellites to improve their disaster preparedness in the event of intensifying storms, including policies for evacuation plans, resource allocation, and emergency response strategies. Businesses can also benefit by using such data to safeguard supply chains and add resiliency to their value chains. The broader implication is that space exploration and its associated technology offer benefits that go beyond space itself. These practical applications impact our lives today and will help prepare for uncertain futures on Earth.

2ND YEAR ON THE LIST

SELF-ASSEMBLY TECH

WHAT IT IS

Self-assembly technology confronts numerous engineering hurdles related to deploying structures in space and constructing them there. It will unlock new pathways for pioneering novel, streamlined, and versatile space architectures.

HOW IT WORKS

Several groups are experimenting with confronting the challenge of space construction. The MIT Space Exploration Initiative's TESSERAE is the preeminent example of using self-assembly technology to construct space structures: Ariel Ekblaw's project uses flatpack structures and self-assembling tiles embedded with electromagnets to snap components into water- and weather-tight structures that can serve humans in space as well as on Earth. TESSERAE tiles were included on Axiom's Ax-1 research mission in 2022 and further tested during the 2023 Horizon zero-gravity flight by the Aurelia Institute. New features of the tiles include autonomous self-assembly through algorithmic design and enhanced bonding reconfigurability. The MIT Space Exploration Initiative is also exploring magnetically programming cubes to stochastically self-assemble. These ElectroVoxels could serve a variety of applications, ultimately providing solutions for space exploration's unknown challenges. Caltech researchers have also implemented self-assembly principles in a solar power demonstrator that successfully beamed detectable levels of power down to Earth. The design uses modules that are 35 cubic feet before launch but unfurl into huge flat squares 50 meters per side after launch. Space Forge is turning to origami to design Pridwen, its deployable heat shield. The shield creates ample surface area for even heat distribution and can be reused on multiple launches.

WHY IT MATTERS

Traditionally, structures in space have been completely utilitarian in their design. When scientists built the International Space Station, they had to launch disparate pieces into space that were assembled by spacewalking astronauts and robotics. Even as sending payloads to space becomes more affordable, this more archaic process for establishing structures in space is still cost prohibitive, complex, and time-consuming. Other challenges include fitting all composite parts within the confines of rockets and ensuring they withstand the harshness of the launch, while addressing the unforgiving conditions for the astronauts assembling the structures. Shifting the paradigm to self-assembling technology will provide solutions for many, if not all, of these challenges. It will enable more cost-effective solutions and architecture that is dynamic and multipurpose, imbuing structures with new vitality and cultural significance. If Ekblaw's visions come to fruition, space will be fitted with stunning and inspiring cathedrals and concert halls, and not just sterile, single purpose research structures. Dynamic structures have other positive implications, such as the possible ability to self-regulate and self-heal. This technology could also have relevance on Earth, by providing dynamic habitats that can adapt to extreme weather and disaster events in real time.

1ST YEAR ON THE LIST

GREEN PROPULSION

WHAT IT IS

Eco-friendly, storable high-performance hypergolic propellants have been the holy grail of space propulsion for decades, but current breakthroughs are making this elusive form of propulsion more of a reality. Green propulsion alternatives will be key for reducing carcinogenic and environmentally damaging propellants.

HOW IT WORKS

Łukasiewicz Research Networks' Institute of Aviation has made significant advancements in the development of green, high-performance, hypergolic propellants. Its new propellant uses hydrogen peroxide as an oxidizer with a novel fuel, offering high performance, hypergolic ignition capability, and simplicity in engine design, potentially reducing costs for satellite platforms, landers, and launch vehicle upper stages. Benchmark Space Systems is another company dedicated to developing green, nontoxic propulsion systems and technologies to support space missions. According to Benchmark, its Halcyon Avant green bipropellant system boasts a 25% increase in fuel efficiency over other green monopropellants. The Space Enabled research group at MIT is exploring the use of wax-based hybrid rocket propellants, such as paraffin and beeswax. These materials potentially offer high performance, cost-effectiveness, and safety advantages compared to traditional toxic propellants like hydrazine. In an entirely different approach, California-based SpinLaunch is working to develop an innovative space launch system powered by kinetic energy. This technology involves a vacuum-sealed centrifuge mechanism that accelerates a rocket to speeds of up to 4,700 mph (7,500 km/h; 2.1 km/s) before releasing it into space. Once released, the rocket's engines are ignited at an altitude of approximately 200,000 feet. Auriga Space offers another novel approach. In 2023, the company unveiled an electromagnetic launch system, akin to a maglev train, using a ground track to magnetically accelerate a vehicle to high altitudes. Like SpinLaunch, once the vehicle reaches a high altitude, it then fires engines for orbital insertion.

WHY IT MATTERS

It comes as no surprise that present-day spacecraft propulsion heavily relies on toxic and cancer-causing hydrazine propellants, presenting unique environmental concerns and associated safety risks. As the number of future space endeavors and applications continues to rise, adopting environmentally friendly space propulsion methods becomes supremely important. A study by the National Oceanic and Atmospheric Administration further highlights the environmental impact of space travel, indicating that global rocket launches (180 in total during 2022) release approximately 1,000 tons of soot into the upper atmosphere per year. Projected increases in rocket launches risk exposing more people in the Northern Hemisphere to increased harmful UV radiation.

Developing more environmentally forgiving propellants or viable alternative propulsion systems will be no easy task but ultimately will be necessary to adopt eco-friendly and nontoxic propellants to replace conventional, hazardous hydrazine-based systems. This change will further be precipitated by shifting regulatory requirements, changing market demands, and also by the technical and economic advantages offered by nontoxic alternatives.

1ST YEAR ON THE LIST

MONITORING ORBITAL DEBRIS

WHAT IT IS

Ongoing tracking and surveillance of defunct human-made objects in Earth's orbit will help prevent collision catastrophes and ensure that space remains accessible to us in the future. Monitoring goals include avoiding collisions of active satellites, understanding debris-generating events, and aiding efforts to mitigate and remedy debris.

HOW IT WORKS

The growing risk posed by orbital debris has highlighted the need for enhanced monitoring as space becomes more congested. For example, SpaceX's Starlink satellites conducted 25,000 collision avoidance maneuvers between December 2022 and May 2023.

US agencies are ramping up efforts to monitor space debris, placing particular emphasis on objects larger than 10 centimeters. But there's also an increasing awareness of the hazards posed by smaller fragments. Traveling at 17,000 mph, debris as small as a penny can wreak havoc on space assets. Recognizing this, the Office of the Director of National Intelligence launched the Space Debris Identification and Tracking (SINTRA) program, specifically aimed at tracking micro space debris. Separately, US Space Command is training AI on its extensive data, aiming to efficiently discern and prioritize critical threats. In October 2023, the FCC enforced its first space debris penalty in a settlement with Dish Network, forcing the company to pay a fee of $150,000 for failing to remove the EchoStar-7 satellite.

Several companies have also entered the field. In 2023, Japan granted Astroscale a contract worth up to $80 million for a mission to gather data on an inactive satellite in orbit. This mission involves launching a spacecraft that will initially use ground-based observations for proximity and then switch to onboard sensors for closer engagement. The spacecraft will then carry out detailed examinations of the defunct satellite using its integrated imagers and sensors. Another company, Odin Space, is working to detect orbital debris via a sensor on a newly launched space tug. Another startup, LeoLabs, monitors the trajectories and movements of numerous spacecraft in low Earth orbit.

WHY IT MATTERS

Centimeter- and millimeter-sized fragments in space pose the most significant threats to missions in low Earth orbit. Yet, less than 1% of these potentially catastrophic objects are currently monitored, and many are inadequately assessed for the risks they present. The persistence of these debris is alarming; without atmospheric drag, they can remain in orbit for centuries. This means any object sent to space without a plan for deorbit is destined to become hazardous debris. The financial and safety implications of space debris are also profound. In March 2023, an approaching piece of space junk threatened the International Space Station, forcing a hasty maneuver of the $150 billion station to safety. Such maneuvers are costly, averaging $1 million in expenses for propellant and operational adjustments.

Fortunately, we are getting much better at monitoring. Enhanced tracking and cataloging have granted satellite operators the capability to adeptly dodge potential collisions, thereby averting substantial collision risks. Consistent monitoring ensures that essential orbital pathways remain navigable, preserving them for future space ventures rather than rendering them too perilous to explore due to collision threats.

1ST 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

Proposed deorbiting solutions include controlled deorbit using spacecraft propulsion; drag augmentation with deployable sails or balloons; and active debris removal. The latter includes concepts like on-orbit capture, lasers to evaporate or slow debris, electric propulsion to dispose debris in graveyard orbits, and inflatable braking devices.

The European Space Agency recently succeeded in guiding a defunct satellite back to Earth, marking the first assisted reentry of its kind. Through complex maneuvers, the agency lowered the satellite's orbit from 320 kilometers to 120 kilometers to ensure atmospheric reentry and burn up. Several startups are also pioneering deorbit efforts: Astroscale's ELSA-M system will be the first to provide multi-removal services, supporting satellite operators including constellations with a compatible magnetic capture mechanism. ClearSpace, another startup, recently secured a contract for ClearSpace-1, the first active debris removal mission to capture and deorbit an object of more than 100 kilograms. Unlike these reactive approaches, D-Orbit's approach is preventive. Its preinstalled Decommissioning Device is externally mounted on satellites before launch. The device will be used for end-of-life maneuvers—once a satellite is no longer functioning, D-Orbit's device will boost the object to burn up in Earth's atmosphere, or into a safer orbit.

WHY IT MATTERS

The escalating issue of space debris isn't just a technical hurdle; it's also an economic opportunity. Introducing financial incentives for space debris cleanup could expedite the process, mitigating the risk of a Kessler Syndrome—a domino effect of collisions that exponentially increase debris. Monetizing orbital debris and space preservation can yield significant savings, with break-even analysis indicating approximately $20 billion saved annually. These costs will soon equalize and then decrease, especially when post-mission disposal practices achieve a 90% success rate, coupled with at least five active debris removals yearly. With forecasts suggesting the space debris monitoring and removal sector could grow from $942.3 million in 2022 to $1.5 billion by 2029, the financial potential is clear.

From a broader economic perspective, clearing space debris effectively unlocks invaluable orbital "real estate." As the space industry burgeons, every cleared orbit paves the way for new satellite deployments, promoting a surge in space-related economic activities and opportunities.

But there are implications beyond the financial. The problem of space debris threatens our deeply human desire to explore and expand. The Kessler Syndrome warns of a bleak scenario where a dense debris field in low Earth orbit instigates a cascade of collisions, rendering space missions perilous or even unfeasible. In such a scenario, Earth could become an unintentional prison, cutting off our access to the cosmos.

COMMERCIALIZATION OF SPACE

2ND YEAR ON THE LIST

OFF-PLANET TOURISM: GETTING TO SPACE

WHAT IT IS

In existence since the 1990s, the commercial space transportation industry initially focused on launching satellites and sending cargo to the International Space Station. Now it's sending tourists on suborbital trips in space.

HOW IT WORKS

In the year between Jeff Bezos' successful first suborbital space tourism flight aboard the New Shepard in July 2021, his Blue Origin took a total of six crewed flights aboard the launch vehicle. In total, it launched 25 nonprofessionals on suborbital flights to the edge of space—a list that includes notable individuals such as actor William Shatner, aviation pioneer Wally Funk, and TV personality Michael Strahan. More recently, Richard Branson's Virgin Galactic completed its first commercial flight, taking its crew to the edge of space aboard the VSS Unity. Members of the flight included two Italian air force officers and an aerospace engineer from the National Research Council of Italy. The flight, called Galactic 01, took the individuals 50 miles above New Mexico and lasted roughly 75 minutes. The succeeding flight, Galactic 02, included Olympian Jon Goodwin along with Keisha Schahaff and Anastatia Mayers, the first mother-daughter duo to fly to space. Startups Space Perspective and World View have a different approach for sending tourists to the stratosphere, namely by balloon. Space Perspective's Spaceship Neptune, equipped with a lounge, bar, and Wi-Fi service, will travel at 12 mph, carrying passengers on sightseeing tours 19 miles above the Earth. World View's balloon-based system will last about six to eight hours and take passengers to an altitude of at least 100,000 feet, allowing the passengers to see the curvature of the Earth.

WHY IT MATTERS

With the tragedy of the Titan submersible, individuals understandably began to compare ocean exploration to that of space. There are similarities and differences between the two. George Nield, who was aboard the New Shepard on March 31, 2022, highlighted those similarities, indicating that both take place in harsh and unforgiving environments, involve a significant level of risk, are only available to a few select individuals, and cost an exorbitantly high amount of money. With these comparisons in mind, Nield admonishes that the space tourism industry needs to update the regulatory framework for commercial human space flight rather than merely rely on informed consent for travelers. He also urges that now is the appropriate time to question whether the industry is ready for a similar tragedy, emphasizing that rushed regulations in this space are essentially bad regulations. These are especially important considerations as a study from the Pew Research Center indicates that while over half of Americans expect space tourism to be commonplace by the year 2073, 65% said they would not be willing to go to space even if given the opportunity. While taking flights to space has its critics, the industry is still valued at $450 billion. Despite the risks involved, affluent thrill seekers will continue to seek novel experiences, such as space flight, instilling continued confidence in the market.

2ND YEAR ON THE LIST

OFF-PLANET TOURISM: STAYING IN SPACE

WHAT IT IS

Staying in space involves constructing and inhabiting innovative structures that can serve tourists as well as businesses and scientists. Private space stations of the future will function as luxury hotels, business parks, and research centers.

HOW IT WORKS

Despite its rebrand, Above Space (formerly Orbital Assembly) still has plans for its private Pioneer Station, described as the first business park in space with gravity, and is taking reservations for its future all-inclusive luxury space hotel. The station, which will be situated in low Earth orbit, is intended to be used by businesses, scientists, and tourists. Pioneer will include a rotating structure to simulate gravity, unlike other space stations. In 2022, Hilton and Voyager Space announced their collaboration to provide a hotel in low Earth orbit. Voyager Space has more recently announced a partnership with Airbus to develop, build, and operate Starlab, the station that will house Hilton's hotel and could one day replace the International Space Station. California-based Orion Span has its own plans for a luxury space hotel known as the Aurora Space Station, with the hopes of offering extended stays in space. If things go according to plan, paying customers will be taken 200 miles above the Earth's surface and spend 12 days at the hotel. Houston-based Axiom Space won NASA's contract to construct the first commercially manufactured module for the ISS. It plans to attach this module in 2026, a second module in 2027, and a third in 2028. After this, its thermal power module will allow Axiom's space station to detach from the ISS to become a commercial free-flying station.

WHY IT MATTERS

Bringing tourists to space and keeping them there for a period of time is no easy task. It also doesn't come cheaply, and critics will always oppose profligate and excessive spending for tourism. But space tourism also channels luxury spending toward continued and advanced research in the space industry. There is the significant opportunity to increase scientific knowledge under the guise of adventure tourism.

In addition to research, space tourism offers obvious economic benefits. It will require new business ecosystems and supply chains, creating entire new industries and jobs. The US Chamber of Commerce anticipates that the US will need more than 1.5 million workers to drive the new space economy. Space hospitality could serve as the testing ground for long-term space missions and colonizing space, providing us with more insights on the systems required to make space colonization possible, and the effects it will have on larger communities living in space.

Visiting space can have other unexpected benefits as well. When Shatner went to suborbital space, he cited experiencing the overview effect, or the transformational and cognitive and emotional shift in a person's awareness when they visit space. This effect would be conceivably more profound for individuals experiencing extended stays in space. Perhaps increased empathy among the affluent is something that critics of space tourism can get behind.

1ST YEAR ON THE LIST

SPACE ENTERTAINMENT AND EVENTS

WHAT IT IS

As we establish long-term settlements in space, we will need forms of entertainment to inspire and stave off the impending isolation being in space elicits. Our time there will assuredly lead to novel events with new cultural significance.

HOW IT WORKS

While not technically in space, electronic duo The Chainsmokers are set to perform the first concert in the stratosphere. The group plans to perform aboard World View's pressurized space capsule tethered to a stratospheric balloon.

Once humans are spending significant time in space, we'll still want to enjoy the cultural elements we are accustomed to here on Earth. MIT-led project Telemetron Orchestra wants to contribute to ways we can create and experience music in space. The project is working to develop musical instruments that function to their full potential only in zero-gravity environments, raising the possibility of a culturally rich life in space. This could enable less gimmicky concert options that one day take place in the actual boundaries of space.

Anticipating future sporting events, the Institution of Engineering and Technology has created a rulebook for how football—soccer to American audiences—would be played on the surface of the moon. Games would involve five players on each team and consist of four 10 minute quarters with 20 minute breaks to give players a chance to rest and recover. The optimistic plan is for these games to actually start happening by 2035, with players wearing slimmed down Apollo spacesuits equipped with internal cooling systems. In a similar vein, the Space Games Federation has identified prospective above-the-Earth sports, such as float ball, which borrows elements from football, dodgeball, and basketball.

WHY IT MATTERS

Whether space becomes a viable option for extended vacations or for human colonization, it will be imperative to bring cultural elements along. These ventures into space will also create new cultures and new pastimes—and economic opportunities. Here, the introduction of microgravity will be both a burden and a benefit. It will hinder us from living our lives exactly as we are accustomed to, and we won't be engaging in the same activities and sports we enjoy on Earth. However, it will also open up new possibilities for innovative competitions. As business parks and other structures become more commonplace, there will be first-mover opportunities to fully take advantage of the space entertainment and event industry. But in the immediate future, space tourism will likely remain a very small percentage of the overall commercial space economy, underscoring the importance of being the first to establish a market and set up shop. While merely being in space would provide an overwhelming source of entertainment for some, individuals will undoubtedly look for new things to do and new ways to stay entertained as we move toward democratized access to space.

1ST YEAR ON THE LIST

PRIVATE MISSIONS

WHAT IT IS

The inception of space travel and exploration was mostly driven by public or governmental interest. However, as early as the 1980s, private organizations began entering the space economy by conducting launches. Now in the 21st century, a growing number of private companies are entering the space economy in earnest.

HOW IT WORKS

China sent its first civilian astronaut into space in May 2023. Gui Haichao, a payload expert, took off from the Jiuquan Satellite Launch Center in northwest China to take part in a crewed mission to the Tiangong space station. Prior to this, all Chinese astronauts in space have been members of the People's Liberation Army.

Japanese startup Ispace had hopes of becoming the first private mission to land an unmanned lunar module on the surface of the moon but was unsuccessful. Its HAKUTO-R Mission 1 module likely ran out of fuel before landing and crashed into the lunar surface. While not successful in landing on the moon, the mission achieved 8 of its 10 goals and also collected valuable data that will be beneficial for future missions.

Jared Isaacman, the billionaire who funded the Inspiration4 Crew Dragon mission, aims to send additional private missions to space under the Polaris Program. The first mission, Polaris Dawn, will attempt to reach the highest Earth orbit ever flown, targeting 870 miles over the Earth. Additionally, the mission also hopes to include the first extravehicular activity for a commercial mission with a civilian astronaut engaging in a spacewalk outside their craft.

WHY IT MATTERS

Private missions require scrappiness and ingenuity and are likely to result in innovations that can only be driven by privatized ventures. Many technologies that ultimately benefit humans on Earth were also used for space exploration. These spillover effects can have immeasurable impact on our daily lives, as we'll continue to see in future space endeavors.

High-profile private missions have the potential to capture public attention and inspire individuals worldwide. This inspiration can lead to a new generation of the public having an interest in space, highlighting the importance of STEM-based education and influencing more students to study science, engineering, and mathematics.

The privatization of space has already proven to have positive effects. SpaceX's reusable rockets have sustainability implications, but they also have greatly contributed to the reduced costs associated with launching payloads to space, acting as a democratizer of the space industry and providing access to a much broader audience. Many of the initiatives associated with space junk removal are also within the private sector. These efforts of cleaning the skies will be crucial for the continuation of the space economy for both public or private sectors. Unfortunately, the private sector is the primary culprit for much of the existing space junk, which is one main drawback of the practice.

2ND YEAR ON THE LIST

SMALLER COMPANIES IN SPACE

WHAT IT IS

Lower barriers to entry into the space industry as well as years of record-setting private investment have given smaller and fledgling companies a seat at the table in the new space economy. But as private investing becomes stingier, smaller companies must focus on core competencies and quality offerings to succeed over competition with weaker fundamentals.

HOW IT WORKS

A number of companies with specialized offerings are already operating in this sphere. There's Firefly Aerospace, which focuses on developing launch vehicles, in-space vehicles, and services for space transportation. Supported by a $112 million NASA contract to focus on lunar payload delivery, it is planning for its vehicles to serve missions in low Earth orbit and also to the moon. NASA selected Relativity Space to provide launch services in its Venture-Class Acquisition of Dedicated and Rideshare (VADR) missions. It was the first company to 3D print rockets and is now applying artificial intelligence and autonomous robotics to its arsenal as the pioneer factories of the future. The Y Combinator-backed startup EPSILON3 provides solutions for space project management through web-based collaboration tools that focus on streamlining tasks related to spacecraft testing and operations. Its customer base includes Firefly, Inversion Space, Rocket Lab, and Virgin Galactic. Vestigo Aerospace places its emphasis on sustainability through deorbit capabilities for CubeSats, small satellites, and launch vehicle upper stages. Rogue Space Systems Corp. is creating satellite vehicles and subsystems for on-orbit services for satellite operators. Its future fleet of Orbital Robots will perform tasks relating to inspection, maintenance, repair, and transport of satellites.

WHY IT MATTERS

The overall market slowdown has had significant impacts on many industries, and unfortunately, the space industry has not been immune: In 2023, investors showed reduced interest in funding large investing rounds for space technology. Still, this pullback does not indicate the Space 2.0 era is coming to a premature end. Investors are anxious and looking for more sure bets. With this in mind, there remains significant enthusiasm for new and innovative space technologies, especially for launch and propulsion systems, manufacturing, and mining. Investors will still be keen on possible returns and novel possibilities the space industry could offer.

Another bright spot in the future market is various countries' interests in returning to the moon. NASA's Artemis program presents compelling opportunities for startups. The US Space Force's drastically increased budget includes a new office for the sole purpose of creating partnerships with the private sector. While private investment remains conservative, government agencies will continue to keep the space economy going. Chad Anderson, managing partner of Space Capital, even thinks the decline in private investment will bring resiliency to the market, as there will be a shift away from momentum investing and back to a focus on fundamentals.

SCENARIOS

SCENARIO YEAR 2036

Preparing for Game Day on the Moon

Marta Peguero of Spain's national women's soccer team rose to prominence during the 2031 Women's World Cup and further displayed her talents in 2035, when she won the Golden Gall for best overall player in the tournament. That's when she was automatically chosen to captain one of the teams participating in the first-ever soccer exhibition match to be played on the moon's surface. This exhibition match will function as a pilot to assess the viability of having future matches on the moon, as well as the possibility of having a more permanent staple of matches under the Lunar Professional Soccer Association. This pilot match will provide scientists and researchers with valuable data on the effects of playing sports in such conditions, affirming their postulations of the dynamics of the moon's reduced gravity on ball movement and overall game play.

But, before any of this can be played out on the moon's surface, Peguero must engage in a strenuous conditioning regimen to ensure her body is prepared for the harsh conditions of space. This comprehensive regimen includes new pharmaceuticals to prepare both the athlete's muscles and brain for the new conditions of space. It also incorporates strength training, aerobic fitness, and balance and coordination exercises to ensure she can adapt to these lower-gravity environments. In addition to exercises, a series of simulated activities aims to prepare Peguero for her experience in space. She will engage in equipment simulation in a neutral buoyancy lab to give her an idea of the movement and activity required to function in the streamlined athletic sports space suits that will be used for the activities. A series of virtual experiences using haptic feedback will give her a sense of how the soccer ball might react on the moon. While the high-fidelity experiences are beneficial, there's still nothing like trying it all out in the natural environment, an opportunity Peguero is strongly anticipating.

ORIGINS OF A MULTI-PLANETARY SPECIES

1ST YEAR ON THE LIST

SEARCH FOR FAR-OFF LIFE

WHAT IT IS

Are we lonely or are we *truly* alone? The quest to discover life beyond Earth taps into a profound human yearning. Uncovering even the most rudimentary life-forms on far-off exoplanets suggests that we aren't a solitary exception. In their pursuit, scientists are open to detecting both the elementary and the complex.

HOW IT WORKS

The search for life beyond Earth spans the simple to the advanced. We scour nearby planets for signs of basic biology, while also scanning the cosmos for sophisticated techno-signatures, aiming to discover alien civilizations across the full spectrum of evolution. One way of detecting a planet that hosts intelligent life is by studying what Earth would look like from light-years away. Recently, a team simulated radio leakage from Earth's mobile towers to predict what an alien civilization might detect from nearby stars like Barnard's Star, just six light-years from us. Though they found our current radio emissions would be difficult to detect, more powerful future systems could substantially increase our chances of being heard.

Other efforts are focused on finding Earth-like exoplanets orbiting nearby stars. China plans to launch the Tianlin space telescope in 2035 to seek potentially habitable planets while SETI scientists are devising plans for a listening post on the far side of the moon. Artificial intelligence is enhancing these celestial search capabilities. Through sophisticated machine learning algorithms, researchers are pinpointing exoplanets by sifting through data from protoplanetary disks that envelop nascent stars. The James Webb Space Telescope further amplifies these efforts, offering unparalleled insights into the atmospheres of planets located hundreds of light-years away like WASP-39 b. Intriguingly, this gas giant akin in mass to Saturn revealed an unexpected presence of sulfur dioxide in its atmosphere.

WHY IT MATTERS

Discovering alien life has always been a focal point in science fiction, often portraying a unified humanity in response—earthly wars halted, borders dissolved, and racial tensions diminished. But we don't yet know if that unity would materialize in reality.

The Drake Equation estimates the number of active, extraterrestrial civilizations in the Milky Way galaxy by considering factors like the rate of star formation, the fraction of those stars that have planets, the number of planets that could potentially support life, and several others. Considering the cosmos' vastness—with trillions of stars and billions of Earth-like planets—the high probabilities suggested by the Drake Equation lead to a perplexing question: Why haven't we encountered extraterrestrial life yet?

This problem is called the Fermi Paradox, a contradiction between the high likelihood of extraterrestrial civilizations existing and our lack of contact with such civilizations. One possible explanation for the Fermi Paradox is the concept of the "Great Filter." This hypothetical stage, popularized by economist Robin Hanson of George Mason University, suggests that there is a phase in the development of a civilization that is almost impossible to pass. It could be that civilizations rarely develop intelligent life, or that advanced civilizations tend to self-destruct, or any other myriad of possibilities. This concept implies that civilizations with the potential to communicate or travel interstellar distances are extremely rare or even nonexistent. The Great Filter is just one of many hypotheses attempting to explain the Fermi Paradox. As we gather more exoplanet data, expect more theories to emerge.

1ST YEAR ON THE LIST

THE SEARCH FOR NEARBY LIFE

WHAT IT IS

The search for nearby signs of life encompasses not only currently thriving organisms but also traces of past life and indicators of potential future habitability. This involves investigating planetary bodies within our solar system—Mars, Europa, Enceladus, Ganymede—for signs of ancient life, current microbial activity, or conditions that could eventually support life.

HOW IT WORKS

Researchers have long examined Mars for signs of life. Recent data from NASA's Mars Perseverance rover reveals persuasive evidence of organic material. The evidence suggests a more intricate organic geochemical cycle on Mars than previously thought, indicating the existence of multiple reservoirs of potential organic compounds. Importantly, the study identified signals associated with molecules that suggest water may have been a crucial factor in the variety of organic matter on Mars. This implies that the essential building blocks for life might have existed on Mars for a much longer duration than previously considered.

Farther away, there are efforts to scope out potential life hospitable moons—specifically, Jupiter's moons. In April 2023, the ESA launched the Jupiter Icy Moons Explorer (JUICE) to search for life's building blocks there, though some moons are considered more promising than others due to the presence of liquid water, an energy source, and nutrients. Ganymede, one of Jupiter's moons, is believed to have an ocean, making it a key target for the mission. NASA also plans to launch the Europa Clipper, which will explore Jupiter's Europa moon to determine if Europa's ocean could be a suitable habitat for extraterrestrial life.

In addition to these efforts, NASA's Jet Propulsion Laboratory is developing a robot called EELS (Exobiology Extant Life Surveyor); it's designed to look for signs of life in the ocean beneath the icy crust of Saturn's moon Enceladus by descending narrow vents in the surface that spew geysers. Although still in testing and development, EELS' ability to navigate a wide variety of terrains opens up new possibilities for exploring environments that were previously considered inaccessible, increasing the chances of finding evidence of past or present life in our solar system.

WHY IT MATTERS

In the words of Carl Sagan, "The significance of a finding that there are other beings who share this universe with us would be absolutely phenomenal, it would be an epochal event in human history." Finding evidence of even *past* life would be significant. It would provide clues that we aren't alone in the universe and also shed light on the possibility of life elsewhere, even if it no longer exists. If life can form on other planets and moons in our galaxy, it raises the prospect of life being present in other parts of the universe.

Narrowing down our search to factors that facilitated life on Earth, such as water, oxygen, and energy sources, is a logical approach. However, discovering evidence of past or early life could also offer insights into our own origins. It prompts us to question the fundamental requirements for life. For instance, is liquid water essential for life to exist? Are we limiting our search by focusing only on factors that sustain life on Earth? Could other biomarkers exist that would provide more comprehensive insights? Additionally, understanding the reasons for the extinction of life elsewhere could help us prevent a similar fate on Earth. It is crucial to comprehend the conditions that support life, as eventually, humanity will need to expand beyond Earth. Scoping out the "real estate" of our local galaxy before it becomes a necessity to move beyond Earth is prudent and a good life insurance policy.

1ST YEAR ON THE LIST

MOON, THEN MARS

WHAT IT IS

As astronaut Buzz Aldrin once said, "Mars is there, waiting to be reached." But first, we must return to the moon. A Mars mission requires advances in propulsion, life support, and radiation shielding. NASA will use the moon as a proving ground for Mars missions, and possibly as a future launchpad.

HOW IT WORKS

Under NASA's Artemis program, aimed at establishing a sustainable presence on and around the moon, the agency created a "Moon to Mars" office to synchronize lunar and Martian exploration efforts. The moon will act as a proving ground for technologies and equipment, including human habitats, destined for Mars. Artemis II will mark the program's first crewed test, evaluating deep space exploration, the Space Launch System rocket, and the Orion spacecraft over a 10-day journey with astronauts on board.

Two behemoth rockets, one from NASA and another from SpaceX, have emerged as the focal points of the US' moon return aspirations. The fabrication, funding, and functioning of these two spacecraft epitomize distinctly divergent strategies for leaving Earth's confines. NASA's plan uses tried-and-true hardware with expendable rocket stages, while SpaceX's Starship uses entirely new hardware, is designed for more people and cargo, and features reusable components. Once we have returned to the moon, the next step is to set up Gateway, the first space station in lunar orbit and a collaboration between space agencies in the US, Europe, Canada, and Japan.

These countries aren't the only ones with moon-to-Mars plans. India successfully landed Chandrayaan-3 in August 2023, making it the fourth country to complete a successful soft landing on the lunar surface. In early 2024, Japan became the fifth country to successfully land on the moon. These achievements follow a failed attempt by Russia to pull off the same feat. As for manned flights, NASA expects its astronauts to be back on the surface of the moon as early as 2025. China, hoping to become the second country to land humans on the moon, has plans for its taikonauts to land on the lunar surface around 2030.

WHY IT MATTERS

The moon-to-Mars approach enables us to test and validate systems required for the long journey to Mars, including long-duration spaceflight, surface operations, and supporting infrastructure. A successful return to the moon is a stepping stone toward the monumental goal of landing astronauts on Mars, which is the most Earth-like planet in our solar system and likely the best chance of finding evidence of past or present life beyond Earth. As Stephen Hawking noted, "The human race shouldn't have all its eggs in one basket, or on one planet. Let's hope we can avoid dropping the basket until we have spread the load."

The problem of getting to the moon, and eventually Mars, isn't so much technical as it is economic. For these ambitious ventures to be sustainable, they need to be economically viable, and it's unlikely that we will achieve consistent and successful missions until there's a clear profit motive. The effort also comes with geopolitical implications, especially given the chilly relationship between the US and China. Both nations aim to send people to the lunar surface in the coming years, but they do not generally collaborate on space research and exploration, and have limited communication in orbit and beyond. This lack of communication and transparency could lead to unintended crises, especially since both countries are planning to land missions at the moon's south pole. It is imperative to establish clear communication channels and collaborations to ensure the safety and success of these missions, and ultimately, the survival and advancement of the human race.

SCENARIOS

SCENARIO YEAR 2052

The Moondust Mariner

By 2050, after a series of successful missions launched from Earth, over 100 humans had established a small but growing settlement on the Red Planet. The feats of engineering and courage were remarkable, but the journeys were neither easy nor cheap—the Earth's gravity makes escaping its grasp expensive. For every launch from Earth, the cost was substantial, around $320.5 million for every 100 metric tons of payload. But recent developments have presented a game-changing alternative: launching from the moon.

The moon has become Earth's pitstop and preparation ground for Mars missions. Engineers, taking advantage of the moon's 1/6th Earth gravity, realized that the energy required to break free from its surface was significantly less. The escape velocity on the moon is only about 2.38 kilometers per second, as opposed to Earth's demanding 11.19 km/s. This translates to massive fuel savings. Moreover, the lack of an atmosphere on the moon eliminates aerodynamic drag, another fuel and cost saver.

But the real game-changer is in-situ resource utilization. Recent lunar expeditions have confirmed vast deposits of water ice, especially at the poles. With the establishment of lunar bases and infrastructure, this ice is now being mined and then split into hydrogen and oxygen—perfect rocket fuel. Launching from the moon can reduce costs to just 25% of what launching from the Earth would be: For the same 100 metric ton payload, the cost is now just $80.1 million. This is a dramatic reduction from the Earth-based price tag. When considering multiple missions over years, the savings will be in the billions.

Now, the Moondust Mariner is ready. Built on the moon using advanced 3D printers, and fueled by lunar resources, it is set to be the first craft to travel from the moon to Mars. The success of the Moondust Mariner will prove a vital point: While Mars might be the future of humanity, the moon is its gateway.

1ST YEAR ON THE LIST

THE SEARCH FOR COSMIC RESOURCES

WHAT IT IS

The quest for cosmic resources encompasses the discovery, identification, and extraction of energy and material resources in outer space. A crucial resource in this pursuit is water, essential not only for human consumption but also as a source of fuel to sustain long-term human presence in space.

HOW IT WORKS

Several countries and space agencies are embarking on missions to find water and other valuable resources in outer space. In 2023, NASA launched the Psyche spacecraft toward the unique, metal-rich asteroid 16 Psyche, believed to be composed of up to 60% iron and nickel. Orbiting between Mars and Jupiter, this asteroid is thought to be the exposed core of a primordial planetesimal. By August 2029, the mission will start investigating this celestial body, offering insights into the early planetary building blocks. Russia's Luna-25 lander aimed to confirm water ice deposits in craters at the lunar south pole, as previously detected by NASA and others. The rover failed to land on the lunar surface, but India's moon rover, which landed shortly after Russia's failed attempt, detected several elements including aluminum, iron, calcium, chromium, titanium, manganese, oxygen, and silicon. NASA's VIPER rover will also soon launch to explore the moon for ice and other resources. This robot, targeting a late 2024 landing, will roam the moon's extreme polar regions for 100 days seeking signs of usable volatiles. VIPER's findings will aid efforts to harness these resources for future human space missions. Farther afield, the United Arab Emirates is exploring the asteroid belt to study water-rich asteroids. This mission aims to visit seven asteroids, tracing the origin and evolution of water in these space rocks. The findings will clarify if asteroids could serve as resource depots for future deep space missions. Even farther into space, the James Webb Space Telescope has detected water vapor around a rocky exoplanet 26 light-years away from Earth. Astronomers are now trying to determine whether that water vapor indicates the presence of an atmosphere around the rocky exoplanet, a finding that could have significant implications for the search for habitable planets. These efforts are part of a broader initiative to understand the availability and distribution of water and other resources in our universe.

WHY IT MATTERS

When Neil Armstrong set foot on the moon in 1969, it was a fleeting visit. Now, our eyes are set on a more permanent stay. However, supporting extended human presence in space requires a robust infrastructure. Hauling all necessary supplies from Earth is a costly endeavor. At present, sending a pound to orbit costs around $10,000. NASA aims to drastically reduce this to just tens of dollars within four decades, and Elon Musk's reusable rockets have already significantly reduced the cost of sending payloads to space. Still, the most economical approach lies in tapping into space's indigenous resources—most importantly, water. Water is essential for sustaining life, but it also has immense potential as a rocket propellant. By decomposing water into its components of hydrogen and oxygen, we can create fuel capable of transforming the moon and potentially other celestial bodies into strategic pit stops for space exploration. Using local resources would reduce reliance on costly fuel launches from Earth's deep gravity well. Rather than launching deep space rockets directly from our planet, we could launch from the moon using lunar-sourced propellant. The moon's lower gravity allows for less propellant to escape the gravitational forces. Ultimately, our pursuit of water and space resources transcends economic or scientific interest; it's about sculpting a sustainable path for humanity's cosmic journey.

1ST YEAR ON THE LIST

UNIVERSE MAPPING

WHAT IT IS

Astrophysicists are working to create a map of the universe that helps us better understand space and time. This effort is dedicated to uncovering the mysteries of our universe's formation, its components including the elusive dark matter, while ultimately enhancing our knowledge of the cosmos.

HOW IT WORKS

Astrophysicists developed the most detailed map to date of the universe's early and middle years using the Atacama Cosmology Telescope. Critically, it shows how light dating back to the Big Bang has been distorted, which appears to affirm the standard model of the universe's development and Einstein's theory of relativity.

While we are substantiating our understanding of one aspect of space, emerging evidence is prompting a reevaluation of other prevailing theories. In its first few months of operation, the James Webb Space Telescope found six galaxies formed within the first 700 million years of the universe that seem to be up to 100 times larger than standard theories predict. This challenges our understanding of the early universe: the mass of the stars in these galaxies exceeds the total mass available in the universe at that time.

The European Space Agency has also developed its own specialized universe cartographer—the Euclid satellite. Launched in July 2023, Euclid will observe how dark matter and dark energy have evolved over time, in an effort to reveal more about their nature and role in our universe. Groundbreaking strides are also being made in gravitational wave detection. The North American Nanohertz Observatory for Gravitational Waves recently detected low-frequency gravitational waves, marking a historic breakthrough after 15 years of searching. This discovery is significant because it opens up a new low-frequency window on the gravitational universe, enabling us to study how galaxies and their central black holes merge and grow over time.

WHY IT MATTERS

The mapping of the universe is of profound importance for several reasons, both scientific and philosophical. First, it challenges existing theories. The discovery of the six galaxies that seem too massive for their age forces scientists to rethink and potentially revise our understanding of the early universe, the formation of galaxies, and the distribution of matter. Second, universe mapping is crucial for understanding dark matter and dark energy, which make up about 95% of the universe. Understanding their properties and behavior will lead to a comprehensive understanding of the universe.

Beyond this, however, mapping the cosmos also has profound philosophical implications. It gives humanity a sense of perspective and scale, both literally and philosophically. The Copernican Revolution, which replaced the geocentric model with a heliocentric one, challenged our fundamental understanding of human significance in the universe and major world religions. Galileo's observations were considered dangerous to the Catholic Church, as the observations undermined its authority. New discoveries could similarly challenge modern fundamental beliefs, and we should be prepared for that.

2ND YEAR ON THE LIST

SPACE HABITATS

WHAT IT IS

The next time we land on the moon, we plan to stay long term. A permanent human presence off-planet requires the construction of space habitats to protect us from the harsh conditions of space. Plans are underway to use local resources.

HOW IT WORKS

As we set our sights on establishing a sustained human presence on the moon and Mars, researchers are exploring various methods to construct habitats using local resources. In 2023, NASA funded multiple projects to help astronauts "live off the land" on the moon. One project plans to use lunar regolith to 3D print structures, landing pads, and roads. Another groundbreaking proposal introduces mycelium—derived from fungus—as a construction material. Mycelium can self-replicate and repair, making extensions and repairs easy. Mycelium also excels as an insulator, fire retardant, and is toxin-free. It even rivals the compression strength of lumber and the flexural strength of reinforced concrete. Separately, Chinese scientists have identified glass fibers in lunar regolith as potential building materials.

Instead of building on the surface, some researchers are looking into underground dwellings on Mars. One team has created robots that can autonomously explore caves and lava tubes as possible habitat sites. Using the planet's natural features could require fewer resources while still providing protection from the harsh climate. Meanwhile, NASA's latest Mars habitat competition crowned a design featuring a massive metal dome enclosing a 3D printer. This design produces hexagonal habitats using Martian-concrete, engineered for durability and radiation safety. Notably, key elements, like the dome and windows, will still need to be transported from Earth.

WHY IT MATTERS

Expanding human presence to the moon and Mars isn't merely about planting flags; it's about ensuring long-term survival in alien environments. The moon experiences dramatic temperature swings, and its thin atmosphere provides no protection from the harmful solar radiation or micrometeorite impacts. Mars, while having a thicker atmosphere than the moon, exposes inhabitants to intense radiation, both from the sun and cosmic rays, and experiences frequent dust storms. Additionally, Mars' atmosphere, composed mainly of carbon dioxide, means habitats not only need to be airtight but also equipped with robust life support systems to provide breathable air.

Building these infrastructures requires a complex supply chain that can stimulate industries both on Earth and, eventually, extraterrestrial environments. The demand for advanced materials and technologies will grow. Companies in radiation shielding, life support systems, or innovative building will tap into this expanding market. These habitats demand specialized tools, opening avenues for precision engineering and robotics. As bases expand, there's a push for self-sufficiency and local resource utilization. This could birth a new space-mining industry. Established habitats might also serve as commercial hubs or research outposts. Private entities might lease space or resources, turning these outposts into economic zones, akin to free trade zones on Earth.

SCENARIOS

SCENARIO YEAR 2047

The Martens' Month on the Moon

The Martens are thrilled to plan their summer vacation: a month-long stay at the Lunar Resort. After last year's tropical getaway to the Bahamas, they are ready for an out-of-this-world adventure. To plan for the big trip, the family scheduled appointments for the required lunar shots—specialized injections to temporarily activate certain genes to help their bodies adapt to the space environment. One set of genes will boost the body's radiation resistance, providing protection from exposure to cosmic rays and solar flares. Another set of genes will make it easier for the inner ear to acclimate to zero-gravity conditions, minimizing dizziness and motion sickness. The Martens don't mind the quick prick of the injections, knowing the lunar genes will optimize their bodies for exploring the moon. Upon their return, the Martens will schedule a visit to receive shots to turn off the temporarily-activated genes, allowing their bodies to readjust to Earth's gravity and radiation levels.

Keith Martens, the dad, is a major history buff. Keith is especially excited that the resort is situated right next to the historic 1969 moon landing site. This was no coincidence—it's strategically located to attract more tourists. Tourism like this makes a long-term human presence on the moon financially viable. The mom, Sandy, is most looking forward to the resort's lunar obstacle courses, which she hopes will rival her favorite "Tough Mudder" competitions on Earth. The Marten kids are equally excited, dreaming of bouncing across the lunar landscape and stargazing from the surface of another celestial body.

After a month of fun and fascinating science, they will return to Earth with amazing memories. But for now, the genetic modifications they're about to undergo will ensure their health and safety in the harsh extraterrestrial environment.

1ST YEAR ON THE LIST

SIMULATED SPACE ENVIRONMENTS

WHAT IT IS

Simulated space environments are artificially created settings on Earth that replicate the conditions of space, including Mars and the moon. The environments are used for training astronauts and studying possible biological and psychological adaptations to space life. The use of virtual reality and 3D printing has enabled more realistic simulations.

HOW IT WORKS

In June 2023, four scientists embarked on a year-long Mars simulation at the Johnson Space Center in Texas. The 1,700-square-foot, 3D printed habitat will expose the crew to Mars-like conditions, where they will conduct experiments, grow food, exercise, and undergo regular testing to provide insights for future Mars missions. The simulation, called the CHAPEA Mission, will also assess the psychological effects of isolation, resource limitations, and communication delays with Mission Control.

China has also developed a simulated environment for moon and Mars mission preparation. A 40-meter-high microgravity tower in Beijing simulates weightlessness experienced on these celestial bodies, providing a cost-effective solution for experiments without the expense of space travel. Researchers will use a linear motor to move objects vertically, approximating four seconds of weightlessness, a more economical approach than launching experiments into orbit.

Virtual reality is also helping us prepare for lunar and planetary surface exploration missions. MIT's RESOURCE project is testing a VR platform displayed on the Oculus Quest 2, designed for geological analysis in lunar and planetary rover exploration missions. The platform integrates environmental data, including temperature, luminosity, and humidity, along with imagery from a commercial lidar camera and RGB imagery.

WHY IT MATTERS

Simulated environments like the Mars replica at the Johnson Space Center can prepare astronauts for the psychological challenges they will face during extended space missions. The stressful circumstances of spaceflight, including confinement within a small space and the physiological effects of living in microgravity, can significantly impact an astronaut's health. NASA hopes that the CHAPEA mission will provide lessons for future astronauts bound for Mars, such as how to collaborate under pressure and deal with homesickness. Kelly Haston, the mission's biomedical researcher and commander, noted the importance of completing the mission without attrition. Though the crew can leave the simulation, Mars has no exit sign, making it essential to understand and address the psychological challenges in advance. Craig Haney, a University of California, Santa Cruz psychologist who researches solitary confinement, highlighted the importance of studying social isolation as it is a dangerous psychological toxin, with debilitating and sometimes permanent effects emerging in just a couple of weeks.

VR also plays a vital role in preparing for space missions and studying extraterrestrial surfaces. It provides a low-cost, immersive environment for studying not only extraterrestrial surfaces but also remote or environmentally sensitive Earth locations. This approach enables researchers and astronauts to explore and understand various terrains and environments without the need for physical presence in space.

1ST YEAR ON THE LIST

BIOLOGICAL ADAPTATIONS FOR SPACE

WHAT IT IS

Surviving space's harsh conditions requires more than physical structures shielding against radiation and other adversities. To truly thrive, researchers are considering biological engineering, reshaping our microbiome and harnessing gene editing to engineer the ideal astronaut for long-term, deep space exploration.

HOW IT WORKS

Astronauts face significant physical changes in space, with the return to Earth posing even greater challenges. In a landmark twin study involving Scott Kelly, who spent nearly a year in space, and his identical twin, Mark, who stayed on Earth, researchers found temporary changes in telomere length, gene expression, cognitive performance, and eye health. Although most reverted to normal upon Scott's return to Earth, some genes exhibited long-term changes, highlighting the need for further research and countermeasures to mitigate the health risks of extended space travel.

Researchers, such as Dr. Chris Mason from Cornell Weil, are working to enhance the human body's resilience against space radiation by activating DNA repair genes and temporarily modifying gene functions. A key focus of Mason's work involves using CRISPR technology to selectively activate genes necessary for space, thereby altering the plasticity of specific targets without completely modifying the genome. Mason's lab at Cornell has engineered chimeric cells combining human and tardigrade genes, the latter being organisms capable of withstanding the vacuum of space. These hybrid cells can trigger tardigrade genes when exposed to radiation, a breakthrough aimed at bolstering human cell resistance to space radiation. Preliminary results indicated an 80% reduction in DNA damage when subjected to X-rays.

The research underscores a pivotal moment in human history when our evolutionary trajectory is no longer solely dictated by natural selection but can be intentionally directed to prepare us for challenges beyond our planet, potentially unlocking a new era of human existence in space.

WHY IT MATTERS

The journey to becoming a multi-planetary species isn't plan B for a dying Earth—it's a recognition of the inevitable: No matter how diligently we care for our planet, the sun will eventually consume it. Humanity therefore will face a choice: migrate or perish.

To avoid the extinction of our species, we must find and colonize a new habitable planet, potentially in a different solar system. However, our current biological limitations mean that the human body is ill-equipped for the journey. Presently, gene-editing technology is permanent and irreversible, which has far-reaching implications, particularly when it comes to germline gene editing (GGE). The primary ethical challenge with GGE is that genetic changes applied to the germline are inherited by subsequent generations—and there is significant debate about the ethics of modifying future children on Earth to participate in space missions.[1]

This is why researchers are not only identifying genes that could make us better suited for space but also figuring out how to make these changes temporary, minimizing discomfort or long-term consequences when we return to our home planet. Moreover, it may be more pragmatic and cost-effective to adapt ourselves rather than undertake large-scale engineering projects for fortification. For example, instead of engineering our environments to block radiation, perhaps we can program our bodies to resist radiation damage.

1. https://link.springer.com/article/10.1007/s11569-023-00438-1

1ST YEAR ON THE LIST

OFFICIAL INVESTIGATIONS OF UAPS

WHAT IT IS

Government efforts to understand unidentified aerial phenomena (UAP) are gaining momentum. Congressional hearings and the establishment of formal offices represent an initial step toward greater transparency and public disclosure on UAPs and also a first step in destigmatizing UAP reporting.

HOW IT WORKS

In 2022, NASA started studying unexplained sightings called "anomalous phenomena." After reviewing about 800 cases by May 2023, the team found no clear proof of alien activity. However, they said it was impossible to draw firm conclusions due to limited data. Shortly later, three whistleblowers, retired military veterans, testified at a House hearing about the UAPs. They warned that the sightings pose a threat to national security and argued the government has been too secretive about them.

Lawmakers who pushed for the hearing called for the government to be more forthcoming about the unidentified anomalous phenomena. In this spirit, the Pentagon's UFO investigative office launched a website to provide public access to declassified information on reported sightings. Managed by the All-domain Anomaly Resolution Office, this initiative focuses on analyzing what the government labels as unidentified anomalous or aerial phenomena. The Department of Defense describes the website as a central repository for publicly approved UAP photos and videos. It will soon facilitate US government and military personnel in reporting objects that infringe US airspace or demonstrate advanced flight capabilities believed to surpass current human technology.

WHY IT MATTERS

"Two possibilities exist: either we are alone in the universe or we are not. Both are equally terrifying."
— Arthur C. Clarke

For years, discussions around UAPs teetered on the fringes of mainstream discourse, often dismissed as conspiratorial. Now, discussions about UAPs have gained legitimacy via congressional hearings, credible witness testimonies, and the creation of official government offices to investigate them. The growing legitimacy of the UAP discussion is fascinating in and of itself, regardless of what the objects prove to be, because it demonstrates how rapidly a topic can transition from taboo to accepted in the mainstream. The legitimization itself warrants study for what it says about the dynamics of idea propagation and normalization.

The testimonies from retired military personnel point to UAPs being more than just an odd phenomenon—they represent a real national security threat. The unknown nature of these sightings makes it difficult for the military to discern friend from foe, an age-old defense challenge. The materials science behind these crafts surpasses our known capabilities, implying either a tremendous covert leap in human technology or an extraterrestrial source.

As these conversations pivot from tabloid tales to the halls of government, the necessity for transparency becomes paramount. The Pentagon's steps to declassify and centralize UAP information signal progress, but the journey to understanding this profound enigma has just begun.

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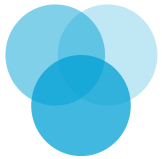

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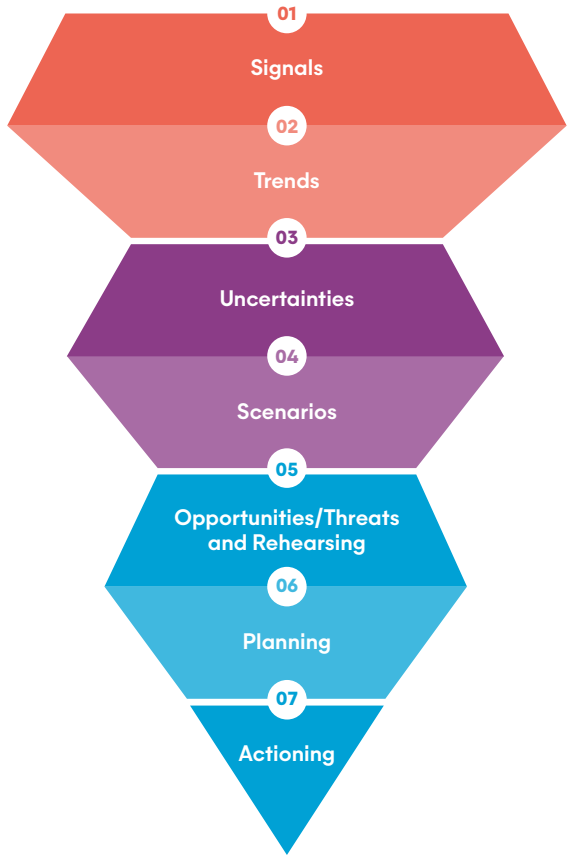

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