A Bridge to the Future

SpaceTech White Paper

FROM BICYCLES TO BIPLANES

Let's return mentally to the year 1903. Two rather eccentric brothers, owners of a bicycle shop in North Carolina, decide that they will accomplish something many thought impossible: heavier-than-air flight.

Naturally, there was a lot of attention to the contraption that achieved this milestone and to the inventors who made it happen. However, not many modern airline passengers think of Orville and Wilbur Wright when boarding their flights from New York to Paris, or Tokyo to Melbourne.

Of course, the evolution of flight from 1903 to 2022 did not take place overnight. Not long after Kitty Hawk, daring pilots in biplanes were conducting dogfights in the skies over Europe. Barnstormers flew around the country, thrilling the locals with daring acrobatics high above the cornfields. Then, of course, there was "Lucky" Lindbergh flying alone across the Atlantic, a hero not unlike the modern astronaut.

Between World Wars I and II, early vestiges of commercial air travel began. Observers then could see a glimmering of what is commonplace today.

Many companies rose and fell in the early days of aviation, and it remains a dynamic sector today.
It would have been hard to imagine, on that day in Kitty Hawk, North Carolina, what the industry would become 119 years later, but it is now a global phenomenon that routinely moves passengers and goods around the world.

From Kitty Hawk to Kazakhstan

In 2022, it is now 61 years since Yuri Gagarin first traveled into Low Earth Orbit. Like the early days of aviation, we are beginning to see a fledgling movement toward space tourism, space manufacturing, and using the space environment to enhance life on Earth.

Today, we are focused on missions to Low Earth Orbit, with the satellite industry and its accompanying technologies leading the way. We don't know where we will be in 50 years or so, but taking a long-term perspective suggests a market that will dwarf anything on our home planet.

At Intro-act, we focus on this big picture, looking at every SpaceX, Virgin Galactic, Axiom, and Blue Origin in the context of what will emerge as human civilization expands beyond the terrestrial ecosystem and into the solar ecosystem. Which companies will remain in LEO or on the Moon, and who will still be there when humans reach Mars and beyond?

We assume that Large-Scale Space Migration (LSSM)—the movement of significant numbers of people and industries—will take place and that it will be a positive development for humanity and the Earth. There is plenty of evidence that our modern technological civilization is straining the carrying capacity of our planet, and that LSSM is one way to ease that burden.

More immediate concerns will be the content of "A Bridge to the Future," like earnings and margins, but the context will be a larger picture—a series of overviews, if you will.

Five Overviews in 2022: Who's Where?

Overview One: The Technological Overview
Overview Two: The Lunar Overview
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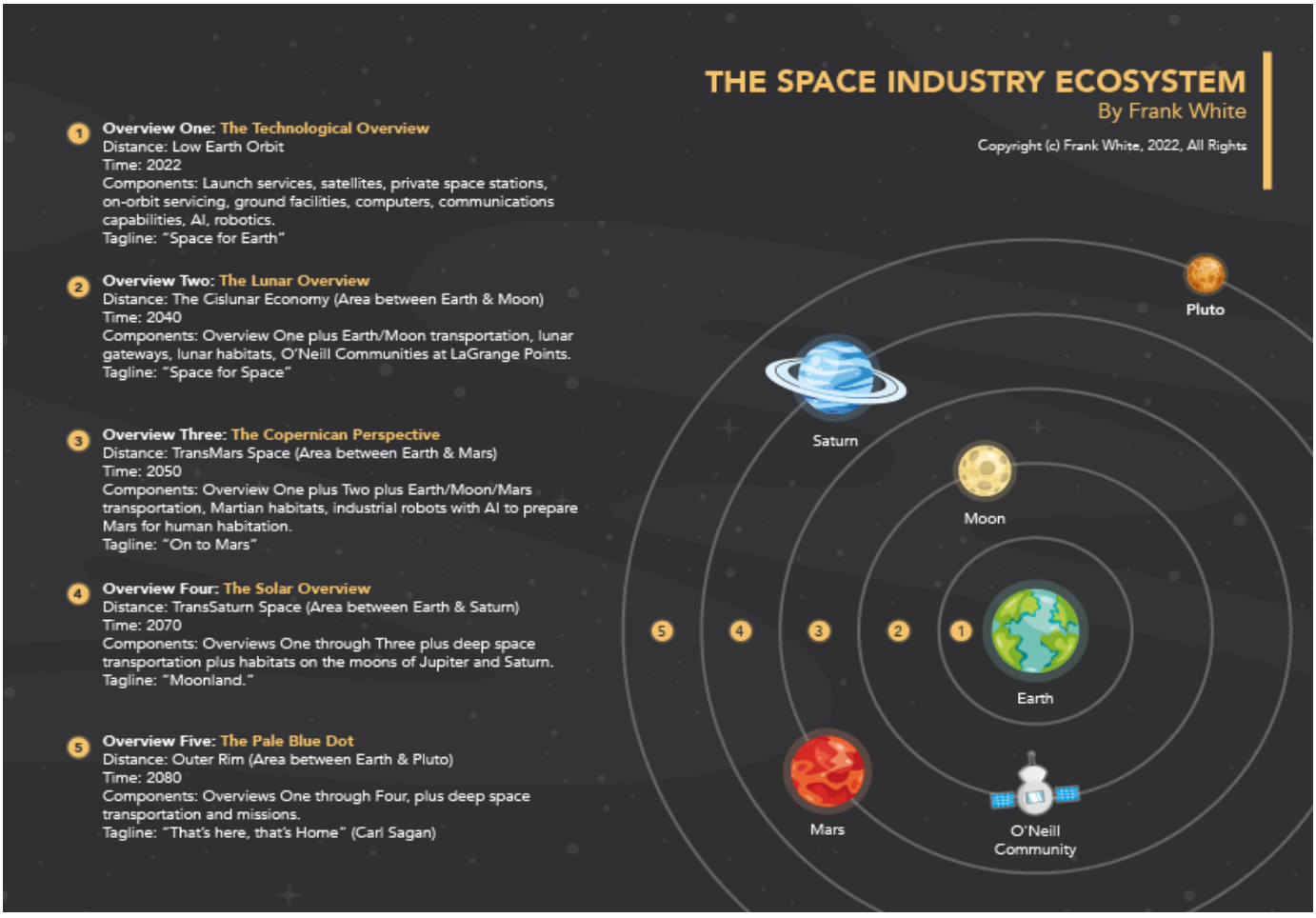
Five Overviews in 2022: Who's Where?

The private sector is playing a crucial role in making space travel and habitation a reality. Indeed, the farther out in the solar system we go, the more expensive it becomes to explore. Thus, deep space is still largely dominated by government space agencies. At present, Low Earth Orbit is the only place where companies are conducting activities independently (without the need of a government agency). Ultimately, any space-based business must have an Earth-based customer in order to be profitable. However, the private sector is increasingly moving deeper, toward the Moon in particular. Their activities beyond the Moon are currently largely limited to contracts from NASA or other government agencies; the companies are not carrying out these missions independently. However, this is bound to change in the coming years and decades. Large-Scale Space Migration (LSSM) would become a reality only through the involvement of private sector. In this Bridge to the Future White Paper #1, we will consider five "overviews" of the human expansion beyond Earth. Who is going there and who is investing in these enterprises?

Chart 1: The Five Overviews

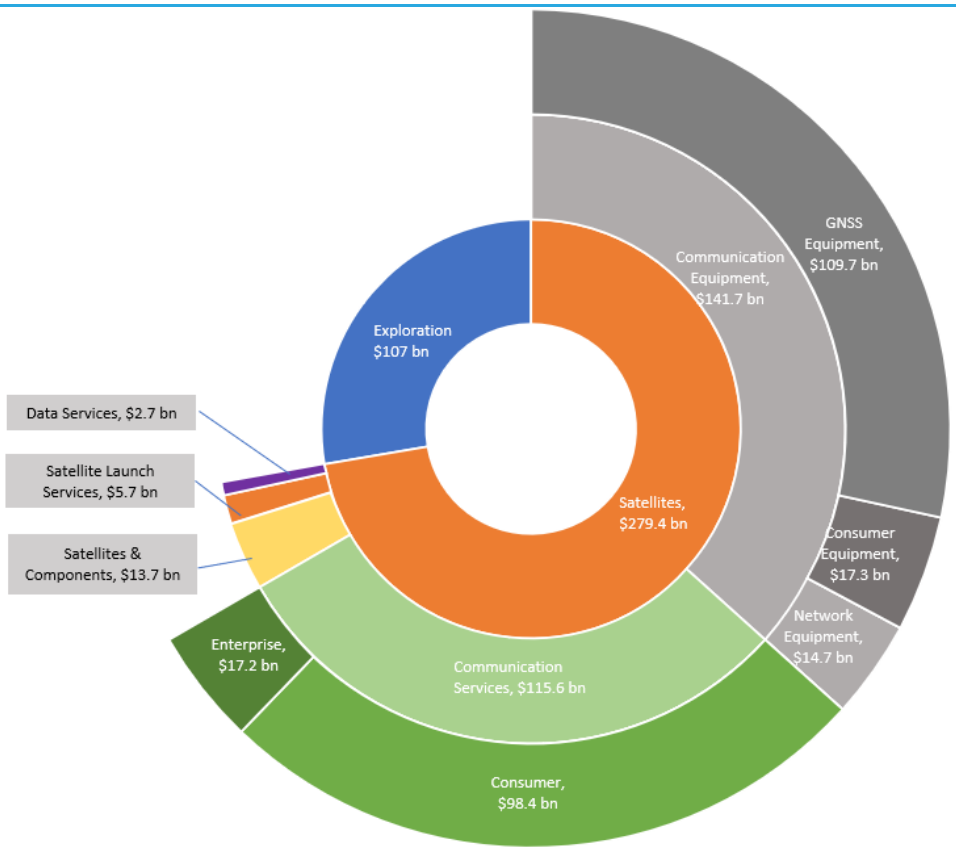


Source: Intro-act, frankwhiteauthor.com

Overview One: The Technological Overview — *"Space for Earth"*

The Technological Overview of the space industry focuses on Low Earth Orbit and companies that are **already largely profitable today**. The Overview includes segments such as launch services, satellites, private space stations, on-orbit servicing, ground facilities, computers, communications capabilities, AI, and robotics. At the end of 2021, the size of the global space economy, which consists of satellite and non-satellite industries, was $386 billion. About 72% of this economy is the satellite segment, which is a key focus area of the Technological Overview. Communication Equipment and Communication Services also make up a significant share of this industry.

Chart 2: The Global Space Economy



Source: Intro-act, Brycetech

Communication Services comprises the segments below:

1. Consumer segment, including satellite TV, radio, and end-user broadband;
2. Enterprise segment, including transponder agreements, managed services over FSS bands, and mobile voice and data over MSS bands; and
3. Remote sensing, which finds applications in areas such as agriculture, change detection, disaster mitigation, meteorology, resources, Earth science, space science, and national security

Communication Equipment comprises of:

1. GNSS equipment - GNSS devices/chipsets;
2. Consumer Equipment - Satellite TV dishes; and

3. Network Equipment - VSATs, gateways, network operations centers, satellite news gathering equipment

Other segments of the satellite industry include Satellites and Components, Satellite Launch Services, and Data Services.

The Satellites and Components segment can be divided based on satellites launched by mission type:

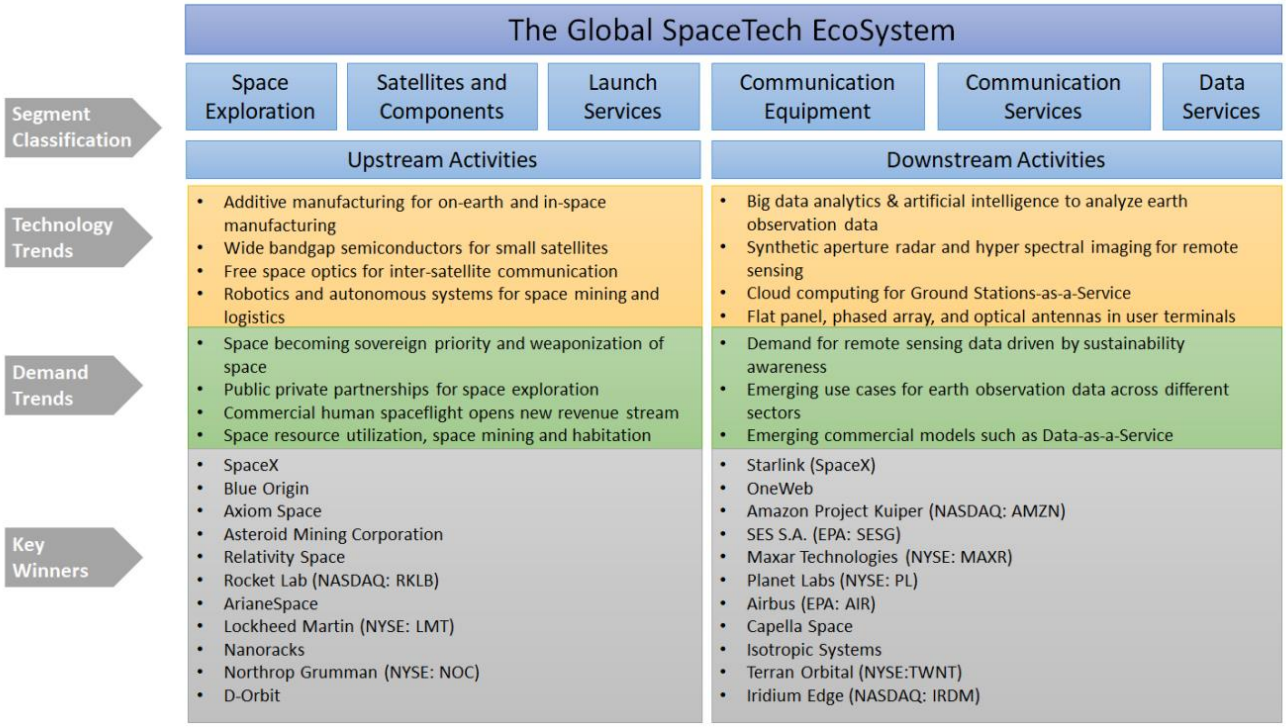
1. Commercial Communications make up the majority with 82%;
2. Remote Sensing makes up 9%; and
3. Other missions, such as R&D, military surveillance, and civil/military communications

The Launch segment can be divided by commercial launch revenue by region:

1. U.S. makes up around 36%
2. Non-U.S. makes up around 64%

Overall, Intro-act divides the global SpaceTech ecosystem into six categories denoted by function. Of course, many companies operate in more than one segment of the industry and one way to evaluate companies is to ask whether they plan to be a single segment or multi-segment enterprise. Space Exploration, Satellites and Components, and Launch Services are included in the "Upstream" activities. The "Downstream" activities consist of Communication Equipment, Communication Services, and Data Services. The graph below shows the key characteristics of the categories, along with some prominent players in each.

Chart 3: Intro-act's SpaceTech Ecosystem Map – Key Segments, Trends, and Winners



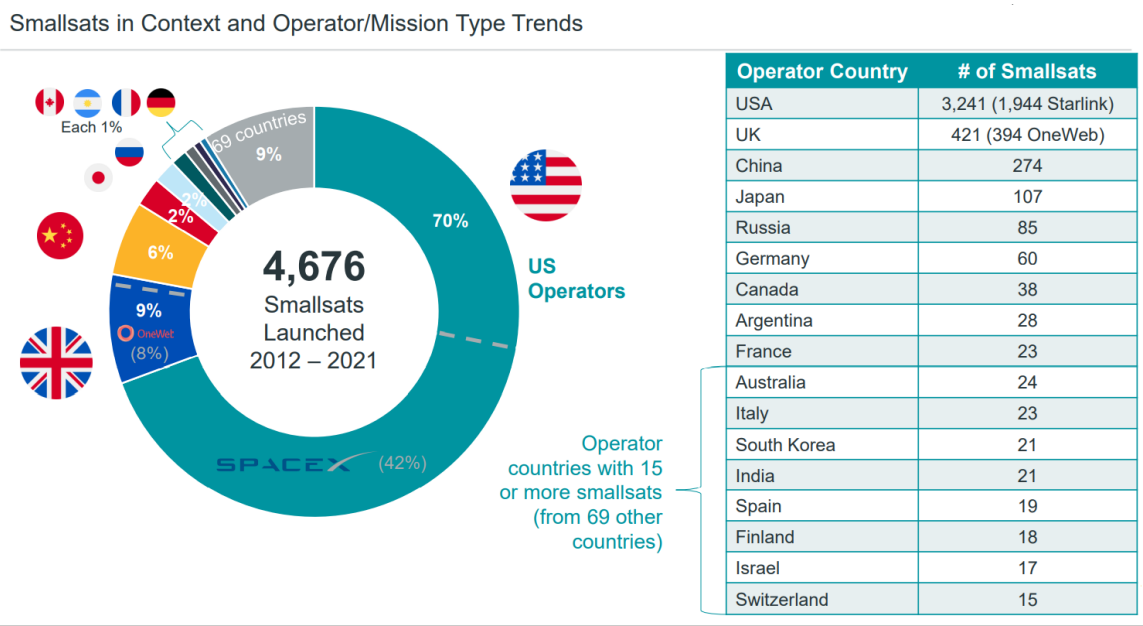
Source: Intro-act

Upstream Activities

Players such as **SpaceX** are into both Upstream as well as Downstream activities, and their business plan assumes that they will be reaching Mars. In fact, SpaceX intends to establish a human community on Mars. We will discuss more about these plans in "The Copernican Perspective." In the near term, the company has received contracts from NASA for transporting cargoes and crews to and from the ISS. SpaceX manufactures its own rockets, namely the Falcon 9 and Falcon Heavy launch vehicles. Additionally, it designs and manufactures rocket engines (Merlin, Kestrel, Draco, and SuperDraco) and Starlink communications satellites. With a high degree of vertical integration, SpaceX performs routine missions to orbit with its Falcon 9 and Falcon Heavy launch vehicles for a diverse set of customers, including NASA, the Department of Defense, international governments, and leading commercial companies.

SpaceX has been instrumental in bringing down launch costs significantly through reusable rockets. At the same time, the viability of smaller satellites has brought down costs further.

Chart 4: Smallsats 2012-2021



Operator Country	# of Smallsats
USA	3,241 (1,944 Starlink)
UK	421 (394 OneWeb)
China	274
Japan	107
Russia	85
Germany	60
Canada	38
Argentina	28
France	23
Australia	24
Italy	23
South Korea	21
India	21
Spain	19
Finland	18
Israel	17
Switzerland	15

Source: Intro-act, Brycetech

The U.S. dominated the smallsat markets in the period 2012-2021. SpaceX alone contributed around 42% of the total smallsat launches globally.

Another strong contender in the space economy is **Blue Origin**, founded by Jeff Bezos, Blue Origin also operates in several of the space segments. It is one of the pioneers in space tourism, and the company intends to use the technology in hypersonic point-to-point travel on the Earth—an example of how technologies for space are useful on the Earth as well. Blue makes its own rocket engines, including BE-3, BE-4, and BE-7, which are used in its space vehicles, New Shepard and New Glenn. Furthermore, United Launch Alliance will also be using a Blue Origin engine in its next space vehicle. Blue aspires to land on the Moon under its project, "Blue Moon." It also has been awarded a contract by NASA to support a commercial space

station—Orbital Reef. This makes it one of the prominent private players in the Upstream segment, apart from SpaceX.

Though Blue Origin is not into Downstream activities in a significant way, Jeff Bezos is championing another project, Project Kuiper, which is involved in Downstream activities**.** Project Kuiper is a part of **Amazon,** the company founded by Bezos. Kuiper plans to provide broadband Internet connectivity through deployment of a large broadband satellite constellation. Kuiper will complete with SpaceX's Starlink and OneWeb.

An additional SpaceTech player to watch is **Axiom Space**. The company aims to own and operate the world's first commercial space station in 2024. In 2020, as part of the broader Next Space Technologies for Exploration Partnerships (NextSTEP) cislunar initiative, NASA awarded Axiom a $140 million contract to provide at least one habitable spacecraft to attach to the International Space Station. Axiom intends to have its spacecraft modules individually launched and assembled in-orbit. Before ISS retirement (and atmospheric reentry), the company plans to detach its modules and commence orbiting on its own as Axiom Station. Axiom plans to provide human spaceflight services to individuals, corporations, and space agencies. In 2022, NASA selected Axiom Space along with \Collins Aerospace to provide astronauts with next-generation spacesuit and spacewalk systems to first test and later use outside the International Space Station, as well as on the lunar surface for the crewed Artemis missions, and to prepare for human missions to Mars.

Another reason for the reduction in the cost of space launches to Low Earth Orbit has been the development of 3D printing. This technology can save 43% of the time when manufacturing a component, compared to manufacturing the same component via traditional methods, and is used effectively by space companies to reduce costs. A top player in the 3D printing space is **Relativity Space,** a U.S.-based space-oriented manufacturing company that designs, develops, and builds 3D-printed rocket launch vehicles for commercial orbital launch services. In addition, the company manufactures 3D-printed rocket engines—Aeon 1 and Aeon R. Relativity operates multiple production, test, and launch sites across the U.S., enabling shorter lead times to launch, and greater launch flexibility for commercial and government customers needing access to space. Relativity is aiming to be the first company to successfully launch an entirely 3D-printed rocket into orbit. They are scheduled to launch a Terran 1 rocket as part of its *Good Luck, Have Fun* mission. The launch for the test flight mission is planned in 2022 from Cape Canaveral, Florida.

Downstream Activities

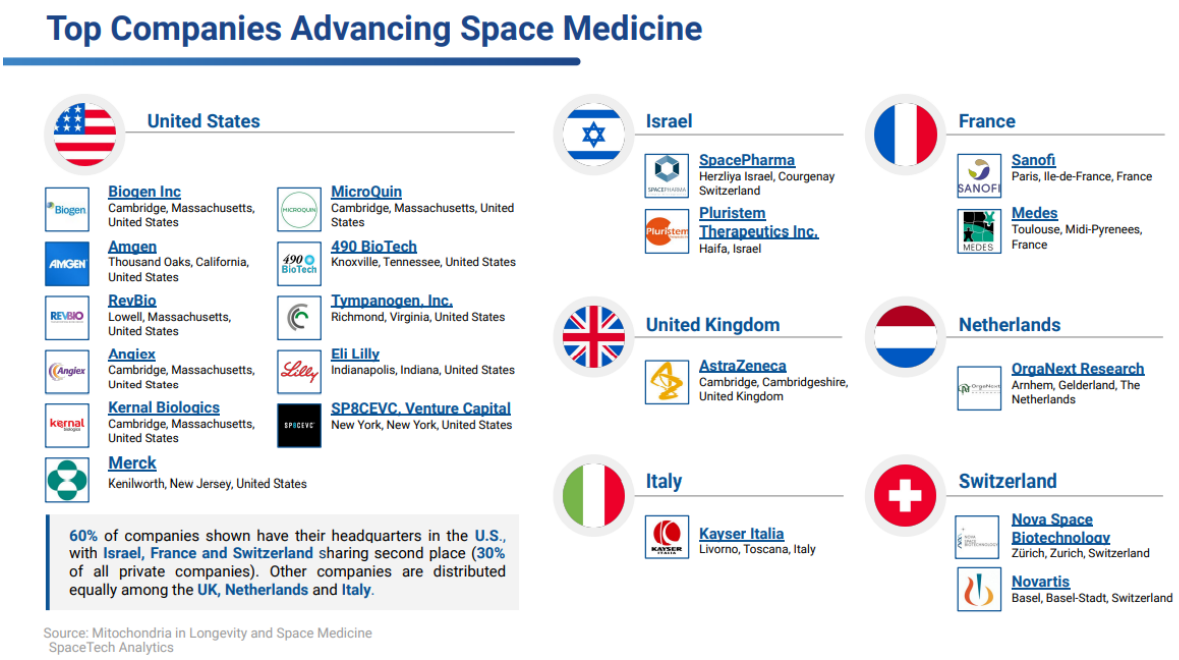
One of the key benefits of the space economy for humans on Earth is Internet connectivity. Several companies have developed satellite constellations to capture the fast-exploding Internet market. The multiple benefits offered by LEO satellites over traditional satellites have prompted **Starlink (SpaceX)**, **Amazon**, and **Oneweb** to enter the race to establish LEO satellite constellations to deliver global Internet connectivity. SpaceX's Starlink plans to launch a minimum of 4,000 satellites to provide fiber-like Internet connectivity to the entire Earth, including the North and South Poles.

OneWeb's satellite network is a B2B model, unlike Starlink's B2C focus, and it is planning to deliver services through existing telecom companies, ISPs, and other distributors to enterprises, governments (including defense), cell network operators, and clusters of communities. It also operates a satellite manufacturing facility in Florida – Airbus OneWeb Satellites, a joint venture with Airbus Defense and Space.

Earth Observation is another contributor to the Technology Overview that has evolved significantly over the past few years. **Planet Labs (PL)** is a leading provider of Earth imaging data and insights, providing services to more than 700 customers around the world. The company images the entire Earth's landmass every day at a high resolution. This powerful data set is collected from ~200 satellites, which makes it the largest Earth Observation fleet of satellites in history; it is designed, built, and operated by Planet Labs. The company captures 1,700+ images on an average for every point on the Earth's landmass, creating a non-replicable historical archive for analytics, machine learning, and insights. The company generates revenue through selling licenses to its data and analytics to customers over an entirely cloud-based platform via fixed-price subscription and usage-based contracts. Most of its revenue is recurring in nature.

Space medicine is another discipline making rapid strides in the "Space for Earth" domain. The chart below gives a list of companies that are working on space medicines.

Chart 5: Top Companies Advancing Space Medicine



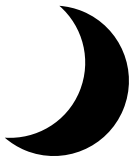
Source: Intro-act, SpaceTech Analytics

Of the total space medicine industry, 25% of the marketplace focuses on bioengineering solutions for astronauts. They primarily work on adverse age-related degenerative conditions: eye and bone implants, or medical hardware to analyze and support astronauts' health. About 5% are dedicated directly to human longevity in space. With time, as more humans start experiencing the space environment firsthand, this segment of human longevity will see dramatic growth. More than 35% of space-related companies provide research equipment for the ISS. Another 25% of the space medical market is focused on the biotechnology industry, dealing with space-related disorders and in situ amino acid production.

Thus, the SpaceTech economy in Earth orbit is much more than tourism spaceflights for the ultra-rich. It encompasses several activities that have been instrumental in improving the lives of people on Earth. From the Internet to meteorology, advancements in technology have benefited humankind immensely. Internet service providers are installing LEO satellite constellations for a faster Internet, Earth observation companies are helping us know our planet more completely, while also serving various industries such as agriculture, weather forecast, and many more. The space economy complements the ground economy in a significant way and helps it to grow faster. With this holistic and futuristic perspective in mind, let's now turn our focus to the next overview—the Lunar Overview.

Overview Two: The Lunar Overview — *"Space for Space"*

Compared with Low Earth Orbit, the Moon is far away—240 miles versus 240,000 miles. At this time, it is difficult for space-based resources to compete with their terrestrial counterparts because of distance, cost, and a lack of customers. However, our natural satellite is close enough to imagine people living there, and industries being located on its surface, without having to be totally independent of Earth. Entrepreneurs are already thinking in terms of the "cislunar economy," which will function in the space between LEO and the lunar region. Several companies are already active, and we expect that **the region will be strongly commercialized (like LEO is today) by the 2040's.** Along with Overview One, this Overview includes Earth/Moon transportation, lunar gateways, lunar habitats, and O'Neill Communities at LaGrange Points. Let's consider why highly practical business people and visionary planners see investment opportunities in this domain.

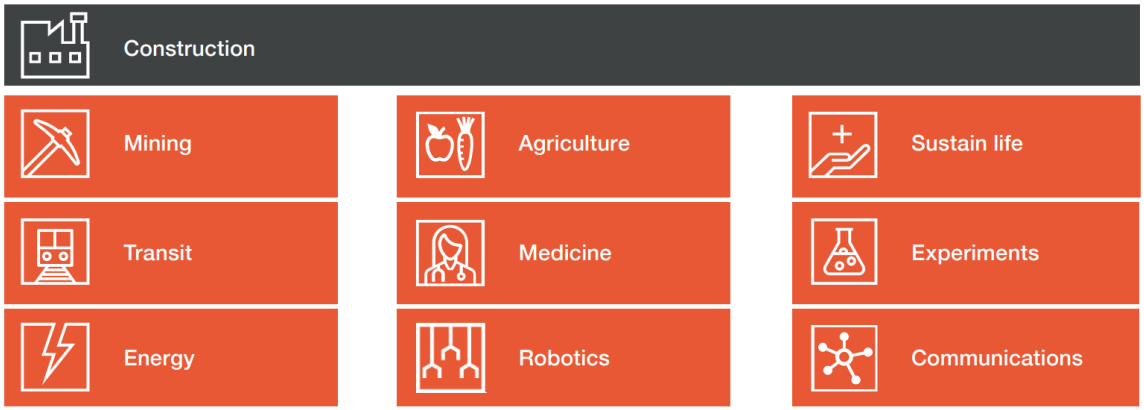


There are many reasons to make the Moon the first object in space to have long-term human communities. First, the Moon is the only celestial body humans have ever visited, with Neil Armstrong becoming the first person to step onto the surface of the Moon. It has been more than half a century since humankind reached the Moon, but it remains the most familiar body in outer space. Second, the Moon is the nearest major celestial body to the Earth. It takes just an average of 3 days to reach it. For perspective, this is far less than what it will take to reach Mars (180-300 days). The delay in communication between the Earth and the Moon is just 1.25 seconds, making it easy to communicate in real-time. Third, the Moon is one of the most studied celestial objects by humankind. We will know a great deal about it before we attempt to go there to stay.

Lunar Habitats

If humans are going to work and live on the Moon, they will need habitats in which to do so. There have been numerous proposals regarding lunar habitats over the years. The designs have evolved as knowledge about the Moon has grown, and as the technological possibilities have changed. These habitats will have to protect humans from radiation, cope with ubiquitous lunar dust, and provide air, water, and food to the lunar citizens. To have a sustaining human presence on the lunar surface, private sector contribution is critical. Government cannot do it alone.

Chart 6: Activities to be Performed on the Moon to Sustain Long-Term Human Presence



Source: Intro-act, PwC

With this backdrop let's discuss a few companies that are planning lunar missions. The biggest advancement in the space industry in the past decade was a reduction in launch costs driven by players such as **SpaceX** and **Blue Origin,** and this has implications for the cislunar economy. The decline in costs has made the entire space ecosystem more economical to a variety of players. For this reason, more than 50 years after the first Moon landing, companies are again aiming for our celestial neighbor. Unlike in 1969, the cost to reach the Moon is far less now. This makes the lunar economy accessible even to smaller nations and private players, many of whom are working on various aspects of a lunar economy, such as transportation, data, and in-situ technologies. Most of these companies are currently working with government agencies to reach the Moon and help establish a sustained human presence there.

1. NASA's Space Launch System (SLS) is being built by **Boeing** for the Artemis Program, with payload capacities reaching 45,000 kg.
2. The Orion Multi-Purpose Crew Vehicle (MPCV), co-designed by **Lockheed Martin** and **Airbus Defense & Space**, plans to house and shuttle a crew of up to six NASA astronauts to the Moon. Lockheed Martin and **General Motors** have also teamed up to design the next generation of lunar rovers, capable of transporting astronauts across farther distances on the lunar surface.
3. In the frame of Artemis Human Landing Systems, NASA awarded **SpaceX** the contract to develop human class landers for astronaut landings on the Moon.
4. On November 2019, **Ceres Robotics** was granted the right to bid on contracts by NASA's Commercial Lunar Payload Services (CLPS) to support the Artemis program.
5. In parallel, the VIPER mission planning saw NASA award three contracts to **Astrobotic Technology**, **Intuitive Space Systems**, and **Masten Space Systems** to develop lunar landers that will transport a specialized rover to the Moon that will survey and map the lunar surface in anticipation of human landings.
6. Another illustration of private actors' involvement is NASA's contract to **Firefly Aerospace** to deliver a package of 10 science and technology missions to the lunar surface in 2023, using Firefly's Blue Ghost lander.
7. In July 2022, NASA awarded a contract worth $73 million to a team led by **Draper Labs**. The commercial delivery is part of NASA's Commercial Lunar Payload Services (CLPS) initiative under its Artemis missions. The experiments riding on Draper's SERIES-2 lander targets Schrödinger Basin on the far side of the Moon and are scheduled for 2025. Scientists hope to study the thermal

and geophysical properties of the lunar interior as well as electric and magnetic properties in a landing location shielded from the Earth's electromagnetic fields.

These examples are a few of the many public-private partnerships between NASA and an ambitious, growing private sector. However, NASA is not the only space agency aiming for the Moon this time. Their colleagues across the world, such as JAXA of Japan and ESA of Europe, are also developing various projects aimed at the Moon.

In Japan, **Mitsubishi** is working on the H3 launcher and HTV-X ship to deliver payloads and cargo directly to the Moon by 2025. **Toyota** is co-designing and building an electric human-driven rover called the Lunar Cruiser alongside JAXA for future use on the lunar surface. **iSpace** is also developing a lander and rover for lunar exploration. It has partnered with UAE government's Mohammed bin Rashid Space Centre (MBRSC) to launch the agency's Moon rover *Rashid.*

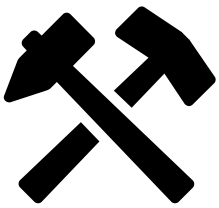
In Europe, the Lunar Pathfinder project includes players such as **Surrey Satellite Technology Ltd** and **Goonhilly Earth Station**. ESA has selected **ArianeGroup** for launch and ground control services, and **PTScientists** will be developing a lunar lander. ESA awarded **Airbus Defense & Space** a contract to build three additional Orion MPCVs, while **Thales Alenia Space** is developing two key modules for the Lunar Orbital Platform Gateway, a small space station designed to orbit the Moon and support the human presence on the surface. The European private sector is rapidly expanding in the field of Space Resource Utilization (SRU), with growing private firms such as **Maana Electric** (specializing in In-Situ Lunar Resource Utilization) and **OffWorld** (developing AI-powered robotics for lunar resource extraction).

Several companies have engaged in the development of SRU technologies globally. Public programs are playing a key role in stimulating the market and establishing primary customers for private companies to emerge and mature their technology.

Chart 7: Companies Involved in the SRU Supply Chain

Source: Intro-act, PwC

To have a sustainable presence on the Moon, the ability to utilize the resources that are already there will be critical. We need technologies to extract resources from the Moon so that we do not depend wholly on supplies from the Earth



OffWorld offers a unique approach to the challenge of economic viability posed by the cislunar region. The company is building AI-enabled robotic mining vehicles that generate customers and income on the Earth prior to expanding beyond LEO. It could be said that companies like **Rio Tinto** are using **OffWorld** as their de facto R&D team to support their own lunar ambitions. In the meantime**, Rio Tinto** is collaborating with the newly formed Australian Space Agency on how its mining technology can be used to extract resources on the Moon and other planets. Rio Tinto has joined the Australian Remote Operations for Space and Earth (AROSE) consortium in a bid to advance Australia's world-leading position in remote

operations. AROSE is a not-for-profit, industry-led consortium with a vision for Australia to be the trusted leader of remote operations on Earth and in space. The Australian government is aiming to triple the size of the nation's space sector by 2030, adding an additional $12 billion to the economy. Similarly, construction giant **Caterpillar** hopes to one day bring its autonomous mining technology to the Moon.

OxEon Energy will work with the Colorado School of Mines to integrate an electrolysis technology to process ice and separate the hydrogen and oxygen. The molecules could then be cooled to produce fuel for cislunar transport. This technology could provide a flexible and scalable solution for future in-situ resource utilization operations on the Moon.

Skyre, also known as Sustainable Innovations, along with partner **Meta Vista USA LLC**, will develop a system to make propellant from permanently frozen water located at the Moon's poles, including processes to separate the hydrogen and oxygen, keep the product extremely cold, and use hydrogen as a refrigerant to liquefy oxygen.

Paragon Space Development Corporation will work with Johnson Space Center and NASA's Glenn Research Center in Cleveland to develop an environmental control and life support system, as well as a thermal control system, that maintain acceptable operating temperatures throughout the Moon's day-and-night cycle. The design of these systems could be adapted for crewed missions to Mars.

Infinity Fuel Cell and Hydrogen Inc. will collaborate with NASA's Johnson Space Center in Houston to develop a scalable, modular, and flexible power and energy product that utilizes new manufacturing methods to reduce cost and improve reliability. The technology could be used for lunar rovers, surface equipment, and habitats.

For humans to reside on the Moon, they will need energy and food that is being produced and health facilities that are being developed there, so that these products and services need not be transported from the Earth. This will give rise to many start-ups specializing in space agriculture and space medicine, as well as other basic requirements of human life. Scientists from the University of Florida have already demonstrated success in growing plants in lunar soil. Though it was a small experiment with only 12 grams of soil from the Moon, it is one step closer to having agriculture there.

Through the Artemis missions, NASA plans to return astronauts to the Moon and establish a long-term presence near the lunar South Pole. A reliable, sustainable power source is required to support habitats, rovers, and even construction systems for future robotic and crewed missions. To help provide this power, NASA is supporting development of vertical solar arrays that can autonomously deploy up to 32 feet in height and retract for relocation if necessary. NASA has selected three companies to further advance work on deployable solar array systems that will help power the agency's human and robotic exploration of the Moon under Artemis. The agency will award a total of $19.4 million to three companies to build prototypes and perform environmental testing, with the goal of deploying one of the systems near the Moon's South Pole by the end of this decade. The awardees include: **Astrobotic Technology**, **Honeybee Robotics**, and **Lockheed Martin.**

NASA's Jet Propulsion Laboratory in Southern California has selected **Microchip Technology Inc**. of Chandler, Arizona, to develop a High-Performance Spaceflight Computing (HPSC) processor that will provide at least 100 times the computational capacity of current spaceflight computers. This key capability would advance all types of future space missions, from planetary exploration to lunar and Mars surface missions.

The table below shows a few of the ongoing and upcoming missions to the Moon.

Chart 8: Missions to the Moon

In Progress	Coming Soon
The Korean Pathfinder Lunar Orbiter, South Korea's first Moon mission, was launched in August 2022.	NASA's Artemis program will return humans to the Moon. The first test flight, Artemis I, is scheduled for November 14.
The CAPSTONE spacecraft intends to prove the feasibility of the unique fuel-saving lunar orbit that the NASA-led international Gateway station will use later this decade.	iSpace Japan's first Moon landing mission, will launch by end of 2022, carrying several international payloads, including UAE's Rashid rover.
China's Chang'e-5 returned lunar samples to Earth in 2020, and is on an extended mission of testing an advanced lunar orbit.	NASA-funded commercial CLPS Moon landing missions begin later this year.
India's Chandrayaan-2 orbiter maps the Moon's topography, studies its composition, and scans for polar ice.	NASA's Lunar Trailblazer orbiter will advance our understanding of water across the Moon for exploration and science.
China's Chang'e-4 performed the first landing on the Moon's far side in 2018, where it's still studying that ancient region.	NASA's VIPER rover launches to the Moon's South Pole in 2024 to study water questions.
NASA's Lunar Reconnaissance Orbiter has been studying the Moon since 2009 with its comprehensive suite of mapping instruments.	

Source: Intro-act, Planetary.org

Lunar Gateways

Lunar gateways would be space stations orbiting the Moon, like the ISS orbits the Earth. NASA's lunar Gateway Program is building a small, human-tended space station orbiting the Moon that will provide extensive capabilities to support NASA's Artemis campaign. Built with international and commercial partnerships, the Gateway's capabilities for supporting sustained exploration and research in deep space include docking ports for a variety of visiting spacecraft, space for crew to live and work, and on-board science investigations to study heliophysics, human health, and life sciences, among other areas. In May 2019, NASA selected **Maxar Technologies** to develop and build the Power and Propulsion Element (PPE) of the Gateway. **Northrop Grumman** is designing the Habitation and Logistics Outpost (HALO) of the Gateway.

O'Neill Communities

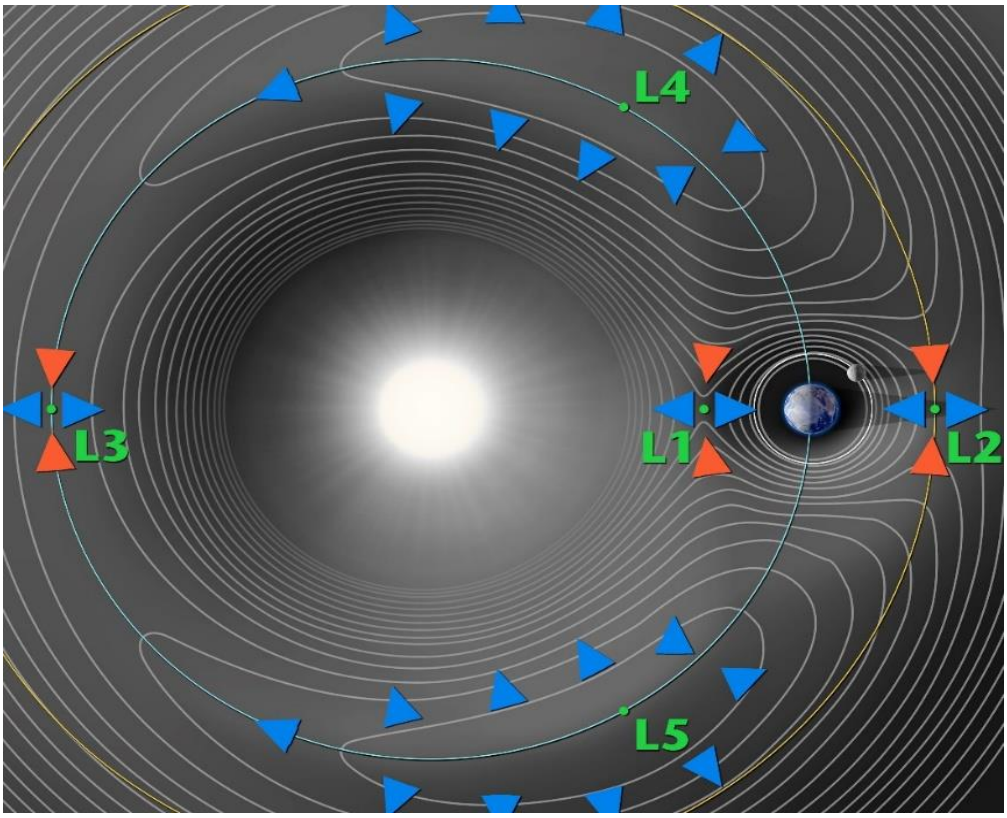
Apart from communities on the Moon, another area that is part of the Lunar Overview is O'Neill Cylinders/Communities. In the 1970s and 1980s, Physicist Gerard K. O'Neill proposed that the most effective geometry to establish habitats in space is a pair of cylinders in "free space," built with extraterrestrial materials, mined from asteroids or the Moon. He believed that their most efficient size would be about four miles in diameter, and perhaps about 16 miles in length. He found a rotation period of two minutes to be ideal with the cylinder axes always pointed toward the Sun. The ultimate goal was an Earthlike environment that included protection from radiation and variable levels of gravity. One possible location was Lagrange Point 5, or L5, situated where the gravity pull of the Earth and the Moon would be balanced, allowing the habitat to be stable permanently, even though it would not be on a planetary surface.

Asteroid Mining

Technologies for asteroid mining are still at a very early stage and it may take some years before this is happening commercially. Although the resources on Earth are finite, few players have turned their attention to outer space for additional opportunities. Research suggests that several asteroids are mineral rich. One company that focuses on space mining is **Asteroid Mining Corporation (AMC).** It is a private British company that is currently developing robotic and satellite platforms to enable the exploration and extraction of off-world resources, including those from asteroids. AMC is building on a series of technological innovations that will pave the way toward the profitable mining of space resources – from the reduction of launch costs to an expansion of robotic capabilities. The company plans to start with near-Earth asteroids and then target the main asteroid belt, between the orbits of Mars and Jupiter.

Asteroid Mining Corporation

Chart 9: A Contour Plot of Lagrange Points of the Earth-Sun System



Source: Intro-act, NASA/ WMAP Science Team

While no companies have yet made a formal commitment to build such a community, Blue Origin founder Jeff Bezos has discussed his vision of having people and industries leave the Earth to benefit the Earth environmentally. He has frequently mentioned space habitats that were based on the O'Neill concept.

Overview Three: The Copernican Perspective — *"On to Mars"*

When Copernicus published his monumental work, *De revolutionibus orbium coelestium*, he effectively advanced the notion that the Earth was not the center of the universe, but rather, a member of a celestial neighborhood, the solar system. He also argued that it was more accurate and simpler to consider the sun,

not the Earth, as the center of this system. Although the idea of a heliocentric, rather than geocentric solar system had existed for centuries, Copernicus, Kepler, and Galileo provided the hypotheses and data needed for wide acceptance. As humanity continues to invest in expansion outward, we will increasingly shift our awareness to the perspective advanced by Copernicus, and come to see ourselves as inhabitants of the solar ecosystem, as well as the terrestrial ecosystem.

In the near term, the Copernican Perspective focuses on the area between the Earth and Mars. We expect **strong commercialization in this region to take place by 2050**. In addition to Overviews One and Two, this Overview covers activities including Earth/Moon/Mars transportation, Martian habitats, and industrial robots with AI to prepare Mars for human habitation.

While Mars is much farther from the Earth than is the Moon, we already have a presence on the Red Planet. NASA currently has two rovers (Curiosity and Perseverance), one lander (InSight), and one helicopter (Ingenuity) exploring the surface of Mars. The Perseverance rover—the largest, most advanced rover NASA has sent to another world—touched down on Mars in February 2021, after a 203-day journey traversing 293 million miles (472 million kilometers). The Ingenuity helicopter rode to Mars attached to the belly of Perseverance and has made numerous flights that are essentially scouting expeditions for eventual human landings. **Lockheed Martin** is the prime contractor for the InSight lander and is responsible for the complete spacecraft system—cruise stage, aeroshell, and the lander itself. Lockheed has a rich experience of supporting deep space missions and had developed the spacecraft for NASA's 2001 Mars Odyssey mission. It has also developed the Curiosity and Perseverance rovers and Ingenuity helicopter, in partnership with **Boeing**.

China is the second country to successfully deploy a rover on Mars. On 14 May 2021, the lander/rover portion of the country's Tianwen-1 mission successfully touched down on Mars and on 22 May 2021, the rover drove onto the Martian surface.

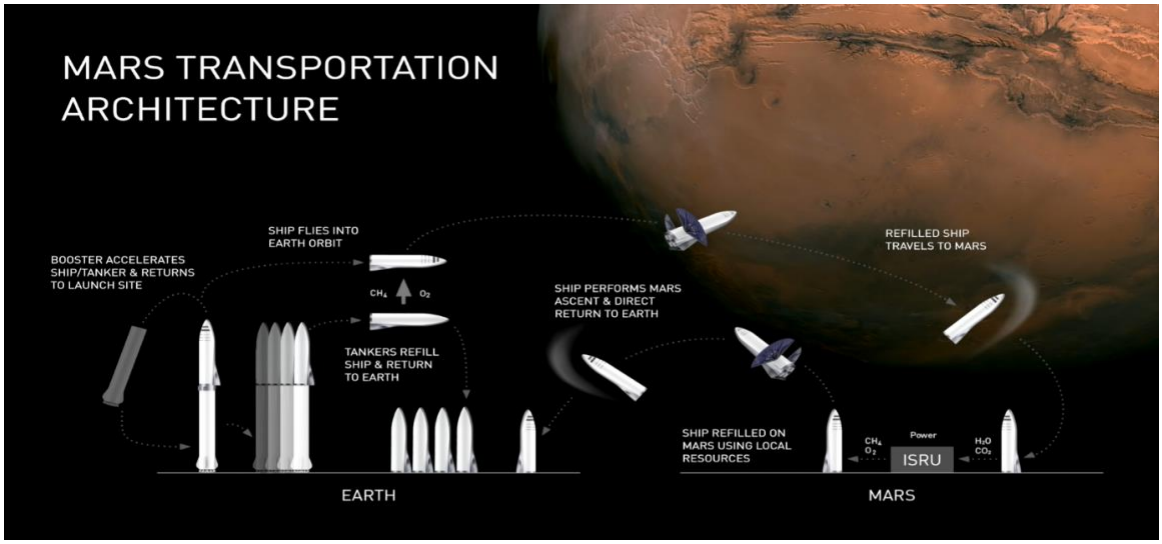
One of the strongest proponent of Mars habitats is Elon Musk, the founder of **SpaceX**. He has been consistently advocating making humans a multiplanetary species by creating a city on Mars. (To learn more, watch this video)

Making humans a multiplanetary species could go a long way to ensure the survival of the human race. If we look at our planetary system, Mars seem to be an ideal candidate for starting this endeavor. Mars is close to Earth compared to other planets, such as Jupiter or Saturn. Mars has similar day and night cycles to that of the Earth, and a total land area similar to the home planet (though Mars is smaller, it has no oceans). Though inhospitable to human life, it is more habitable than Mercury or Venus.

Musk has talked about having a million people settle on the Red Planet. His company will need to do a lot of ground work to reach that scale, but it is moving in the right direction. Its Starship spacecraft and Super Heavy rocket (collectively referred to as Starship) represent a fully reusable transportation system designed to carry both crew and cargo to the Earth's orbit, the Moon, Mars, and beyond. Starship will enter Mars' atmosphere at 7.5 kilometers per second and decelerate aerodynamically. The vehicle's heat shield is designed to withstand multiple entries, but given that the vehicle is coming into Mars' atmosphere so hot, SpaceX still expects to see some ablation of the heat shield.

The engine propellant used by SpaceX rockets today is methane. Mars has water (H_2O) and carbon-di-oxide (CO_2). Thus, having a methane-powered space vehicle could be a great step in sustainable transportation to and from Mars. The company hopes to develop methane (CH_4) on Mars from H_2O and CO_2. This will eliminate the need to carry fuel from planet Earth. Moreover, the technologies developed for Mars can find applications on the Earth and vice-versa.

Chart 10: Mars Transportation Architecture



Source: Intro-act, YouTube, SpaceX

Another player supporting Mars missions is **Rocket Lab**. NASA's Escape and Plasma Acceleration and Dynamics Explorers, or ESCAPADE spacecraft, planned to launch in October 2024, will spend 11 months in interplanetary space before entering a highly elliptical orbit around Mars. ESCAPADE consists of two identical interplanetary Photon spacecraft developed by Rocket Lab. Both spacecraft are about the size of a mini-fridge and weigh no more than 250 pounds (120 kilograms), excluding fuel.

Below are few of the "in progress" and future missions to Mars. With lots of attention from big private players such as SpaceX and various government agencies, Mars certainly is the next planned destination after the Moon.

Chart 11: Missions to Mars

In Progress	Coming Soon
NASA's Perseverance rover landed in February 2021 and will search for past life and collect samples for return to the Earth.	Japan's Martian Moons eXploration (MMX) mission launches in 2024 to collect samples from Mars' largest Moon Phobos for return to the Earth.
China's Tianwen-1 is an orbiter and rover mission that arrived in February 2021 to study the planet.	The NASA-funded ESCAPADE twin orbiters will launch in 2024 to study the red planet's atmosphere and past.
The United Arab Emirates' Hope orbiter arrived in February 2021 and will build a complete picture of the Martian atmosphere.	Mars Sample Return is a series of missions by NASA and ESA to return samples from Mars to Earth in the early 2030s.
NASA's MAVEN orbiter studies what happened to Mars' atmosphere.	ESA's ExoMars rover will launch sometime by 2030 to find signs of life on Mars.
NASA's InSight lander studies the planet's interior.	
ESA's ExoMars Trace Gas Orbiter searches for atmospheric gases linked to life as we know it.	
India's Mangalyaan orbiter is a technology demonstration mission studying the planet.	
ESA's Mars Express surveys the planet and searches for subsurface water.	
NASA's Curiosity rover explores an ancient lake bed that once had conditions that could have supported life.	
NASA's Mars Reconnaissance Orbiter studies the planet with a high-powered camera and relays communications between the surface and the Earth.	
NASA's long-lived Odyssey monitors surface changes.	

Source: Intro-act, Planetary.org

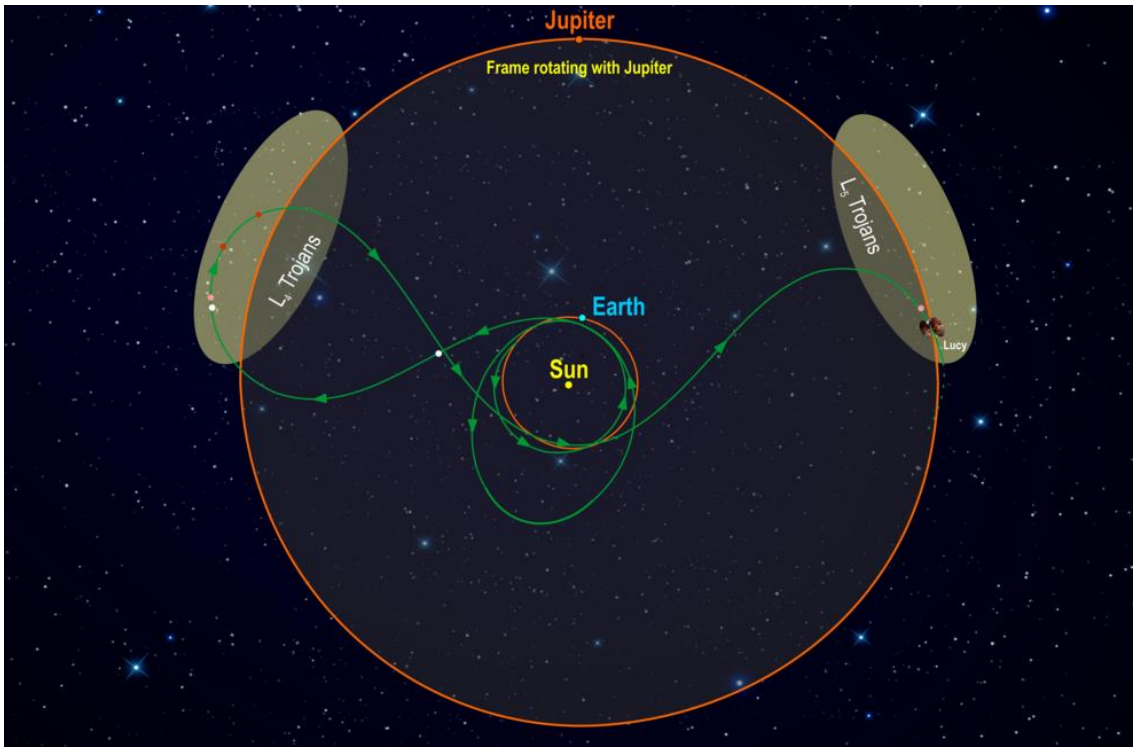
Flying aboard NASA's Mars Reconnaissance Orbiter, HiRISE (High Resolution Imaging Science Experiment) is the largest telescopic instrument ever sent beyond Earth's orbit. It is able to image the Martian surface up to five times the resolution provided by the Mars Global Surveyor, identifying images as small as a coffee table. HiRISE is developed by **Ball Corporation**.

Overview Four: The Solar Overview — *"Moonland"*

The Solar Overview covers the TransSaturn space or the area between the Earth and Saturn. Evidence suggests that the moons of Jupiter and Saturn are habitable. This Overview envisages deep space transportation and habitats on the moons of Jupiter and Saturn—hence the tagline *"Moonland."* Beyond Mars, most of the exploration is currently funded by government agencies but **we expect commercialization of this Overview by 2070**. Even today, the agencies contract with companies for the spacecraft, rockets, and equipment used in these missions.

A key player in these deep space missions is **Lockheed Martin**. The company built and will operate the spacecraft for NASA's Lucy mission that aims to study Trojan asteroids associated with Jupiter. The Lucy spacecraft launched aboard a **United Launch Alliance's** (a joint venture of **Lockheed Martin** and **Boeing**) Atlas V rocket in October 2021. With boosts from Earth's gravity, Lucy will complete a 12-year journey to eight different asteroids. This will be the first mission to explore the Jupiter Trojan asteroids, a population of asteroids that lead and follow Jupiter in its orbit around the Sun. The Lucy team will use the cratering record on these asteroids to better understand the history of our Solar System. Lucy will cover almost 4 billion miles over its 12-year journey.

Chart 12: Lucy's Orbital Path



Source: Intro-act, Southwest Research Institute, NASA

The spacecraft's path (green) is shown in a frame of reference where Jupiter remains stationary, giving the trajectory its pretzel-like shape. After launch in October 2021, Lucy has two close Earth flybys before encountering the Trojan targets. After flying by the Patroclus-Menoetius binary in 2033, Lucy will continue cycling between the two Trojan clouds every six years.

This spacecraft builds on years of technology development from numerous planetary missions like Mars Odyssey, OSIRIS-Rex, and InSight, among others. Lucy's Terminal Tracking Camera (T2CAM) system, a pair of identical cameras that are responsible for tracking the asteroids during Lucy's high-speed encounters, was designed, built, and tested by **Malin Space Science Systems**.

Previous probes in this ring include Pioneer 10, Voyager 1, and Voyager 2. Pioneer 10 (originally designated Pioneer F) is an American space probe launched in 1972 that completed the first mission to the planet Jupiter. Voyager 1 was launched by NASA on September 5, 1977 to study the outer solar system and interstellar space beyond the sun's heliosphere. The probe made flybys of Jupiter, Saturn, and Saturn's largest moon, Titan.

Voyager 2 is a space probe launched by NASA on August 20, 1977 to study the outer planets and interstellar space beyond the sun's heliosphere. As a part of the Voyager program, it was launched 16 days before its twin, Voyager 1, on a trajectory that took longer to reach the gas giants Jupiter and Saturn but enabled further encounters with ice giants Uranus and Neptune. Voyager 2 remains the only spacecraft to have visited either of the ice giant planets. Voyager 2 successfully fulfilled its primary mission of visiting the Jovian system in 1979, the Saturnian system in 1981, the Uranian system in 1986, and the Neptunian system in 1989. The spacecraft is now in its extended mission of studying interstellar space. It has been operating for 45 years and 2 months as of October 20, 2022, and has reached a distance of 131.44 AU

(12.218 billion mi) from the Earth. There are several missions from various space agencies to Jupiter and Saturn.

Chart 13: Southern Hemisphere Cloud Belts of Jupiter

Source: Intro-act, NASA/JPL-Caltech/SwRI/MSSS/Kevin M. Gill

NASA has authorized a mission extension for its Juno spacecraft, which is exploring Jupiter. The agency's most distant planetary orbiter will now continue its investigation of the solar system's largest planet through September 2025, or until the spacecraft's end of life. This expansion tasks Juno with becoming an explorer of the full Jovian system—Jupiter and its rings and moons—with multiple rendezvous planned for three of Jupiter's most intriguing Galilean moons: Ganymede, Europa, and Io. JunoCam, the camera aboard the spacecraft, was developed by **Malin Space Science Systems**.

JUICE—JUpiter ICy Moons Explorer—is the first large-class mission in ESA's Cosmic Vision 2015-2025 program. Planned for launch in 2023, it will spend at least three years making detailed observations of Jupiter and three of its moons—Ganymede, Callisto, and Europa. The Jupiter Icy Moons Explorer is an interplanetary spacecraft in development by ESA with **Airbus Defense and Space** as the main contractor.

NASA's Europa Clipper spacecraft will perform dozens of close flybys of Europa, gathering detailed measurements to investigate whether the moon could have conditions suitable for life. Europa Clipper is not strictly a life detection mission—its main science goal is to determine whether there are places below Europa's surface that could support life. The spacecraft, in orbit around Jupiter, will make nearly 50 flybys of Europa at closest-approach altitudes as low as 16 miles (25 kilometers) above the surface, soaring over a different location during each flyby to scan nearly the entire moon. **SpaceX's** Falcon Heavy will launch the mission. The total contract award amount for launch services is approximately $178 million.

Chart 14: Missions to Jupiter and Saturn

In Progress	Coming Soon
NASA's Juno studies the planet's core to help us understand how planets and our solar system formed.	ESA's JUICE launches in 2023 to explore Jupiter and its icy Moons: Europa, Callisto, and Ganymede.
	NASA's Europa Clipper launches in 2024 to determine whether Jupiter's moon, Europa, could support life.
	NASA's Dragonfly launches in 2027 to explore Saturn's moon, Titan.

Source: Intro-act, Planetary.org

NASA's Dragonfly launches in 2027 to explore Saturn's moon, Titan. Dragonfly is a rotorcraft lander mission—part of NASA's New Frontiers Program—designed to take advantage of Titan's environment to sample materials and determine surface composition in different geologic settings. The mission concept includes the capability to explore diverse locations to characterize the habitability of Titan's environment, to investigate how far prebiotic chemistry has progressed, and even to search for chemical signatures that could indicate water-based and/or hydrocarbon-based life. Mission partners include **Lockheed Martin Space, Malin Space Science Systems**, and **Honeybee Robotics**, among others.

Overview Five: The Pale Blue Dot — *"That's here, that's Home"*

On February 14, 1990, NASA's Voyager 1 spacecraft, at a distance of 3.7 billion miles from the Earth, zipped toward the far edge of the solar system. It took an image of the Earth, which looked nothing more than a pale blue dot in the vast space. Carl Sagan, part of Voyager's imaging team, is credited with the idea of having Voyager 1 take the famous image.

Chart 15: An Updated Version of the Iconic "Pale Blue Dot" Image Taken by the Voyager 1

Source: Intro-act, NASA/JPL-Caltech

"Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our

joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every "superstar," every "supreme leader," every saint and sinner in the history of our species lived there—on a mote of dust suspended in a sunbeam."

From Pale Blue Dot, 1994

The Pale Blue Dot Overview looks at the area between the Earth and Pluto. As we look outward beyond the solar ecosystem, the majority of the development in the Pale Blue Dot Overview is through space telescopes that will study the universe. We expect **commercialization of this region by 2080**. A key upcoming mission in this segment is the Roman Space Telescope. It is a NASA observatory designed to study dark energy, exoplanets, and infrared astrophysics. The Roman Space Telescope will conduct multiple observational strategies, including surveys of exploding stars called supernovae, galaxy clusters, and mapping out the distribution of galaxies in three dimensions. (Measuring the brightness and distances of supernovae provided the first evidence for the presence of dark energy.) This telescope will extend the studies to greater distances to measure how dark energy's influence increased over time. It will measure precise distances to galaxy clusters to map how they grew over time. The mission will also pinpoint the distances to millions of galaxies by measuring how their light becomes redder at greater distances, a phenomenon called redshift. The farther off a galaxy is, the redder its light appears when we see it. Mapping out the 3-D positions of galaxies will allow astronomers to measure how the distribution of galaxies has changed over time, providing another measure of how dark energy has affected the cosmos. Roman is scheduled to be launched on a **SpaceX** Falcon Heavy launch vehicle in 2027.

Ball Aerospace & Technologies Corp built seven science instruments for Hubble, two star trackers, five major leave-behind equipment subsystems, and more than eight custom tools to support astronauts during servicing missions. It is also designing and developing the Wide Field Instrument (WFI) Opto-Mechanical Assembly for the Roman Space Telescope mission.

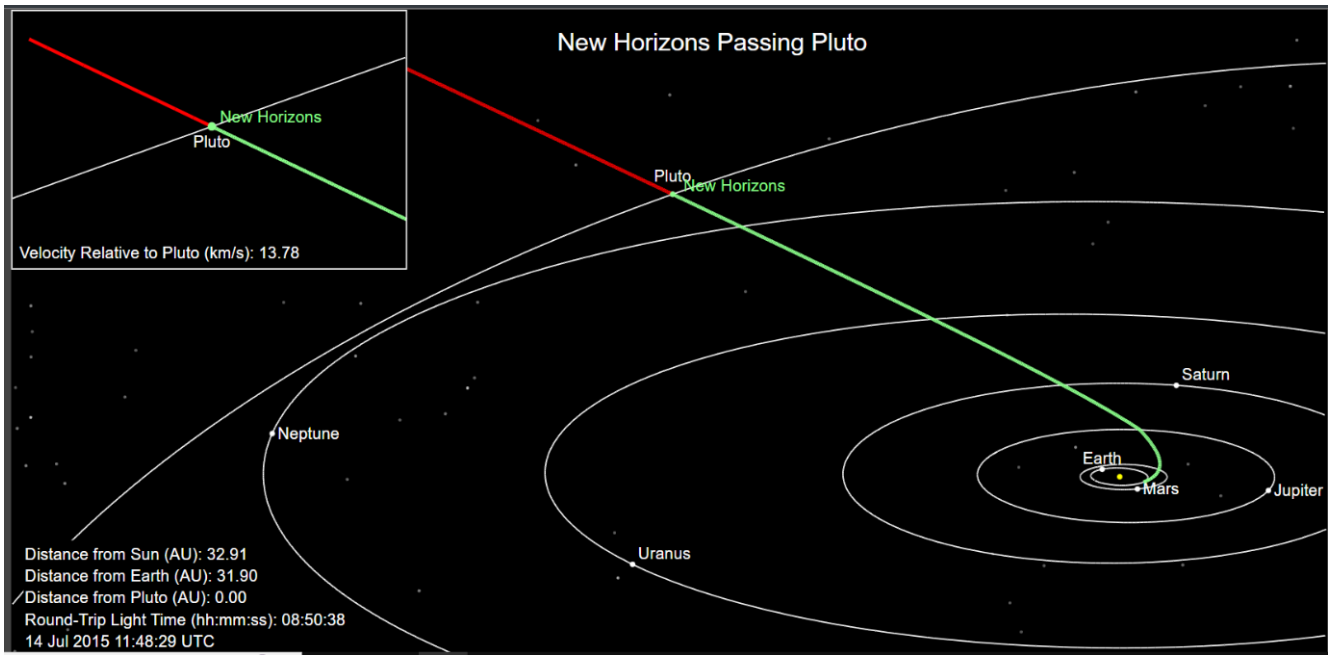
Chart 16: Missions for the Solar System and Beyond

In Progress	Coming Soon
NASA's Hubble Space Telescope is a multipurpose astrophysics and planetary science observatory.	NASA's Roman Space Telescope will launch in 2027 and image Earth-sized exoplanets.
ESA's CHEOPS precisely measures the diameters of known exoplanets.	
NASA's TESS hunts for exoplanets around a specific type of bright stars.	
NASA's JWST launched in 2021 to build on the Hubble Space Telescope's capabilities.	

Source: Intro-act, Planetary.org

The New Horizons mission is helping us understand worlds at the edge of our solar system by making the first reconnaissance of the dwarf planet Pluto and by venturing deeper into the distant, mysterious Kuiper Belt. New Horizons launched in January 2006 and swung past Jupiter for a gravity boost and to conduct scientific studies in February 2007. It was launched using an Atlas V rocket, designed by **Lockheed Martin**.

Chart 17: New Horizons Passing Pluto



Source: Intro-act, The Johns Hopkins University Applied Physics Laboratory

New Horizons accomplished its prime mission with a successful flyby of Pluto on July 14, 2015. After a decade-long journey, traveling 3.26 billion miles (5.25 billion kilometers) across our solar system, New Horizons flew by Pluto and its five moons, Charon, Nix, Hydra, Kerberos, and Styx, at a closest approach distance of 7,759 miles (12,487 kilometers) above Pluto's surface. The flyby was the first exploration of a world so far from the Earth.

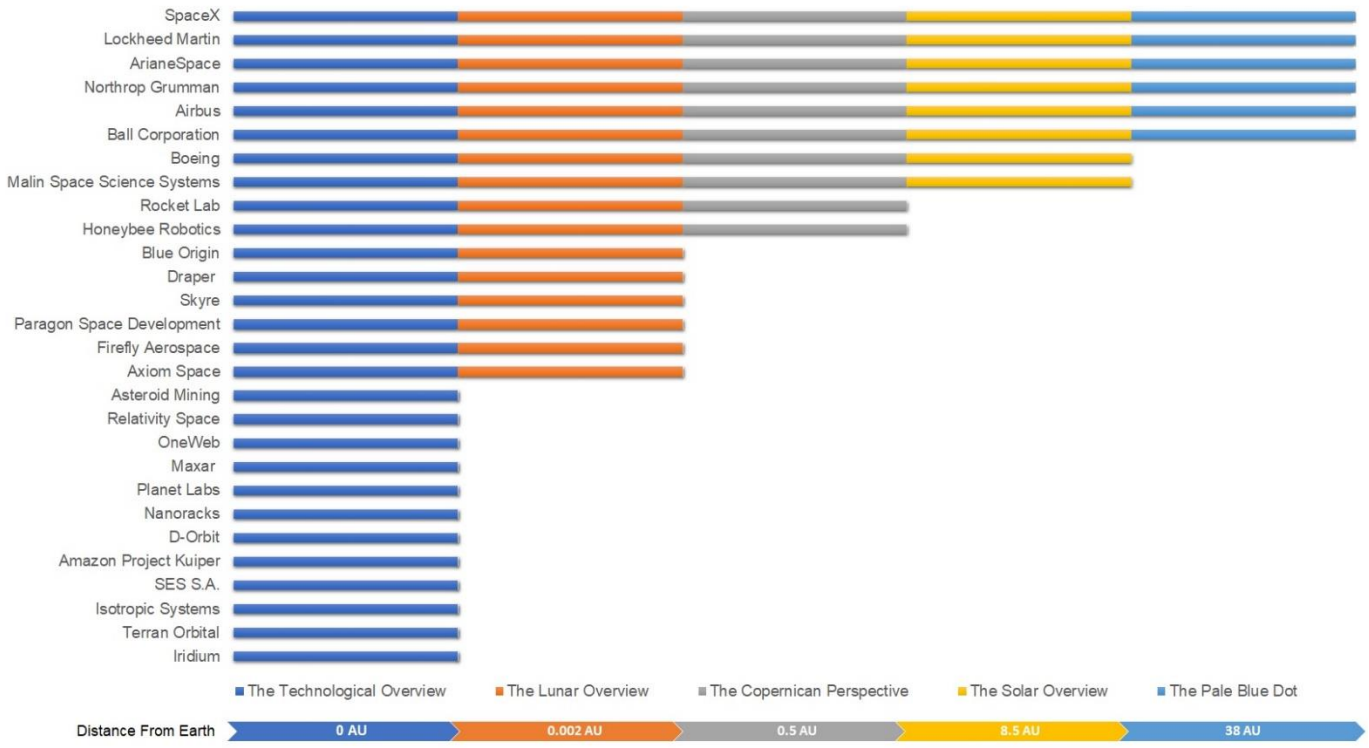
The Prime contractor for ESA's CHEOPS is **Airbus Defense and Space**, Spain. CHEOPS launched aboard a Soyuz-AT launch vehicle in December 2019. Contractor was **Arianespace**. The prime contractor for NASA's JWST was **Northrop Grumman**.

Five Overviews in 2022: Who's Where?

Like other industries, it is difficult to clearly categorize each SpaceTech player into one of the Overviews. There are companies in the Technological Overview who may not extend their reach very far beyond Low Earth Orbit. At the same time, several other players, like SpaceX, Blue Origin, Airbus, Lockheed Martin, and Boeing, operate in more than one segment. The same is true for other Overviews. Overall, there are over 100 companies operating in various segments of the SpaceTech economy. The chart below shows the key players operating in each of the five Overviews as of 2022.

Another notable point is that, as we might expect, there are fewer active players (and investors) as we move farther away from the Earth. These companies are typically supporting government missions as contractors. SpaceX and Blue Origin have clearly stated ambitions for the Moon missions, with SpaceX aiming to establish communities on Mars. While LEO is already commercialized, it will take decades to commercialize deep space.

Chart 18: The Five Overviews: Who's Where?



Source: Intro-act

Humans have lived on only one planet so far. The farthest a human has traveled to date is to our own Moon, the satellite of Earth. Thus, we still have a long way to go in space exploration and migration. Looking at the developments in the space economy, however, lunar and Martian communities seem achievable in the coming decades, as do O'Neill-style communities. While the ultimate costs of this "Great Migration" may be high, it will definitely happen if the return on investment is even higher!

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