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The American Space Industry: A History of Innovation and An Analysis of Future Policy

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The American Space Industry:
A History of Innovation and An Analysis of Future Policy

Introduction

This paper explores the innovations of the private space industry with specific focus on the maturing markets providing services ranging from commercial transport to fully developed commercial space stations for research and tourism. The shift from the government-led National Aeronautics and Space Administration (NASA) ventures to commercial industry dominance has allowed several prominent companies to monetize their innovations in a competitive market. Special emphasis is placed on new launching systems and satellite configurations that provide a more competitive environment that spurs technical and market innovation. Additionally, ongoing international treaties are listed to relate how these 20th century treaties are impacting the 21st century's industry. Finally, this paper examines property rights in space and how current legislation is delineating more rights for those who engage in sectors such as space tourism, lunar settlements, and regolith mining.

History of the Government-led Space Industry

Established in 1958, NASA captured the imagination of America's innovative talent and successfully completed century defining missions while providing the world with unparalleled advancements in technology. While many innovations before the world wars were driven by private entrepreneurs, the existential threats during the Second World War served as an impetus for government sponsored innovation. Specifically, the jet engine and rocketry fields were bolstered from both captured German scientists and intellectual property as well as continued US military funding for aeronautics research. For example, the X-15 Hypersonic Aircraft project tested the limits of how far beyond the sound barrier conventional aircraft could achieve.[1]

Consequently, the American space industry had a strong foundation to build upon. Before the US could send a man into space with Project Mercury, the Soviet Union had already sent cosmonaut Yuri Gagarin to low earth orbit which stoked a fire under patriotic US innovators.[2] To catch up to the Soviets, the Gemini Project in 1965 and 1966 allowed NASA to practice the fundamentals of extra-vehicular activity (EVA) as well as maneuvering objects in low earth orbit (LEO).[3] With regards to this burgeoning industry, many of the critical spacecraft components were sourced from private contractors who would bid to provide the parts at the lowest cost to NASA. Subsequently, smaller aerospace firms were able to receive financing to create these specialized parts to serve future missions. With this broad foundation of both government and commercial innovators providing components to NASA, Project Apollo culminated in July 1969 with the first moon landing; a new age of innovation and exploration was heralded not only by the US public but to the free world at large.[4]

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[1] Yvonne Gibbs, ed., "NASA Armstrong Fact Sheet: X-15 Hypersonic Research Program" (NASA, August 13, 2015), https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-052-DFRC.html.
[2] Sandra May, ed., "What Was Project Mercury?" (NASA, February 27, 2015), https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-was-project-mercury-58.html.
[3] Sandra May, ed., "What Was the Gemini Program?" (NASA, February 23, 2015), https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-was-gemini-program-58.html.
[4] Flint Wild, ed., "What Was the Apollo Program?" (NASA, February 24, 2015), https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-was-apollo-program-58.html.

However, this optimism for the future waned as the American public lost interest in the field and funds for exploration were rerouted to other domestic agendas. With the last moon landing in December of 1972, NASA reorientated its mission to exploring zero gravity experiments in LEO. In fact, the Skylab Project of 1973-1974 provided the US with its first space station to conduct experiments.[5] Along with the Apollo-Soyuz Joint Program in July 1975, these experiments in LEO laid the foundation for what would become the International Space Station (ISS).[6] The next phase for NASA, however, was the Space Shuttle Program which lasted from 1981-2011.[7] Though this program would involve the Challenger and Columbia disasters, NASA received invaluable experience servicing objects in LEO such as the ISS which started in 1998 with the Russian Zarya Control Module; a fact which will be important for future discussions.

Starting in the 21st century, a rekindled desire to revisit the moon and eventually reach Mars led to both the Constellation and Journey to Mars Programs wherein probes and rovers were sent to the two bodies laying the groundwork for future expeditions.[8] However, when the Space Shuttle was decommissioned in 2011, the United States became dependent on Russia's Soyuz rocket and capsule system to reach LEO. In response, the 2011 Commercial Crew Program tasked private firms to create a domestic capacity for returning to LEO and beyond.[9] Therefore, the structure of the launching market was shifted from a government sponsored monopoly to a private oligopoly with a few private firms competing for government contracts. For example, SpaceX's Dragon capsules and Falcon 9 rockets have replaced the dependency on the Soyuz and reinvigorated domestic spaceflight with other companies like Blue Origin joining the US private industry. These launch vehicles will be instrumental in modern projects such as the Artemis Program. First started in 2017, the Artemis Program plans on returning humanity to the moon in a more sustainable fashion with a Lunar Gateway space station in polar orbit and with Artemis Base Camp set up in a polar crater which is slated for completion in the coming decades.[10] Finally, in 2021 the Commercial LEO Development Program was announced that seeks to replace the role of the ISS in providing scientific space modules as well as commercial space station facilities for a burgeoning space tourism industry.[11]

Example of Private Industry Opportunities and Challenges

These remarkable developments, however, come with their own set of technical and collective challenges which yield both public and private benefits. For instance, the SpaceX Starlink program endeavors to provide internet access across specific longitudes by deploying small satellites known colloquially as CubeSats for their shape and compact size. These CubeSats have

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[5] Melanie Whiting, ed., "Skylab: America's First Space Station" (NASA, May 14, 2018), https://www.nasa.gov/feature/skylab-america-s-first-space-station.
[6] NASA Content Administrator, "The Apollo-Soyuz Mission" (NASA, April 16, 2015), https://www.nasa.gov/mission_pages/apollo-soyuz/astp_mission.html.
[7] Flint Wild, ed., "What Was the Space Shuttle? "(NASA, June 2, 2015), https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-the-space-shuttle-58.html.
[8] John F Conolly, "Constellation Program Overview" (Constellation Program Office, October 2006), https://www.nasa.gov/pdf/163092main_constellation_program_overview.pdf.
[9] Danielle Sempsrott, ed., "Commercial Crew Program Overview" (NASA, August 11, 2022), https://www.nasa.gov/content/commercial-crew-program-overview.
[10] Brian Dunbar, ed., "What Is Artemis?" (NASA, July 23, 2019), https://www.nasa.gov/what-is-artemis.
[11] Michael Johnson, ed., "Commercial Destinations Development in LEO" (NASA, March 21, 2021), https://www.nasa.gov/leo-economy/commercial-destinations.

a foldable solar panel the deploys once in orbit to provide power and form uninterrupted internet connections to the rest of the world. For example, SpaceX recently brought their Starlink program online for the Ukrainian people following the Russian invasion and subsequent destruction of critical telecommunication infrastructure.[12] By the nature of these satellites' low weight and compact size, Cubesats are easily added to other launch missions which has spurred other companies across the world to innovate and build their own. However, there are negative externalities associated with deploying so many satellites even if they are relatively compact.

Many ground-based observatories are complaining of Starlink's CubeSats ruining their data collection efforts as the light from such satellites are creating streaks in their pictures.[13] Furthermore, the public good of the clear night sky is being polluted with ever more space stations and satellites. Since there is currently no consequence for "polluting" the world's orbits with defunct satellites, Earth may eventually be subject to a Kessler Syndrome event whereby defunct and active satellites would collide and create a cascading cloud of debris destroying a sizable amount of world telecommunication infrastructure. The losses could be in the billions of dollars and destroy both commercial and military satellites bringing the world to a level of tension not seen since the Cuban Missile Crisis. To ameliorate this issue, the US Space Force is endeavoring to fund missions to deal with defunct satellites.[14]

Outer Space Treaties

Given this exploration of the modern space industry and its endemic issues have been addressed, an overview of the treaties signed by most spacefaring powers is prudent. The first treaty to delineate how countries were to conduct themselves in space was ratified in 1967 and called the "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies", also known as the Outer Space Treaty (OST). The OST guarantees that signatories will explore to benefit all of mankind without regard for how scientifically or economically developed the countries are. To encourage cooperation, every signatory is free to investigate and access all areas of space; that is to say, no country can claim sovereignty over any area of a celestial body.[15]

The second treaty, the Rescue Agreement, passed in 1968 was concerned with the rescue of astronauts in distress and will have an important role in interpreting how space tourism is to be conducted; this policy includes both assistance in space as well as international waters following the astronauts' descent.[16] Afterwards, the Convention on International Liability for Damage Caused by Space Objects passed in 1972 mandated that the country who launched an

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[12] Lerman, Rachel, and Cat Zakrzewski. "Elon Musk's Starlink Is Keeping Ukrainians Online When Traditional Internet Fails." *The Washington Post*. WP Company, March 21, 2022. https://www.washingtonpost.com/technology/2022/03/19/elon-musk-ukraine-starlink/.

[13] Emily Zhang, "SpaceX's Dark Satellites Are Still Too Bright for Astronomers," *Scientific American* (Scientific American, September 10, 2020), https://www.scientificamerican.com/article/spacexs-dark-satellites-are-still-too-bright-for-astronomers/.

[14] Sandra Erwin, "Space force eager to invest in debris removal projects" (SpaceNews, February 10, 2022), https://spacenews.com/space-force-eager-to-invest-in-debris-removal-projects/.

[15] "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies," UNODA Treaties, accessed April 19, 2022, https://treaties.unoda.org/t/outer_space.

[16] "Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space" (United Nations Office for Outer Space Affairs), accessed April 19, 2022, https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introrescueagreement.html.

object into space liable for any damages that may result but required that individuals petition their own state to sue as only states are allowed to bring cases against other states.[17] Concerns about possible damages during a Kessler Syndrome event or the more recent near collision with Chinese spacecraft and Starlink's CubeSat cluster illustrate how this treaty might be used to delineate penalties and determine guilt for damages.[18] To help prevent collisions, the Registration Convention of 1974, formally known as The Convention on Registration of Objects Launched into Outer Space, requires that all space bound objects be registered with the UN for monitoring.[19]

While these agreements have provided a limited basis for international cooperation, they lack a cohesive framework for dealing with collective action problems regarding the exploration and colonization of celestial bodies. The Moon Agreement of 1979 set out to reiterate the main points of the treaties mentioned above but also provide an executive or enforcement framework in addition to the structural framework for how disputes would be resolved.[20] However, no spacefaring countries have signed the treaty as they do not want to be constrained by the whims of an international body or be prevented from engaging in colonization efforts. Essentially, spacefaring countries have adapted provisions similar to the International Law of the Sea where they clearly benefit from the cooperation with respect to free access to all celestial bodies, liability conventions, emergency assistance, and registration of all vessels. All further agreements on duties to other nations are stipulated within smaller treaties with close partners, usually militarily allied countries.

Property Rights

Personal Property

Given the space treaties described above, there is international consensus that no specific country can fully claim territory outside the Earth's atmosphere. However, this leaves certain property rights in question. For instance, there are concerns that a company or country could collect defunct satellites and boosters, and the sensitive technologies within, by claiming "salvage" as ships do according to the International Law of the Sea.

Intellectual Property

To address the question of intellectual property, the World Intellectual Property Organization (WIPO) identified in 1997 that IP rights for spaceborne inventions may need to be delineated.[21]

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[17] "Convention on International Liability for Damage Caused by Space Objects" (United Nations Office for Outer Space Affairs), accessed April 19, 2022, https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introliability-convention.html.

[18] Andrew Jones, "China's Space Station Maneuvered to Avoid Starlink Satellites" (SpaceNews, December 28, 2021), https://spacenews.com/chinas-space-station-maneuvered-to-avoid-starlink-satellites/.

[19] "General Assembly Resolution 3235 (XXIX) ." United Nations Office for Outer Space Affairs. Accessed April 19, 2022. https://web.archive.org/web/20080328222817/http://www.unoosa.org/oosa/en/SpaceLaw/gares/html/gares_29_3235.html.

[20] Kena Alexander, Agreement governing the activities of States on the Moon and other Celestial Bodies (UNODA Treaties), accessed April 19, 2022, https://treaties.unoda.org/t/moon.

[21] "Meeting of Consultants on Inventions Made or Used in Outer Space" (World Intellectual Patent Organization, March 6, 1997), https://www.wipo.int/export/sites/www/patent-law/en/developments/pdf/inventions_space.pdf.

These concerns stem from the capacity of other nations to disregard intellectual property as no enforcement agreement exists specifically regarding space. Potentially, the WIPO could use current international agreements regarding international airspace and broadly interpret them to include earth orbits. The commonly held boundary between the atmosphere and space is referenced to be the Karman line at 100 kilometers above sea level; however, this boundary is artificial and has no scientific basis. The interpretation of what international airspace is and where it has limits will likely be discussed only when the first accusation of IP theft occurs whether this is done in orbit in a space station or in a base held by a rogue actor off on another celestial body.

Patents and Trade Secrets

Even back in the early days of commercial space aviation, NASA has provided open access to its patents through its T2-Technology transfer program. NASA has also allowed for generous cross licensing with many of its developers to spur innovation. Many of the newest technologies such as Transhub expandable habitats have been used by subsequent firms to develop their own takes on these technologies. With many former NASA employees starting up such firms, they can innovate and receive financing for projects much faster than if NASA did all the production in-house. Additionally, it is worth noting that transport companies like SpaceX are not patenting their rocket technology; instead, they are relying on trade secret protections to safeguard their inventions. In fact, most of the patents SpaceX holds are for the Starlink program and printed circuits.[22]

Recent Legislation

The US 2015 SPACE Act, the Spurring Private Aerospace Competitiveness and Entrepreneurship Act, provides the right for companies to mine resources from asteroids; however, there are no universally delineated property rights during space-based ventures.[23] Instead, the Act provided for the Artemis Accords in which other nations that are engaging in spacefaring activity with the US will respect each other's laws during those missions.[24] Similar to the US, the UK passed a Space Industry Bill in 2018, formerly known as **"**A Bill to Make Provision About Space Activities and Sub-orbital Activities and for Connected Purposes" which provides a framework agreement for their burgeoning space industry.[25]

The Philippines have also passed perhaps the most clearly delineated legislation on property rights in 2019. Their Space Act created the Philippine Space Agency (PhilSA) and a framework agreement to "license, sell or otherwise make available any patent, copyright, industrial design, trademark, trade secret or other like property controlled."[26] Making use of this

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[22] "SpaceX Started Patent Filing" (Insights by GreyB, October 25, 2021), https://insights.greyb.com/spacex-patents/.
[23] "H.R.2262 - U.S. Commercial Space Launch Competitiveness Act," accessed April 19, 2022, https://www.congress.gov/bill/114th-congress/house-bill/2262/.
[24] NASA, "The Artemis Accords," October 13, 2020, https://www.nasa.gov/specials/artemis-accords/img/Artemis-Accords-signed-13Oct2020.pdf.
[25] "Space Industry Act 2018," Legislation.gov.uk (Queen's Printer of Acts of Parliament), accessed April 19, 2022, https://www.legislation.gov.uk/ukpga/2018/5/contents/enacted/data.htm.
[26] "REPUBLIC ACT No. 11363," Article V(d) An Act Establishing the Philippine Space Development and Utilization Policy and Creating The Philippine Space Agency, and for Other Purposes, accessed April 19, 2022, https://lawphil.net/statutes/repacts/ra2019/ra_11363_2019.html.

framework, PhilSA worked with Japan, Bhutan, and Malaysia in designing, manufacturing, and launching CubeSats such as the Maya series. With the Cubesat model, future satellites for fields like communications and weather observation have become relatively inexpensive for small countries to produce and fit comfortably on rockets with extra cargo capacity like the Falcon 9.[27] Additionally, China has foregone international collaboration and created a military-civilian integrated system for space launches that blurs the line between where military security begins and civilian operations end, causing alarm for some national security analysts.[28]

The current framework of bilateral and multilateral agreements will be increasingly difficult to enforce as new countries and their domestic companies join burgeoning markets like CubeSat production. Not only will legislation and treaties need to be created and ratified but also enforcement mechanisms need to be created. Finding a balance between national interest, corporate claims, and the global space environment will be increasingly important to continue peacefully expanding the space industry.

New Sectors for Commercialization

Space Tourism

One of the most nascent sectors for commercialization is space tourism whereby civilians will be able to purchase a ticket, similar to an airplane ticket, to enjoy the thrills of low earth orbit like maneuvering in zero gravity and observing the Earth's horizon. Many celebrities and prominent business owners have reserved spots on exclusive passenger lists. Unlike normal aviation, which might be subject to a regulator like the Federal Aviation Administration, spaceflight for tourism is not yet regulated.[29] Therefore, rumblings about what this could entail for the Rescue Agreement and Liability Treaty abound. Nations and companies have a requirement to aid these ventures if they are in trouble, but these ventures are not required to have competent pilots or passengers. Additionally, the nations that launch such vehicles can be held liable for any disasters that take place.

Some of these early players include Virgin Galactic who is estimating the price of a ticket for their space plane to be around half a million dollars apiece. While Boeing has yet to fully launch a crewed Starliner capsule in a commercial venture, they are also interested in the tourism industry and have the added benefit of their capsule being compatible with Atlas V, Delta IV, Falcon, and Vulcan Rockets. SpaceX's Dragon capsules aboard their Falcon rockets may also engage in space tourism; additionally, their Starship rocket will allegedly be able to take passengers beyond LEO and commercialize fly-bys of the moon. Finally, Blue Origin is using their New Glenn rockets to bring their New Shepard modules to LEO and eventually rendezvous with their planned Orbital Reef space station.

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[27] Kristine Sabillo, "SpaceX Brings Philippines' Maya-1 Cube Satellite to ISS" (ABS-CBN News, June 29, 2018), https://news.abs-cbn.com/news/06/29/18/spacex-brings-philippines-maya-1-cube-satellite-to-iss.

[28] Mingyan Nie, "Space Privatization in China's National Strategy of Military-Civilian Integration: An Appraisal of Critical Legal Challenges," *Space Policy* 52 (March 12, 2020), https://doi.org/https://doi.org/10.1016/j.spacepol.2020.101372.

[29] Michal Pietkiewicz, "Space Tourism Law- A Brief Overview," *4th International Multidisciplinary Scientific Conference on Social Sciences and Arts SGEM2017, MODERN SCIENCE*, December 20, 2017, https://doi.org/10.5593/sgemsocial2017/12/s02.085.

Space Settlements

As mentioned above, Blue Origin is planning on creating a LEO commercial space station that will service its passengers using New Shepard modules to dock at one of its berths. The habitat itself will be designed and constructed with the help of the Sierra Nevada Corporation who also designed the Starliner spaceplane, which will be produced by Boeing. Blue Origin has termed the habitat a commercial and tourism destination designed to hold 10 individuals. Since the ISS is slated to become obsolescent in the coming decade, the Orbital Reef will provide the US and other countries a new station to conduct experiments in LEO.

To ameliorate the looming issues with the aging ISS, a company called Axiom Space plans on refurbishing modules and components within the station to make it at least partially habitable for the foreseeable future. This venture is especially relevant because the ongoing conflict between Russia and Ukraine may cause Russia to accelerate the removal of their Zarya module which was previously slated to be removed in 2024. New modules by Axiom Space can supposedly be added to maintain the functionality of existing modules until removal or the ISS degrades into an unrecoverable orbit. Before that time, Axiom plans on detaching its modules to create another space station to rival the Orbital Reef. Paralleling these private commercial enterprises, China launched the beginning modules for their Divine Palace or Tiangong Space Station in 2021. The only other nationally funded space station being planned is the Lunar Gateway space station to be placed by the US in the southern polar orbit of the Moon to serve as a supply depot and port for craft heading to Artemis Base Camp. At this basecamp, up to 4 astronauts will perform 30–60-day surveys and various habitability missions while testing equipment for base expansion and eventual Martian colonization. Not wanting to be left behind in this race, China and Russia have announced a joint International Lunar Research Station as an alternative to the US-run Artemis Program though exact specifications are scarce.

Space Mining

To construct these bases, mining regolith, suspended dust and solid rock from the Moon or asteroids, will provide the needed materials for both further financing exploration and building the expansions itself. Contrary to hyperbolic ideals of canisters of precious materials being dropped into Earth's gravity well, those harvested materials will be used instead to craft new spacecraft or expand bases in-situ (in the situation). However, material resources from mining could also be rerouted to the citizens via a dividend model like what Alaska does for its oil production.[30] In either case, expanded habitats are planned to enshroud near-earth asteroids allowing samples to be taken while preventing debris from flying out and damaging surrounding craft. Afterward, asteroids are likely to send their material to space stations in orbit around celestial bodies to have ready access to the network of facilities needed for further refinement. Additionally, the moon, functionally one gargantuan asteroid with one-sixth Earth gravity, has plenty of iron and other necessary elements to facilitate the construction or expansion of any Lunar Base. There is likely to be an expansion of companies with innovative or novel methods of processing ore; however, existing mining companies have the specialized knowledge for mining within a gravity well. Combining their specialized knowledge with smaller firms that will an

[30] Morgan Sterling Saletta and Kevin Orrman-Rossiter, "Can Space Mining Benefit All of Humanity?: The Resource Fund and Citizen's Dividend Model of Alaska, the 'Last Frontier,'" *Space Policy* 43 (February 17, 2018): pp. 1-6, https://doi.org/10.1016/j.spacepol.2018.02.002.

organic innovative growth mindset will allow for crews to perform cutting edge experiments and expansions. Therefore, lessons learned from mining the moon will likely translate into mining dwarf planets between Mars and Jupiter like Ceres, Pallas, Juno, and Vesta along with the many smaller bodies in the Main Asteroid Belt.

Concerning the specific materials, iron deposits will be harvested for structural support and fabrication of needed components. Some have even theorized that "iron can be microbially extracted from Lunar and Martian regolith simulants and 3D printed into tough structural materials".[31] Additionally, polished iron alloys can be used to reflect sunlight towards solar kilns for processing ore. With respect to water found in ice deposits, it will be not only useful for human consumption but can also be split into hydrogen and oxygen to create rocket fuel. Most of Luna's regolith is oxygen with calcium and magnesium as trace elements with the latter element being strong enough under lunar gravity to function as a usable construction material. Furthermore, silicon harvested from the regolith can be used to create semiconductors and solar cells for sustainable power generation. Rare materials may also be found in higher concentrations in asteroids compared to Earth with the lack of gravity making excavation less difficult as heavier metals cannot sink into a molten core. The unwanted elements can also be used as insulation to protect against solar radiation and micrometeorite impacts.

Conclusion

NASA laid the groundwork for the now burgeoning private space industry. By building its vehicles using a commercial bid system, private contractors were able to use the NASA T-2 technology transfer process to focus on perfecting construction processes rather than inventing a technology from scratch. These contractors would go on to form their own ventures and lay the groundwork for today's modern companies. However, modern companies such as SpaceX and Blue Origin are mostly funded by wealthy billionaires and venture capital synthesizing engineering aspirations with the means to complete such enterprises. However, all of these space ventures, with notable mention of SpaceX's Starlink program, have both created positive and negative externalities with the worst negative externality possible being the colliding of space debris that could possibly create a Kessler event that would wipe out most of the LEO infrastructure. Space policy will, therefore, need to be drafted to prevent such an event.

With regards to policy, the 20th century space treaties do not have the binding power or force to compel states to abide by their provisions; perhaps a comprehensive revision to all facets of space-based ventures could ameliorate these issues. However, because countries and companies are not likely to want international regulation and supervision, bilateral and multilateral agreements such as the Artemis Accords have replaced these universal treaties with tailored and specific agreements clearly delineating rights and responsibilities for specific missions. Additionally, very few countries have addressed property concerns, and there is a growing trend in the largest space transport providers to avoid patents and stick to trade-secret protections ostensibly to prevent their innovations from being copied. Determining how this trend in property right protections will evolve and impact the nascent space tourism, settlement expansion, and mining sectors will be of great interest for policymakers in the decades to come.

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[31] Sofie M. Castelein et al., "Iron Can Be Microbially Extracted from Lunar and Martian Regolith Simulants and 3D Printed into Tough Structural Materials," *PLOS One*, April 28, 2020, https://doi.org/10.1101/2020.11.15.382614.

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