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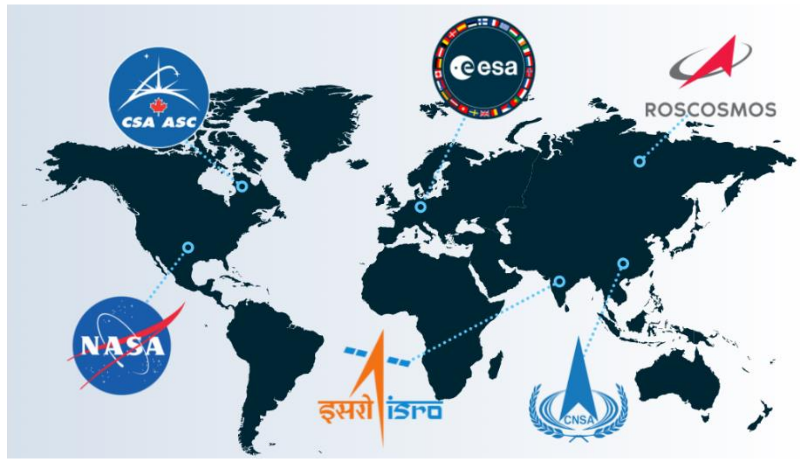
MINING ON THE MOON: POLICY PATHS FORWARD



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Executive Summary

Mining for critical resources on the moon has emerged as a new frontier in the growing competition between the U.S. and China. Helium-3 (^3He), found in much greater abundance on the moon than on Earth, is the primary driver for lunar resource extraction given its necessity for two high-priority emerging technologies: 1) nuclear fusion and 2) quantum computing. ^3He's elemental properties enable the optimization and operationalization of fusion and quantum, both of which offer capabilities of the highest caliber for their respective applications in energy efficiency and machine problem solving (cryptography, data modeling, theoretical research, drug discovery, etc.). Failure to be first in securing moon-based ^3He deposits threatens national security and undermines U.S. authority in future outer space governance and exploration.

Mining on the moon is situated in technical complexity, legal ambiguity, and high capital costs. Successful helium-3 extraction may also cause escalation between the U.S. and China that could trigger wider and deadlier conflict, perhaps even on the moon. Private companies are taking on the burden of innovation and rocket manufacturing, but without public sector support and governance, corporate monopolies of critical resources like helium-3 could disrupt global markets and undermine federal institutions and authority. The uncharted nature of lunar mining presents numerous policy avenues that serve to mitigate potential negative externalities. Regardless of what is or is not pursued, a few things are certain: clearly defined boundaries, informational transparency, and international collaboration are necessary in creating a sound political, economic, and social ecosystem for lunar mining and any future celestial endeavor.

Facets of Moon Mining

Natural Resources and In-Situ Resource Utilization (ISRU)

^3He will be the most sought-after resource given its rarity on earth (and its benefits for emerging technologies), but mining the moon encompasses a variety of critical resources that will be useful for growing industry and bolstering resource independence[i].

Rare-earth elements, minerals, and metals are used for electronics such as smartphones, computers, or medical equipment[ii] [iii]. According to the USGS, the U.S. is 100% reliant on Chinese imports of yttrium and 80% reliant on rare-earth metals and compounds (lanthanides, scandium, and so on)[iv]. The moon could be the key to achieving resource independence for these needed minerals. The mission costs of mining outweigh its opportunity cost (not mining), which is that China can exploit supply-chain vulnerabilities and harm U.S. industry necessary for economic stability and critical infrastructure[v].

ISRU, which refers to the extraction of resources on the moon to sustain lunar infrastructure, will be crucial for moon mining operations. This consists of mining water (in the form of ice) for oxygen and rocket fuel—eventually even for drinking and agriculture—or using regolith on the surface for radiation-resistant habitat construction. Silicon, metals, and fiber refinement provide utility for lunar bases and on-site scientific experimentation. The moon's extremely thin atmosphere and position towards the sun enhances the abilities of harvesting solar energy, especially given that certain materials needed to maintain it (like silicon) are on the moon. Using resources on the moon to support infrastructure should serve to embolden efforts for mining operations[vi]. The lack of ISRU application on asteroids makes it a more infeasible alternative to the moon, in addition to their lack of proximity, predictability, and available information[vii].

Costs & Benefits

The technical challenges in mining are the largest roadblock to tapping into ^{3}He's potential. One kilogram (kg) of ^{3}He costs $20 on average, as there are only 20-60 kgs distilled each year (from aging nuclear warheads) across the U.S., China, and Russia[viii]. If it cost $500 million to finance one moon mining mission, 50 kgs brought back to Earth would still yield a profit of $500 million[ix]. It is estimated that 44 tons of ^{3}He (~40,000 kgs) would be needed to meet annual electricity needs for the whole nation. Experts believe that three tablespoons of ^{3}He would generate as much power as 5,000 tons of coal, and without negative environmental impact[x] [xi]. It could take anywhere between 100,000 to 1 million tons of regolith to yield one kg of ^{3}He, but that is not unusual at least for terrestrial standards. Conveniently, three meters is the deepest point at which to dig to acquire ^{3}He on the moon which can speed up the mining process.[xii] [xiii]

Mining requires long-term operationality, which necessitates the transportation and on-site assembly of mining equipment and living infrastructure for mining personnel. Habitability itself has been a decades-long research and development project by public and private scientists alike. Thousands of variables need to be considered to support permanent residence on the moon, which means a thousand things can go wrong if not more than adequately prepared. Interlune and Magna Petra are companies whose purpose is developing mining technologies; NASA is developing rovers, robotics, and life support systems; SpaceX and Blue Origins are manufacturing rockets[xiv] [xv] [xvi]. There is a collaborative public-private movement dividing the duties of innovation to achieve this massively complex feat. NASA and Interlune plan on touching down on the moon's surface by 2027, and Magna Petra plans on a year-long capture-and-return demonstration mission on the moon in 2029, bringing back tens of kgs of ^{3}He[xvii] [xviii] [xix]. Billions of dollars may be needed, but the market is estimated to be worth nearly $10 billion by 2032[xx]. The investments will not only pay off companies but also spur greater innovation reducing the costs for ultra-high contrast MRIs, maximizing energy generation with nuclear fusion, and being able to cool quantum chips to near absolute zero[xxi].

Ambiguous Legality

International law surrounding outer space is insufficient and vague, which poses numerous problems for future moon mining efforts. There are a few widely quoted international agreements that help frame space law and conduct.

The first is the Outer Space Treaty (OST) of 1967, issued by the UN Office for Outer Space Affairs (UNOOSA)[xxii]. Its most important tenet is that outer space is "not subject to national appropriation," meaning no country *should* claim sovereign territory of any region or celestial body[xxiii]. Though, most of the OST is mired in ambiguity, like how outer space should only be used for "peaceful purposes," or whether national appropriation includes resource extraction. What are the specific constraints or factors that may lead to an action being considered unpeaceful, and can private companies mine on the moon if they do not claim territory under their government? The Rescue Agreement (1968) and Liability Convention (1972) expand on inter-state collaboration and accountability for space debris, but still only focus on state-sponsored activities[xxiv]. The last of the Cold War-era space agreements was the Moon Agreement (1979), which essentially replicates the OST (in all its vague language) but worded specifically for the moon[xxv].[1] These two decades set a strong foundation for government conduct, but it was not foreseen that private companies would have as big of a stake in space exploration and resource extraction as they do today[xxvi].

The Artemis Accords (2020) differ from these previous agreements because they were made in the age of private sector space exploration. Championed by the U.S. and currently signed by 55 other countries (not including China or Russia), the purpose and scope of these accords was to create a community of transparency, collaboration, and accountability, but ultimately legitimize (and even legalize, at least through international consensus) resource extraction in outer space[xxvii]. The U.S. and China have a mutual understanding that the first one to get there will lay down the laws of the land, or at least the global norm going forward.

Escalation Problems

Political scientists posit that war (in many cases) results from a commitment problem, which in this case revolves around the ability to maintain peaceful competition between U.S. and Chinese mining efforts. If there is equal access to ^{3}He and an equal probability that avoiding war will yield the most benefits for each side, the cost of fighting will prevent it from occurring. However, as soon as one side believes that they may no longer be able to commit themselves to peaceful negotiation, war over access to resources may be the only option despite its costliness, or perhaps because of it. Accommodating an adversary is possible if there are clear and enforceable boundaries and codes of conduct. Therefore, escalation into deadlier conflict

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[1] Only 18 countries are a part of this agreement; China, Russia, and even the U.S., are not.

because of unequal resource distribution or biased legal frameworks and treaties should not be seen as deterrent to moon mining. Rather, war may be a consequence of the absent effort to find mutually beneficial agreements[xxviii].

Implications For Policy

Scientific Idealism for an Improved Relationship with China

The Wolf Amendment in 2011 has since prevented NASA from collaborating with China's space program, the chief reason why China was not a main partner in developing the International Space Station (ISS)[xxix]. China was left out, so it made its own space station called Tiangong. With the help of Russia, they are planning to construct The International Lunar Research Station with the intention of giving the U.S. the same treatment[xxx]. The Artemis Accords are not legally binding, and enforcement of international law is generally a tricky matter. However, there is a case we can learn from that provide ideas for how to approach negotiation with China and avoid creating a zero-sum environment in space.

The Antarctic Treaty of 1961, like the OST, outlines how territory in Antarctica cannot be claimed by any nation. The primary purpose of the continent is to support global efforts for scientific research and environmental protection. A hallmark of the treaty is that research findings and collected data must be shared freely across the international community. Transparency inspires collaboration, and nothing is more galvanizing than scientific advancement for the benefit of humankind. Future space policy should not follow in the path of President Trump's Executive Order 13914, which directly challenged the accepted belief that space is a "global commons.[xxxi]" Rather, active efforts must be made to extend a partnership with Beijing on the premise of collective technological advancement and sustainable resource extraction in space to avoid war and inefficient use of resources. Efforts will need to be made initially by America to foster a standing of "good faith," which will require legislation that overturns the Wolf Amendment and a technocratic approach to diplomacy[xxxii]. Additionally, the SPACE Act (2023), if passed, would prohibit purchase of services and equipment from China, so to foster collaboration and transparency, this bill should be shut down[xxxiii].

Public-Private Sector Collaboration

Governments are restricted in ways corporations are not, and by leveraging private sector motivations and resources, international legalities can be side-stepped ultimately avoiding intense scrutiny and even escalation. In 2023, U.S. companies like SpaceX, Blue Origin, and Rocket Lab launched 117 commercial rockets into space. There are over 3,800 subcontracts under the largest space companies working in conjunction with NASA, from asteroid mining companies like AstroForge to defense contractors like Lockheed Martin or Northrop Grumman[xxxiv]. As NASA continues to experience budget cuts, and as the private space industry continues to expand and invest, legislation like the Space Resource Exploration and Utilization Act (introduced in 2015) and other bills like it should be passed. What this does is reduce bureaucratic barriers for space companies to invest, develop, and operate, and facilitate favorable economic conditions so these companies may thrive[xxxv]. Vast, a growing space company, is on track to launch the first commercial space station in 2026 called Haven-1. It is partnered with dozens of other space companies and is working with the ISS and NASA to make sure it is operable in the long term[xxxvi]. Private companies cannot achieve their aspirations on capital alone, they need coalitions with other companies, and most importantly, legislative backing by Congress and support from federal agencies and administrations. Economic papers by Sommariva et al. and Kornuta et al. performed net present value (NPV) calculations for moon mining missions and arrived at the conclusion that a public-private model generates positive NPV, whereas a private only generates negative NPV[xxxvii] [xxxviii].

International Outer Space Authority

Resources on the moon are an example of a common property resource (CPR), which is a rivalrous and non-excludable good that often is subject to being monopolized, depleted, or both[xxxix]. Companies that mine ^{3}He first will have the ability to exploit market demand for profit and supply-chain control. An independent international outer space authority that created laws and regulations on moon mining would be able to set the norm for space mining and monitor adherence to those norms without bias (ideally)[xl].[2] The Artemis Accords are a good start, but the U.S. created it and ultimately benefit the most from it because of outlined "safety zones" that were designed to partition areas for private sector mining[xli] [xlii]. To create this organization, there are several necessary considerations and/or requirements that must be outlined[xliii] [xliv]:

1) Create a **comprehensive code of conduct** that echoes the ideals and purpose of the Three Pillars of sustainability as outlined by the 1987 Brundtland Commission report, "Our Common Future[xlv]."
    a. *Environmental*: Mining should be sustainable, adaptive, and continue to mitigate climate change, not exacerbate it[xlvi].
    b. *Economic*: Resources should be allocated proportionately, governments should monitor private power, and sustainable development goals should be intrinsic to indicating mining performance.
    c. *Social*: Hazards towards humans should be accounted for and avoided to the best ability.
2) **Prevention of property rights** so that no monopolies can form and so that the international organization maintains its authority.

[2] This is like the framework laid out by the United Nations Convention on the Law of the Sea, or like the power of oversight the International Atomic Energy Agency has on power plants and uranium enrichment facilities.

3) Extending the sentiments of the Global Report Initiative sector standards and International Sustainability Standards Board standards to **reinforce transparency**.
4) **Facilitate collaboration** for stakeholders by ensuring productive channels of communication between all parties.
5) Require licensing, reporting, and monitoring of stakeholder activities to cultivate a **system of accountability and trust**.

Mining on the moon is an inevitability, and technology is advancing faster than policy can keep up. Still, it is not too late to be proactive and create policy that both secures the nation and benefits humanity with all ^{3}He has to offer.

Endnotes:

[i] Anand, M., I. A. Crawford, M. Balat-Pichelin, S. Abanades, W. van Westrenen, G. Péraudeau, R. Jaumann, and W. Seboldt. "A Brief Review of Chemical and Mineralogical Resources on the Moon and Likely Initial in Situ Resource Utilization (ISRU) Applications." *Planetary and Space Science*, Scientific Preparations For Lunar Exploration, 74, no. 1 (December 1, 2012): 42–48. https://doi.org/10.1016/j.pss.2012.08.012.

[ii] NASA Jet Propulsion Laboratory (JPL). "The Lunar Gold Rush How Moon Mining Could Work." Accessed July 14, 2025. https://www.jpl.nasa.gov/infographics/the-lunar-gold-rush-how-moon-mining-could-work/.

[iii] Mineral Resources Program. "Minerals with Net Import Reliance on China | U.S. Geological Survey," March 14, 2025. https://www.usgs.gov/media/images/minerals-net-import-reliance-china.

[iv] Mineral Resources Program. "Minerals with Net Import Reliance on China | U.S. Geological Survey," March 14, 2025. https://www.usgs.gov/media/images/minerals-net-import-reliance-china.

[v] Hedrick, G., and S. Mills. "MINING RARE EARTH ELEMENTS ON THE MOON." MITRE Corporation, 2022. https://www.hou.usra.edu/meetings/lpsc2022/pdf/2633.pdf.

[vi] Peng, Zhang, Dai Wei, Niu Ran, Zhang Guang, and Liu Guanghui. "Overview of the Lunar In Situ Resource Utilization Techniques for Future Lunar Missions | Space: Science & Technology." *Science Partner Journals* 3 (2023): 1–18. https://doi.org/10.34133/space.0037.

[vii] Peng, Zhang, Dai Wei, Niu Ran, Zhang Guang, and Liu Guanghui. "Overview of the Lunar In Situ Resource Utilization Techniques for Future Lunar Missions | Space: Science & Technology." *Science Partner Journals* 3 (2023): 1–18. https://doi.org/10.34133/space.0037.

[viii] Lafleur, Alyssa. "Scaling Lunar Helium-3 for Fusion and Quantum Tech: Insights from Jeffrey Max." *Space Insider* (blog), May 26, 2025. https://spaceinsider.tech/2025/05/26/scaling-lunar-helium-3-for-fusion-and-quantum-tech-insights-from-jeffrey-max/.

[ix] Lafleur, Alyssa. "Scaling Lunar Helium-3 for Fusion and Quantum Tech: Insights from Jeffrey Max." *Space Insider* (blog), May 26, 2025. https://spaceinsider.tech/2025/05/26/scaling-lunar-helium-3-for-fusion-and-quantum-tech-insights-from-jeffrey-max/.

[x] Einhorn, Bruce. "China, US Are in a Space Race to Make Billions From Mining the Moon's Minerals - Bloomberg." Bloomberg, May 17, 2022. https://www.bloomberg.com/news/features/2022-05-17/china-us-are-in-a-space-race-to-make-billions-from-mining-the-moon-s-minerals?embedded-checkout=true.

[xi] Simko, Thomas, and Matthew Gray. "Lunar Helium-3 Fuel for Nuclear Fusion: Technology, Economics, and Resources." *World Futures Review* 6, no. 2 (June 1, 2014): 158–71. https://doi.org/10.1177/1946756714536142.

[xii] David, Leonard. "Interlune Plans to Gather Scarce Lunar Helium-3 for Quantum Computing on Earth." *SpaceNews* (blog), January 23, 2025. http://spacenews.com/interlune-plans-to-gather-scarce-lunar-helium-3-for-quantum-computing-on-earth/.

[xiii] imko, Thomas, and Matthew Gray. "Lunar Helium-3 Fuel for Nuclear Fusion: Technology, Economics, and Resources." *World Futures Review* 6, no. 2 (June 1, 2014): 158–71. https://doi.org/10.1177/1946756714536142.

[xiv] “NASA’s First Flight With Crew Important Step on Long-Term Return to the Moon, Missions to Mars - NASA,” April 8, 2025. https://www.nasa.gov/missions/artemis/nasas-first-flight-with-crew-important-step-on-long-term-return-to-the-moon-missions-to-mars/.

[xv] David, Leonard. “Interlune Plans to Gather Scarce Lunar Helium-3 for Quantum Computing on Earth.” *SpaceNews* (blog), January 23, 2025. http://spacenews.com/interlune-plans-to-gather-scarce-lunar-helium-3-for-quantum-computing-on-earth/.

[xvi] Magna Petra. “Magna Petra | Helium-3.” Accessed July 16, 2025. https://www.magnapetra.com.

[xvii] David, Leonard. “Interlune Plans to Gather Scarce Lunar Helium-3 for Quantum Computing on Earth.” *SpaceNews* (blog), January 23, 2025. http://spacenews.com/interlune-plans-to-gather-scarce-lunar-helium-3-for-quantum-computing-on-earth/.

[xviii] Lafleur, Alyssa. “Scaling Lunar Helium-3 for Fusion and Quantum Tech: Insights from Jeffrey Max.” *Space Insider* (blog), May 26, 2025. https://spaceinsider.tech/2025/05/26/scaling-lunar-helium-3-for-fusion-and-quantum-tech-insights-from-jeffrey-max/.

[xix] “NASA’s First Flight With Crew Important Step on Long-Term Return to the Moon, Missions to Mars - NASA,” April 8, 2025. https://www.nasa.gov/missions/artemis/nasas-first-flight-with-crew-important-step-on-long-term-return-to-the-moon-missions-to-mars/.

[xx] SNS Insider. “Space Mining Market Size to Worth USD 9.15 Billion by 2032, at a CAGR of 20.68% | SNS Insider,” April 11, 2025. https://finance.yahoo.com/news/space-mining-market-size-worth-133000121.html?guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAANem_jzCs_9K_ORTtTJ7eVRkAyK8SOOIwVFggxVnKYBCwJJC-B5ySMu0ENLtZL63wbmyhMbKr1MwTL1AYuWF7fK-DMVOMoiuJDXACVcnHFyzb2wEhOgFpNBfM1gJvone0titbeFeZ5F96WWKjyLj84hFwVjZJWiYym1pIqvUYGRj&guccounter=2.

[xxi] Meyerson, Rob. “What Would the World Look Like with an Abundance of Helium-3? - Interlune,” November 13, 2024. https://www.interlune.space/blog/what-would-the-world-look-like-with-an-abundance-of-helium-3.

[xxii] Sanders, Gerald B., Julie E. Kleinhenz, and Dale Boucher. “Lunar Mining and Processing: Considerations for Responsible Space Mining & Connections to Terrestrial Mining.” Las Vegas, NV. Accessed July 16, 2025. https://ntrs.nasa.gov/citations/20230012983.
[xxiii] UNOOSA. “The Outer Space Treaty.” Accessed July 16, 2025. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html.

[xxiv] Sanders, Gerald B., Julie E. Kleinhenz, and Dale Boucher. “Lunar Mining and Processing: Considerations for Responsible Space Mining & Connections to Terrestrial Mining.” Las Vegas, NV. Accessed July 16, 2025. https://ntrs.nasa.gov/citations/20230012983.

[xxv] Sanders, Gerald B., Julie E. Kleinhenz, and Dale Boucher. “Lunar Mining and Processing: Considerations for Responsible Space Mining & Connections to Terrestrial Mining.” Las Vegas, NV. Accessed July 16, 2025. https://ntrs.nasa.gov/citations/20230012983.

[xxvi] Yee, Sarah R. “The Meteoric Rise in the Privatization of Space Meets the Dark Side of the Moon.” *California Western International Law Journal* 55, no. 2 (2025).

[xxvii] “Artemis Accords - NASA,” October 13, 2020. https://www.nasa.gov/artemis-accords/.

[xxviii] Powell, R. "War as a Commitment Problem | International Organization." *Cambridge University Press* 60, no. 1 (2006): 169–203. https://doi.org/doi:10.1017/S0020818306060061.

[xxix] Einhorn, Bruce. "China, US Are in a Space Race to Make Billions From Mining the Moon's Minerals - Bloomberg." Bloomberg, May 17, 2022. https://www.bloomberg.com/news/features/2022-05-17/china-us-are-in-a-space-race-to-make-billions-from-mining-the-moon-s-minerals?embedded-checkout=true.

[xxx] Einhorn, Bruce. "China, US Are in a Space Race to Make Billions From Mining the Moon's Minerals - Bloomberg." Bloomberg, May 17, 2022. https://www.bloomberg.com/news/features/2022-05-17/china-us-are-in-a-space-race-to-make-billions-from-mining-the-moon-s-minerals?embedded-checkout=true.

[xxxi] Yee, Sarah R. "The Meteoric Rise in the Privatization of Space Meets the Dark Side of the Moon." *California Western International Law Journal* 55, no. 2 (2025).

[xxxii] Yee, Sarah R. "The Meteoric Rise in the Privatization of Space Meets the Dark Side of the Moon." *California Western International Law Journal* 55, no. 2 (2025).

[xxxiii] Sen. Rubio, Marco [R-FL. "S.1483 - 118th Congress (2023-2024): SPACE Act." Legislation, May 9, 2023. 2023-05-09. https://www.congress.gov/bill/118th-congress/senate-bill/1483.

[xxxiv] Yee, Sarah R. "The Meteoric Rise in the Privatization of Space Meets the Dark Side of the Moon." *California Western International Law Journal* 55, no. 2 (2025).

[xxxv] Yee, Sarah R. "The Meteoric Rise in the Privatization of Space Meets the Dark Side of the Moon." *California Western International Law Journal* 55, no. 2 (2025).

[xxxvi] "Roadmap — Vast." Accessed July 16, 2025. https://www.vastspace.com/roadmap.

[xxxvii] Lee, Yeolan, and Eric A. Fong. "The Art of Living Together: Space Mining Ecosystem, Sustainability and Accountability." *Emerald Insight*, Accounting, Auditing & Accountability Journal, 37, no. 5 (2024): 1428–56. https://doi.org/10.1108/AAAJ-12-2022-6174.

[xxxviii] Sommariva, Andrea, Leonella Gori, Barbara Chizzolini, and Mattia Pianorsi. "The Economics of Moon Mining." *Acta Astronautica* 170 (May 1, 2020): 712–18. https://doi.org/10.1016/j.actaastro.2020.01.042.

[xxxix] Lee, Yeolan, and Eric A. Fong. "The Art of Living Together: Space Mining Ecosystem, Sustainability and Accountability." *Emerald Insight*, Accounting, Auditing & Accountability Journal, 37, no. 5 (2024): 1428–56. https://doi.org/10.1108/AAAJ-12-2022-6174.

[xl] Yee, Sarah R. "The Meteoric Rise in the Privatization of Space Meets the Dark Side of the Moon." *California Western International Law Journal* 55, no. 2 (2025).

[xli] "Artemis Accords - NASA," October 13, 2020. https://www.nasa.gov/artemis-accords/.

[xlii] Vega, María Fernanda Luna. "Equity on the Moon and Beyond: Legal Analysis and Proposals for Space Regulation in the 21st Century." *International Journal for Public Policy, Law and Development* 2, no. 3 (June 30, 2025): 13–17.

[xliii] Lee, Yeolan, and Eric A. Fong. "The Art of Living Together: Space Mining Ecosystem, Sustainability and Accountability." *Emerald Insight*, Accounting, Auditing & Accountability Journal, 37, no. 5 (2024): 1428–56. https://doi.org/10.1108/AAAJ-12-2022-6174.

[xliv] Vega, María Fernanda Luna. “Equity on the Moon and Beyond: Legal Analysis and Proposals for Space Regulation in the 21st Century.” *International Journal for Public Policy, Law and Development* 2, no. 3 (June 30, 2025): 13–17.

[xlv] Lee, Yeolan, and Eric A. Fong. “The Art of Living Together: Space Mining Ecosystem, Sustainability and Accountability.” *Emerald Insight*, Accounting, Auditing & Accountability Journal, 37, no. 5 (2024): 1428–56. https://doi.org/10.1108/AAAJ-12-2022-6174.

[xlvi] CBC. “How Bad Is Rocket Pollution? Fly to the Stars to Find out | CBC News,” 2025. https://newsinteractives.cbc.ca/features/2023/rocket-pollution/.