FEATURES

Galactic Gold Rush: The Promise and Perils of Mining Beyond Earth

Image courtesy of NASA, 2018

Devi Kuscer '29

Introduction

For decades, humanity has looked beyond Earth for solutions to terrestrial problems. As global warming and resource depletion intensify, worlds outside our own are viewed not as an unrealistic hope, but as a practical solution for humanity's future survival. Reserves of critical elements, such as platinum, are in short supply, causing costs to rapidly rise and directly endanger continued technological development (Andrews et al., 2015). However, the mining of these commodities often involves unethical and unsustainable practices (Iles, 2020). Space mining—often called extraterrestrial resource extraction (ERE)—has the potential to alleviate the Earth of these problems through harvesting materials like water, gold, and platinum from extraterrestrial bodies.

However, this ambitious project is accompanied by a steep ethical cost. Pristine extraterrestrial environments could become polluted, and nations or corporations with the greatest wealth could monopolize the industry, leading to an even larger wealth gap. Given the long history of global exploitation—such as the destruction of around 20% of the Amazon rainforest —is it possible for ERE to avoid propagating humanity's terrestrial mistakes beyond Earth?

The Feasibility and Current Targets of ERE

Due to the high costs of launching space missions, space mining remains a purely theoretical endeavor. For example, NASA's recent OSIRIS-Rex mission to the asteroid Bennu, which collected and returned a sample of the asteroid's surface, cost around $1.16 billion (Cost of OSIRIS-REx, 2020). However, the increase in the amount of material collected from celestial bodies signifies major developments in ERE technology. Nevertheless, these missions have yet to return with samples large enough to make space mining commercially viable.

A difficulty with making space mining feasible is the high upfront cost stemming from the development and launch of custom-built spacecraft, with one model estimating the total cost of a mission to the main asteroid belt at around $100 billion (Probst et al., 2019). This problem could be addressed through innovative approaches aiming to increase the rate of material return to Earth, such as the utilization of smaller, mass-produced spacecrafts, which would both increase the processing rate of mined materials and reduce the development costs of missions (Calla et al., 2018).

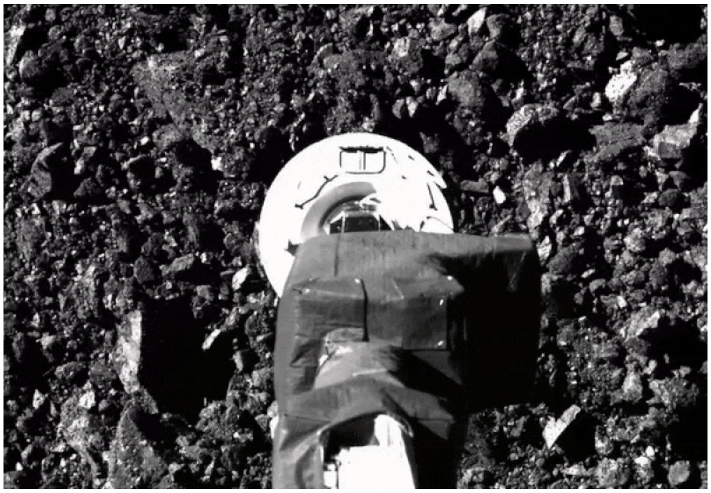

Figure 1. OSIRIS-Rex collecting a sample of the surface of Bennu (NASA/Goddard/University of Arizona, 2020)

Additionally, the chosen resource and its intended market destination play a large role in the terrestrial success of ERE. For asteroid-mined platinum group metals (PGMs) to become practical, their quantity must be substantial enough to substitute an equivalent amount of terrestrial material—over 100,000 tons of platinum. Thus, at present, the most economically viable path appears to be mining volatiles—such as water and ammonia— for astronaut use at mission destinations instead of transporting supplies from Earth, a process referred to as In Situ Resource Utilization (ISRU) (NASA, 2023a).

ISRU is a principal objective of NASA's Artemis III mission, which is scheduled to return people to the moon by 2027. By sustaining the mission's crew through ISRU, space exploration would become far more efficient and cost-effective (NASA, 2023b). The development of technology used for this purpose also marks a crucial step in ERE, as it could potentially be adapted for future metal-focused extraction.

A major milestone in ERE came in 2023, when the OSIRIS-Rex spacecraft collected and returned a 121.6 gram sample of Bennu's carbon-rich surface—the largest amount of space material brought to Earth to date (Gaskill, 2025). This record-breaking sample demonstrates the potential for the production of goods with space-mined resources. For example, catalytic converters, a crucial component of vehicles which convert toxic exhaust fumes into less harmful substances, require just 3–7 grams of platinum per unit, meaning that even the small sample from Bennu could supply multiple converters (APMEX, 2023). By adapting mission design to return larger quantities of material, the industry is demonstrating clear progress towards a scalable future.

Potential candidates for the mining of Earth-rare metals have already been identified. Asteroid 1986DA is four times closer to the Earth than Bennu, and has been estimated to contain nickel, iron, cobalt, and platinum in amounts exceeding terrestrial supplies. If Asteroid 1986DA were mined and the extracted metals sold over 50 years, they could potentially be worth around $11.65 trillion (Sanchez et al., 2021). This high profit showcases the allure of the industry despite current setbacks.

Current and Potential Legal and Governmental Challenges Regarding ERE

The pursuit of space mining is currently complicated by a significant legal vacuum and increasing geopolitical conflict over ownership. The foundational 1967 Outer Space Treaty (OST) established a legally gray area: although it strictly forbids claims of sovereignty over celestial bodies by any single nation, it does not discuss the exploitation of extraterrestrial resources by private companies (UNOOSA, 1966). As a result, nations could take advantage of this ambiguity by using private companies as a legal bypass to indirectly establish extraterrestrial monopolies. Although newer frameworks have attempted to establish principles that account for modern problems, they come with their own limitations.

Some countries have already begun to adapt to the age of the commercial exploitation of space. The U.S. (US Congress, 2015) and Japan (Japanese Law Translation,

Figure 2. Animation of Artemis explorers on the Moon (NASA, 2025)

2021) have passed domestic laws that grant their national companies legal rights over the resources they extract in space. This action essentially bypassed the communal spirit of the OST by granting rights to space resources to private companies rather than the nation, thereby creating a dangerous legal precedent where access to and ownership of valuable resources like water and precious metals are determined by national jurisdiction rather than international consensus. Moreover, the potential for individual profit is equally large: American astrophysicist and public educator Neil deGrasse Tyson has predicted that "the first trillionaire there will ever be is the person who exploits the natural resources on asteroids" (Kramer, 2015). Tyson's statement contrasts the values of the OST, which presented space as "a common heritage of mankind," and further highlights the concern with how mined resources should be divided.

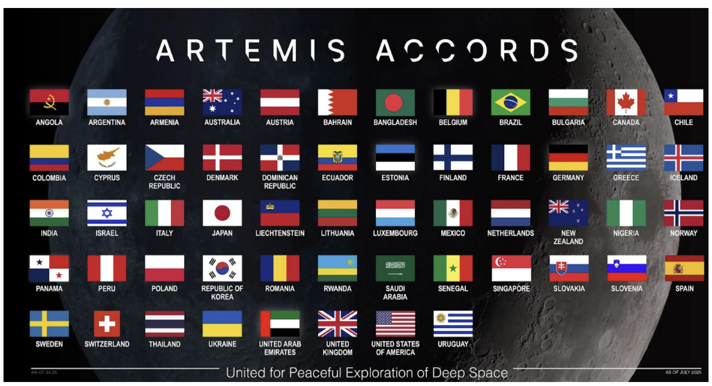

Figure 3. Signatory countries of the Artemis Accords (NASA, 2025)

The Artemis Accords, a non-binding agreement established in 2020, attempts to alleviate these concerns by providing a set of principles to further govern humanity's behavior in space (NASA, 2020). The framework, signed by 56 nations, explicitly states that resource extraction does not constitute a nation claiming ownership of a part of outer space, therefore ensuring that ERE does not go against the laws set by the OST. The accords also introduce the concept of "safety zones" —areas where signatories must provide notification of their activities and commit to coordination to avoid harmful interference. Such zones would allow for increased transparency and would lessen the possibility of conflict. However, as the framework is not legally binding, nations are not obligated to follow through on their commitments. Moreover, nations with major stakes in the space industry, such as Russia and China, have not signed the Accords, arguing that the agreement is too "US-centric" (Gross, 2023). Russia, in particular, has criticized the agreement's stance on ERE, comparing it to a form of colonialism. Sergei Savelyev, deputy head of international cooperation at Roscosmos, stated: "There have already been examples in history when one country decided to start seizing territories in its own interests and everyone remembers how that turned out." (Times, 2020). Such remarks make us beg the question of whether the accords will genuinely limit the monopolization of space resources, or whether they will encourage it.

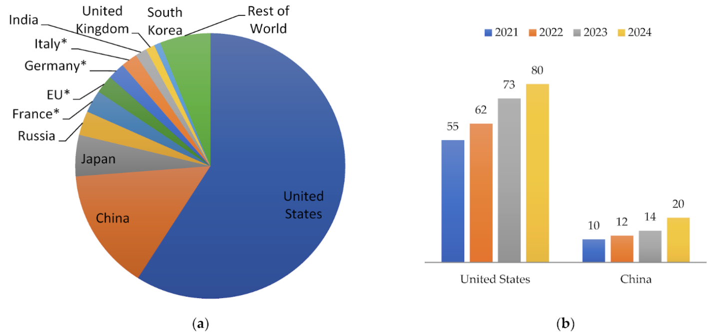

Figure 4. Government spending on space programs in billions of dollars. a) global distribution, b) comparison of US and China (Pietrzak, 2025)

Ethical, Environmental, and Equity Issues

Although space mining offers a solution to the pollution of the Earth's environment, it also has the potential to cause irreversible harm to extraterrestrial environments. Unregulated mining operations outside the Artemis Accords and the OST could introduce terrestrial contamination and create significant debris, destroying pristine environments that could be highly informative for scientific research on our solar system Nelken-Zitser, 2025).

Another major ethical dilemma centers around who will benefit from the vast wealth of space. Unchecked resource utilization risks mirroring historical colonial exploitation, where powerful nations or wealthy corporations gain riches while developing countries are excluded (Rivkin et al., 2021). Nations with successful space programs—such as the US, Japan, and China—as well as private companies involved in space exploration have a clear advantage in ERE over developing countries without an established space sector, such as Bangladesh or Rwanda (Central Intelligence Agency, 2023). The concentration of spacefaring technology among only a few nations and corporations means that, by default, these entities would be the first to establish mining claims, further inhibiting the ability of developing nations to establish themselves in the global space industry (Kirby, 2024). Without robust, globally mandated safeguards, such as an unbiased global authority that oversees extraterrestrial activities, global inequality could widen as space becomes a new source of wealth for the privileged few rather than the common heritage of all mankind.

Conclusion

Space mining offers the potential for the expansion of human development both on and beyond Earth. It promises a sustainable and highly profitable source of vital materials and a way to cut the costs of exploration; however, the question of whether humanity's destructive behaviour is eliminated completely or simply shifted to the realm of outer space remains unanswered.

Despite its exciting implications, commercial-scale extraction likely remains decades away. Costs are too high, current technology is underdeveloped, and humanity has yet to even return to the moon. However, real progress is constantly being made. NASA's Artemis III mission aims to drastically increase humanity's presence in space, and with the depletion of Earth's critical resources, the space-mining industry is expected to reach more than $23 billion by 2040 (Mordor Intelligence, 2025). These projections highlight humanity's determination to continue exploring the cosmos, expanding our reach far beyond Earth, and establishing ourselves as a true space-faring species.

References

Andreas Makoto Hein, Robert Matheson, Dan Fries. A Techno-Economic Analysis of Asteroid Mining. International Astronautical Congress 2018, Oct 2018, Bremen, Germany. ffhal-01910095f.

Andrews, D. G., Bonner, K. D., Butterworth, A. W., Calvert, H. R., Dagang, B. R. H., Dimond, K. J., Eckenroth, L. G., Erickson, J. M., Gilbertson, B. A., Gompertz, N. R., Igbinosun, O. J., Ip, T. J., Khan, B. H., Marquez, S. L., Neilson, N. M., Parker, C. O., Ransom, E. H., Reeve, B. W., Robinson, T. L., & Rogers, M. (2015a). Defining a successful commercial asteroid mining program. *Acta Astronautica*, 108, 106–118. https://doi.org/10.1016/j.actaastro.2014.10.034.

APMEX. (2023, August 16). *How Much Platinum is in a Catalytic Converter?* - APMEX. APMEX. https://learn.apmex.com/answers/how-much-platinum-is-in-a-catalytic-converter/.

Calla, P., Fries, D., & Welch, C. (2018). *Asteroid mining with small spacecraft and its economic feasibility.* https://doi.org/10.48550/arxiv.1808.05099.

Calla, P., Fries, D., & Welch, C. (2019). Asteroid mining with small spacecraft and its economic feasibility. *ArXiv:1808.05099 [Astro-Ph]*. https://arxiv.org/abs/1808.05099.

Central Intelligence Agency. (2023). *Space agency/agencies* . Cia.gov. https://www.cia.gov/the-world-factbook/about/archives/2023/field/space-agency-agencies

Cost of OSIRIS-REx. (2020, August 7). The Planetary Society. https://www.planetary.org/space-policy/cost-of-osiris-rex.

Gaskill, M. (2025, August 22). *NASA's Bennu Samples Reveal Complex Origins, Dramatic Transformation.* NASA Science. https://science.nasa.gov/missions/osiris-rex/nasas-bennu-samples-reveal-complex-origins-dramatic-transformation/.

Gross, M. (2023, January 27). *The Artemis Accords: International Cooperation in the Era of Space Exploration.* Harvard International Review. https://hir.harvard.edu/the-artemis-accords/.

Iles, A. M., Alastair. (2020). *HYLE 26-1 (2020): The Ethics of Rare Earth Elements Over Time and Space.* Www.hyle.org. https://www.hyle.org/journal/issues/26-1/martin.htm,

Japanese Law Translation. (2021, December 23). *Act on the Promotion of Business Activities for the Exploration and Development of Space Resources - English - Japanese Law Translation.* Www.japaneselawtranslation.go.jp. https://www.japaneselawtranslation.go.jp/en/laws/view/4332/en.

Kirby, H. (2024). *Spring 2024 Comment International Space Law in a New Space Age: What Laws Will Regulate Space Mining and NASA's Gateway Program? International Space Law in a New Space Age: What Laws Will Regulate Space Mining and NASA's Gateway Program?* https://www.smu.edu/-/.media/site/law/students/law-journals/spring-2024-comments/kirby_final.pdf.

Kramer, K. (2015, May 3). *Neil deGrasse Tyson Says Space Ventures Will Spawn First Trillionaire.* NBC News. https://www.nbcnews.com/science/space/neil-degrasse-tyson-says-space-ventures-will-spawn-first-trillionaire-n352271.

Mordor Intelligence. (2025, November 7). *Space Mining Market Report | Industry Analysis, Size & Forecast Overview.* Mordor Intelligence. https://www.mordorintelligence.com/industry-reports/space-mining-market-industry.

NASA. (2020). *THE ARTEMIS ACCORDS PRINCIPLES FOR COOPERATION IN THE CIVIL EXPLORATION AND USE OF THE MOON, MARS, COMETS, AND ASTEROIDS FOR PEACEFUL PURPOSES.* https://www.nasa.gov/wp-content/uploads/2022/11/Artemis-Accords-signed-13Oct2020.pdf?emrc=68f31bd19f945.

NASA. (2023a, July 26). *Overview: In-Situ Resource Utilization - NASA.* NASA. https://www.nasa.gov/overview-in-situ-resource-utilization/.

NASA. (2023b, September 30). *In-Situ Resource Utilization (ISRU) - NASA.* Nasa.gov. https://www.nasa.gov/mission/in-situ-resource-utilization-isru/.

Nelken-Zitser, J. (2025, February 25). *Moon mining could net billions, but astronomers say it's bad for science.* Business Insider. https://www.businessinsider.com/mining-moon-minerals-lucrative-bad-news-science-research-astronomists-2025-2.

Pietrzak, M. (2025). Economic and Social Aspects of the Space Sector Development Based on the Modified Structure–Conduct–Performance Framework. *World, 6(2), 79.* https://doi.org/10.3390/world6020079

Probst, A., Nitzl, C., Kraus, F., & Förstner, R. (2019). Cost Estimation of an Asteroid Mining Mission using Partial Least Squares Structural Equation Modelling (PLS-SEM). *Acta Astronautica, 167.* https://doi.org/10.1016/j.actaastro.2019.07.032.

Rivkin, A., Milazzo, M., Venkatesan, A., Frank, E., Vidaurri, M. R., Metzger, P., & Lewicki, C. (2021). Asteroid Resource Utilization: Ethical Concerns and Progress. *Bulletin of the AAS, 53(4).* https://doi.org/10.3847/25c2cfeb.173706d5.

Sanchez, J. A., Reddy, V., Bottke, W. F., Battle, A., Sharkey, B., Kareta, T., Pearson, N., & Cantillo, D. C. (2021). Physical Characterization of Metal-rich Near-Earth Asteroids 6178 (1986 DA) and 2016 ED85. *The Planetary Science Journal, 2(5), 205.* https://doi.org/10.3847/psj/ac235f.

Times, T. M. (2020, April 7). *Russia Compares Trump's Space Mining Order to Colonialism.* The Moscow Times. https://www.themoscowtimes.com/2020/04/07/russia-compares-trumps-space-mining-order-to-colonialism-a69901.

UNOOSA. (1966, December 19). *Outer Space Treaty.* United Nations Office for Outer Space Affairs. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html.

US Congress. (2015). *H.R.2262 - 114th Congress (2015-2016): U.S. Commercial Space Launch Competitiveness Act.* Congress.gov. https://www.congress.gov/bill/114th-congress/house-bill/2262.