Water Beyond Earth : Space Resource Extraction, Helium-3 and the Future of Energy-Water Security

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ABSTRACT

The growing demand for water, energy, and critical minerals has encouraged governments and private companies to explore resources beyond Earth. Recent advances in lunar exploration, asteroid prospecting, and space resource technologies have transformed outer space from a domain of scientific exploration into a potential source of strategic resources. Among these resources, water occupies a uniquely important position. Lunar water ice can support human habitation, sustain industrial activities, and be converted into hydrogen and oxygen for rocket fuel. At the same time, asteroids and celestial bodies may contain minerals essential for renewable energy technologies and future industrial development. This article examines the emerging relationship between space resource extraction, water security, and energy transitions. It analyses the role of in-situ resource utilization (ISRU), the strategic significance of lunar water, the prospects of helium-3 and asteroid mining, and the implications of extraterrestrial resources for terrestrial sustainability. The article argues that water will likely become the foundational resource of the future space economy and that developments in space resource utilization may reshape long-term energy systems, industrial supply chains, and global approaches to sustainable development.

Keywords *: Space Resource Extraction; Lunar Water; In-Situ Resource Utilization (ISRU); Energy Security; Space Mining; Helium-3; Water-Energy Nexus; Sustainable Space Development.*

1. INTRODUCTION

Natural resources have largely been seen as terrestrial resources throughout human history. Extraction of water, minerals, hydrocarbons, and other energy sources from the Earth's crust has facilitated economic development, industrialization, and human well-being. However, the advent of the twenty-first century has heralded a new frontier in natural resource management. Development in space technology, reduction in the cost of space missions, and geopolitical motivations for space exploration have brought the issue of extraterrestrial mining to the fore. What once belonged to the realm of fantasy is fast becoming a reality. NASA geologist Harrison Schmitt, the last human to walk on the Moon during the Apollo 17 mission in 1972, has long argued that humanity's return to the lunar surface is not merely a matter of exploration but of economic and strategic necessity. In his influential book Return to the Moon, Schmitt presented a compelling vision of the Moon as a repository of resources that could transform Earth's future energy landscape.[1] Central to this vision is Helium-3 (^3He), a rare isotope believed to exist in significant quantities within the lunar regolith.[2] Helium-3 has attracted considerable attention as a potential fuel for future nuclear fusion reactors.[3] Unlike conventional nuclear fuels, it is non-radioactive and promises the possibility of clean, low-carbon energy generation with minimal radioactive waste. The NASA study conducted in 1988 revealed the possible application of helium-3 in advanced fusion technology, while further scientific studies have pointed to it as one of the most prospective sources of energy outside our planet.[4] Despite the fact that the creation of fusion technology is still experimental, and many difficulties exist in creating and controlling fusion reactions, the development of fusion energy receives enormous attention from investors and organizations.

The concept of energy production through fusion processes in deuterium and helium-3 is a fascinating approach and serves as an example of how energy could be produced in a different manner and would play a critical role in solving the problem of decarbonization of the Earth.[5] Having considered all the efforts made by States in order to meet their climate responsibilities and reach net zero in the nearest decade, outer space becomes an increasingly relevant part of the discussion about the energy future of humankind. This is illustrated by considerable investments in the field of exploration and exploitation of space by a number of countries capable of utilizing the space for such purposes. Interest in the use of space resources is driven not only by scientific motivation. On the contrary, the necessity to search for alternative resources, guarantee energy security, sustain technological leadership, and ensure sustainability becomes quite urgent.[6] In addition, it should be noted that the topic discussed here is far

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beyond space exploration issues. Firstly, it is obvious that the problem of energy sources is closely related to that of water resources. Thus, energy will be needed for water extraction, treatment, transport, and distribution while no energy sources can be made without water. This type of relationships between resources is referred to as the water-energy nexus. With the emergence of novel space activities, there will be opportunities for expanding the water-energy nexus off-Earth as well. Water in lunar environment can be exploited as an energy resource supplying hydrogen and oxygen, and minerals in space may prove instrumental in creating renewable energy resources in the future. This paper discusses the connections arising between space resources, water resources, and energy considerations. To start with, water is regarded as the most valuable resource in the initial stages of exploiting space resources.

1.1. Water as the First Strategic Resource in Space

Out of all the resources found on heavenly objects, water has proven to be the most strategically important one. In the last twenty years, various scientific expeditions have found ample proofs regarding the existence of huge amounts of frozen water at polar areas of the moon.[7] These areas have been deprived of sunlight for billions of years and thus store reserves of frozen water that could be extracted in the future. The finding of water on the moon has completely changed its strategic significance.[8] Back in the Apollo age, the moon was seen as a useless place that offered little benefit except research purposes. Water has several qualities that make it more useful than other space materials. First, it is indispensable for human survival. Future lunar habitats, scientific stations, and industrial facilities will require reliable supplies of potable water. Second, water can support agricultural and life-support systems necessary for long-duration missions. Third, and perhaps most importantly, water can be separated into hydrogen and oxygen through electrolysis. These elements are among the most efficient chemical propellants currently used in space transportation. Consequently, lunar water represents more than a consumable resource. It functions simultaneously as a life-support resource, an industrial input, and an energy carrier. This multifunctionality explains why water has become central to contemporary plans for lunar exploration and settlement.

1.2. In-Situ Resource Utilization and the Production of Energy in Space

The process of extraction of space resources may be broadly classified into two types based on the place where the space resources extracted would be utilized. One of these involves the ISRU, whereby resources are mined and utilized for subsequent in-space activities.[9] For example, some space resource architectures intended to aid in future missions to the moon involve mining resources from the moon to develop fuel for other moon missions. The other type involves the mining of resources for use on earth.[10] For example, mining asteroids for precious metals, such as platinum and rhodium, to sell on Earth falls within this category. The concept of ISRU lies at the heart of contemporary space resource strategies. ISRU refers to the extraction and utilization of local resources at a destination rather than transporting supplies from Earth.[11] The economic rationale for ISRU is compelling. Launching materials from Earth remains expensive despite significant reductions in launch costs achieved by reusable launch systems. Moving any mass to outer space is very costly due to its energy and infrastructure needs. Transporting any spacecraft far away from earth becomes very expensive due to increased fuel requirements and operational complexity. Making use of natural resources available there will significantly decrease these expenses. Water obtained from the surface of the moon can be transformed into hydrogen and oxygen to act as propellant for spacecraft in the cis-lunar space. This technology would make it possible to build refueling stations, fuel depots, and even transportation systems beyond the orbit of earth. Several organizations are researching ISRU technologies. The Artemis program by NASA recognizes the importance of resource utilization in the process of exploring the moon. The same applies to other organizations like ESA and JAXA. Implementation of ISRU will bring about a paradigm change in space logistics. Instead of moving all the supplies from the earth, future explorations will have local access to essential supplies. In this regard, lunar water acts as an energy source that supports transportation, habitation, and industry.

2. SPACE RESOURCES AND THE FUTURE OF THE GLOBAL ENERGY TRANSITION

Apart from water, celestial bodies can potentially hold large amounts of minerals that have importance for the energy transition happening right now. There is evidence suggesting that asteroids and planets may have deposits of nickel, cobalt, platinum group elements, rare earth elements, and many more minerals that have been crucial to the development of renewable energies. With the transition toward low-carbon energies, there has been an exponential increase in the need for strategic minerals. Renewable energies such as electric cars, batteries, wind turbines, photovoltaic solar cells, and hydrogen require vast amounts of these minerals.[12] In the case of asteroids, in particular, much interest has been generated since some of them appear to have concentrations of precious metals that far exceed the levels contained on Earth. Metallic asteroids have concentrations of platinum group metals that are higher than those typically found on Earth. While significant challenges exist at present, the theory is that space mining would be able to complement terrestrial mining at some point in the future. As mentioned earlier, the applicability of space resources to energy transitions goes beyond the concept of space mining. Some of the technologies that can be developed as part of space mining can end up being useful on Earth – even within the renewable energy sector. Thus, while there is much uncertainty in terms of economic viability, investments made in space resource technologies can be profitable outside of space too.

2.1. Helium-3 and the Prospect of Future Energy Systems

Among proposed extraterrestrial resources, helium-3 occupies a unique position in discussions of future energy systems. Helium-3 is a rare isotope deposited on the lunar surface through billions of years of exposure to solar wind. Interest in helium-3 stems primarily from its potential role in nuclear fusion. Fusion energy is often described as the ultimate clean energy source because it promises enormous energy output with relatively limited radioactive waste. Some fusion concepts suggest that helium-3 could serve as an attractive fusion fuel because of its favourable reaction characteristics. Advocates have therefore proposed the Moon as a future source of helium-3 for terrestrial energy generation. Estimates suggest that substantial quantities may be embedded within lunar regolith, potentially offering a long-term energy resource.[13] Notwithstanding these opportunities, helium-3 must be treated cautiously. The process of developing commercially-viable fusion is still ongoing, and there are no operating fusion power plants that run off a cycle of helium-3. Moreover, the extraction, processing, transportation, and utilization of helium-3 would necessitate technological abilities that have yet to be developed on a commercial level. As such, helium-3 must be considered less an energy solution than a future strategic resource of greater importance if fusion processes prove viable down the line.

2.2. Sustainability Beyond Earth

The potential for accessing resources from outer space will necessarily bring about issues concerning the sustainability of such actions. Proponents of space exploration have pointed out that it is possible to alleviate strain on the planet's environment through the utilization of outer space resources.[14] This is because the harvesting of resources from the moon, for example, will supplement the available terrestrial mineral supplies and also help to decrease harmful mining practices. These views are more valid given the increasing need for batteries, renewable energies, and technologies. In this case, meeting this growing demand using outer space resources could potentially ease the burden on Earth's environmental resources. Nevertheless, resource extraction from outer space also creates concerns due to the potential for alteration of the extraterrestrial environments, production of space debris, and other sustainability issues. It is therefore important that sustainability continues to be a guiding principle when developing frameworks for managing space resources. The objective should not be the replication of historical extractive models but the development of responsible and sustainable frameworks capable of balancing economic opportunity with environmental stewardship.

3. GOVERNANCE AND INTERNATIONAL COOPERATION

While advances in the technologies involved in space resource mining have outpaced the development of laws and institutions governing them, international laws consider outer space as a place that can be explored and exploited freely by any state. However, despite its recognition of outer space as a freely usable area, there are still many disputes over ownership and exploitation of these extraterrestrial resources. Some current projects aimed at clarifying some aspects of space resources utilization include Artemis Accords that encourage transparency and cooperation among member states.[15] The contemporary resurgence of interest in the Moon is therefore driven not only by scientific ambition but also by economic and geopolitical considerations. While the United States and Russia once dominated space exploration, a broader group of States, including Luxembourg, Japan, the United Arab Emirates, and India, have adopted policies aimed at capitalising on the opportunities presented by the commercial space sector. Amongst all celestial bodies, the Moon continues to occupy a uniquely strategic position because of its proximity to Earth and its potential resource wealth. Recent space missions illustrate this renewed focus. NASA's Artemis programme represents the first sustained effort to return humans to the lunar surface since Apollo 17 and is intended to establish the foundations for long-term lunar exploration and eventual missions to Mars. Likewise, India's Chandrayaan-3 mission demonstrated the country's growing capabilities in lunar exploration and reinforced its status as an emerging space power.[6] These programmes are supported by substantial public investment and increasingly involve private-sector participation. However, alongside technological advancements and economic aspirations, important questions arise regarding the legal framework governing the exploration and exploitation of lunar resources[17].

However, the provisions of the treaty are still the subject of debate, especially in relation to the ownership and utilization of resources from the moon. Article 4 asserts that the exploration and use of the Moon will be "the province of all mankind" whereas Article 7 imposes some obligations concerning protection of the environment. Most importantly, Article 11 of the Agreement asserts that "the Moon and its natural resources are the common heritage of mankind." This clause has been the center of contemporary debates surrounding commercial extraction of resources in outer space. The controversy related to the Article 11 provision can be explained through reference to the principle of non-appropriation stipulated under Article II of the 1967 Outer Space Treaty. According to this Article, outer space, the Moon, and other celestial bodies are not subject to national appropriation by claims of sovereignty, occupation, use, or by any other means. While the principle of sovereignty has been clearly prohibited by the Treaty, there is some ambiguity in terms of property rights over extracted resources. This ambiguity has provided room for various interpretations. For instance, none of the states that are actively involved in the commercial exploitation of space resources have ratified the Moon Agreement. Rather, many states have legislated domestically to grant ownership rights to space resources. This includes the United States, which was the first country to do so with the passing of the Commercial Space Launch Competitiveness Act of 2015.[18] The act stipulates that

United States citizens undertaking any commercial activity involving the exploitation of space resources have the right to own, transport, utilize, and sell those resources according to relevant law.

Executive Order 13914 issued by the US government in April 2020 stated that Americans have the legal rights to commercially explore, recover, and utilize resources located in outer space. The Executive Order did not accept the idea that the Moon should be treated as a "global commons." The US has also dismissed the Moon Agreement, stating that the latter is not a part of customary international law at all. This approach greatly encouraged the efforts of commercial organizations like Planetary Resources and Deep Space Industries to mine resources on space objects. Other countries took almost the same line. Luxembourg adopted the Law on the Exploration and Use of Space Resources in 2017, proclaiming the fact that space resources can become privately owned property. The same thing happened in Japan and the United Arab Emirates. In India, where there is no proper national space legislation yet, the Indian Space Policy of 2023 is applicable. Clause 4(13) recognises "the right of non-governmental entities engaged in the commercial recovery of asteroid or space resources to possess, own, transport, use, and sell such resources, subject to India's international obligations."[19]

Perhaps the most significant geopolitical development in this area has been the emergence of the Artemis Accords. Developed by NASA and the United States Department of State, the Accords constitute a non-binding framework intended to guide civil space exploration and utilisation in the twenty-first century. Grounded in the principles of the Outer Space Treaty, the Accords seek to establish common norms relating to transparency, interoperability, emergency assistance, heritage preservation, and resource utilisation. The Accords represent the first major international initiative on space governance since the adoption of the Moon Agreement.[20] Their rapid expansion reflects a renewed global interest in shaping the legal and political architecture of outer space. By October 2024, forty-five countries had joined the Accords, signalling growing support for a cooperative framework governing civil space activities. The Artemis Accords remain controversial. Critics argue that the framework was developed largely under United States leadership without broad multilateral negotiation and therefore risks creating the perception of unilateral norm-making. As support for the Accords grows, an increasing number of States may adopt domestic legislation that facilitates commercial resource extraction and aligns with the principles embodied within the Accords. At the same time, these developments have undoubtedly contributed to the expansion of the commercial space sector. Space resource activities are increasingly viewed as a critical component of a future trillion-dollar space economy.

NASA has already awarded contracts to several companies, including Lunar Outpost, Masten Space Systems, and ispace Japan, to collect lunar material and transfer ownership to the agency. Such initiatives represent important precedents in the practical implementation of space resource utilisation. Meanwhile, Russia and China have emerged as the principal critics of the Artemis framework and have deepened cooperation through joint lunar initiatives. China has expressed concern regarding the concept of "safety zones" contained within the Accords, while Russia has characterised the framework as excessively American-centric.[21] Both States have questioned whether the Accords constitute an attempt to establish new norms outside existing multilateral processes. The Artemis Accords are increasingly taking shape as a new Washington consensus on space governance.[22] While there have been many developments on the front of national laws and business ventures that have sped up the rate of development in this field, they have also posed certain concerns about the future of international law. These practices together might eventually weaken the normative impact of the Moon Agreement and transform notions of property, usage, and regulation in outer space. Without any internationally recognized mechanism for governance, there is ambiguity for both state actors and private companies. Property claims, environmental protection, dispute settlement, benefit-sharing, and regulation are some areas that need to be clarified through international collaboration. The future success of space resource activities rests not only on technological advancement but also on establishing effective governance.

4. CONCLUSION

The nascent space economy will radically alter existing concepts regarding natural resources, energy security, and sustainability. Although media coverage tends to concentrate on the concept of asteroid mining and unprecedented amounts of minerals available, water may turn out to be the most crucial resource during the first stages of the utilization of natural resources in outer space. The unique property of lunar water is its ability to serve human life support systems, industries, and energy supply. The use of ISRU technologies could enable humanity to make water a key element of a future cis-lunar economy based on fuel production, transportation, and sustained human presence away from Earth. Nevertheless, the search for new resources, particularly asteroids and their minerals, and other potential energy sources like helium-3 can become part of a future energy transition and economic development. Despite the existence of numerous technological, economic, and policy-related barriers, today's direction of space programmes seems to indicate the importance of resource utilization for space exploration. It appears that the connection between water and energy may go beyond the boundaries of Earth in the near future.

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Nothing is softer or more flexible than water, yet nothing can resist it