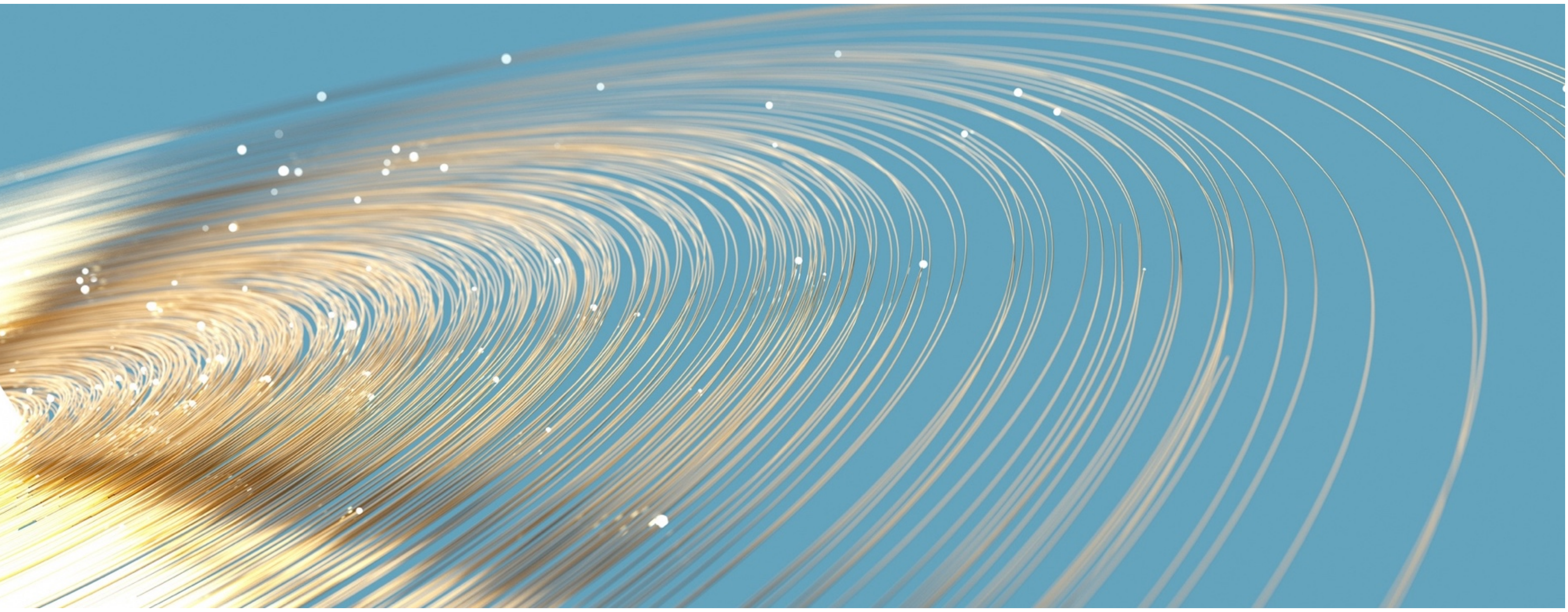

PULSE | July 2024

Space Resources – the Potential for Hydrogen

CONTENTS

01 Why you should care

02 What you need to know

03 Examples in motion

04 Where is the pulse heading?

05 Final word

Author: **Richard Sear,** Managing Partner

Why you should care

I recently saw an incredible video showing the massive number of SpaceX[1] rocket launches from Cape Canaveral between 2010 and 2023. It was dazzling to see a few launches a year, growing to a few a quarter, to a few a month, to now weekly. Our journey into space has already reached escape velocity, and it represents not only a pursuit of knowledge but also the opportunity to establish a sustainable presence beyond Earth. Despite its desolate appearance, the moon, with its proximity and resources, is a key focus in this new time of space exploration. Recent discoveries have confirmed the presence of hydrogen[2], primarily in the form of water ice at lunar poles, which has, in turn, received considerable interest from governments and corporations. The abundance of this element could be the anchor needed for lunar colonization, providing life support and fuel to drive increased exploration, and transforming our own energy consumption patterns back here on Earth.

For industries related to aerospace, materials, mining, energy, and technology, the presence of hydrogen on the moon offers up business opportunities with mind-boggling numbers at play. I do not love saying this in this way, but as we transition from exploration to exploitation of space resources, the potential to harvest and utilize lunar hydrogen would dramatically change the economics of space travel and habitation. One industry of fascination is the companies that come with expertise in automation and process control systems. They are ideally positioned to develop the sophisticated technologies required to extract and manage these resources efficiently.

What you need to know

As laid out above, lunar hydrogen is a critical resource for sustained human activity on the moon and beyond. To outline the mechanics in place, it is useful to understand the two places on the moon where hydrogen is typically found:

- **Water ice in shadowed craters**[3]: The moon's poles have multiple craters that never receive sunlight, trapping water ice for what might be billions of years. These shaded regions maintain temperatures below -150°C, which keeps the water ice from sublimating into space. These types of deposits were confirmed by instruments aboard missions like NASA's Lunar Reconnaissance Orbiter[4] and India's Chandrayaan-1, which detected hydroxyl signatures associated with water ice. The importance of these deposits cannot be overstated as they

[1] https://youtu.be/QPMwu04VF38?feature=shared
[2] New findings in lunar soil samples suggest Moon water could fuel future space exploration (thenationalnews.com)
[3] Secrets of the Moon's Permanent Shadows Are Coming to Light | Quanta Magazine
[4] New Research Sheds Light on the Ages of Lunar Ice Deposits – NASA.gov

provide a potentially abundant source of water, vital for life support and as a component in the synthesis of rocket fuel.

- **Hydroxyl in lunar regolith**[5]: In addition to ice, large amounts of hydrogen exist as hydroxyl groups bonded within the minerals of the lunar soil, or regolith. These hydroxyl molecules are formed by the interaction of the solar wind with the lunar surface, where hydrogen nuclei (protons) from the solar wind collide with the oxygen in the silicate minerals. This source is more uniformly distributed across the lunar surface than polar water ice, offering additional, though technically challenging, resourcing opportunities.

Both types of sources are important not only in supporting life by providing air and water but also as a fundamental element for rocket fuel production, thus potentially enabling the moon to serve as a launchpad for deeper space missions, or as one of my friends likes to say, a future roadside space diner stop.

It is also important to know the competing and, in some cases, complimentary *extraction techniques* for hydrogen from the lunar surface. There are several potential techniques, each with its own set of challenges and needed future innovations:

- **Robotic mining for water ice**[6]: The most direct method involves robotic missions designed to mine the ice directly from shadowed craters. These robots, such as Honeybee Robotics RedWater concept, would need to be capable of operating in extremely low temperatures and navigating rugged crater terrain. Technologies under development for such missions include thermal drills that can penetrate ice and regolith mixtures, heating them sufficiently to extract water vapor.
- **Regolith heating**[7]: For areas rich in hydroxyl, heating the lunar soil can release trapped water molecules. This method may use solar concentrators or nuclear-powered heaters to raise the temperature of the regolith, thus freeing the water vapor, which can then be condensed and collected. These types of systems require robust energy solutions and efficient thermal control technologies to manage the high-energy processes involved, which further complicates scaling.
- **Electrolysis for Resource utilization**[8]: Once water is extracted, it must be processed into usable forms using electrolysis, a technique that uses electricity to split water into hydrogen and oxygen. The resulting oxygen can support life or be used in oxidation reactions for chemical processes, while hydrogen can be used as a fuel. This process would be integral to a closed-loop life support system, reducing the need for resupply missions from Earth.
- **Automation and remote operations**: Given the very harsh conditions and the distance from Earth, high levels of automation and remote-control capabilities are necessary to ensure optimal use of assets and efficiencies. Advances in AI

[5] Solar wind particles likely source of water locked inside lunar soils | Astronomy.com
[6] Drilling for water ice on Mars: How close are we to making it happen? | Space.com
[7] Review of energy supply techniques for ice in-situ thermal mining in lunar permanently shadowed regions - ScienceDirect
[8] ESA - Exploration of the Moon - In-Situ Resource Utilisation (ISRU) Demonstration Mission

and robotics are essential to managing these operations, requiring systems that can not only perform physical tasks but also make autonomous decisions based on real-time environmental data.

Each of these techniques highlights the need for solution providers that converge the world of robotics, thermal engineering, and automated systems design necessary to harness lunar resources effectively. For companies with expertise in automation and advanced control technologies, these challenges represent unique opportunities to lead in the development of off-earth industrial capabilities.

There are some important challenges facing the execution of the elements laid out earlier:

- **Extreme temperatures:** The lunar poles are among the coldest places in the solar system. This extreme cold can hinder the mechanical and electronic functions of mining equipment, requiring innovations in materials and engineering to maintain operational efficiency during these times and for operations that are likely in operation around the clock.
- **Remote operations:** The continued (but closing) lag in communication between the Earth and the Moon adds a layer of complexity to remote operations, driving a need for advanced autonomous systems and AI to make real-time decisions without human intervention. Expect more on board/on device intelligence as a result intelligence.
- **Resource localization and mapping:** Identifying precise locations of water ice and ensuring the accuracy of resource maps is important for efficient extraction given the need to make accurate assessments with limited acceptable failure rates. Doing so requires sophisticated sensing equipment and data analysis tools capable of high-precision reliability.
- **Energy requirements**: As I laid out above, the processes of mining, heating regolith, and splitting water into hydrogen and oxygen are very energy intensive. Developing a reliable power source on the moon, possibly through solar arrays or nuclear power, presents a tremendous engineering challenge.

Examples in motion

NASA's Artemis Program[9]**:**

NASA plans to use the already launched Artemis program to pursue continuous missions to the moon's South Pole to explore and utilize water ice deposits. The purpose of the missions is to test technologies for drilling and extracting ice from the lunar surface, providing valuable data on the feasibility of large-scale resource utilization.

International collaborations:

[9] NASA's Artemis program: Everything you need to know | Space.com

The European Space Agency (ESA) is collaborating with international partners to develop the "Lunar Pathfinder" mission[10], which includes sending orbiters equipped with ground penetrating radars to map water ice deposits accurately. These missions are going to be important for planning where to establish the first lunar bases near resource-intensive locations

Private Sector Initiatives:

Private companies, including ispace[11] and Blue Origin, are developing lunar landers that could carry equipment for initial hydrogen extraction experiments. These missions are pivotal as they will provide insights into the practical elements of in-situ resource utilization (ISRU) and its integration with human-staffed bases.

Where is the pulse heading?

There is a substantial amount of unknown with respect to hydrogen extraction. Nevertheless, as we see significant advances in two core areas, the promise of practical execution becomes ever nearer.

Technological innovations:

Several anticipated technological advances will enhance the efficiency and feasibility of operations on the moon:

- **Advanced robotic systems**: Over the coming decade, we expect to see significant advances in robotic technology tailored for lunar conditions. Systems are being designed to operate during the lunar night, which lasts approximately 14 Earth days and experiences temperatures as low as -173°C. Innovations in battery technology and thermal insulation will be critical for these systems to maintain functionality in extreme conditions.
- **AI and autonomous decision-making**: By 2030, artificial intelligence systems capable of autonomous decision-making will most likely govern the operation of lunar machinery. AI systems will be designed to handle unexpected challenges without real-time human intervention. This is important given the light-speed delay in communications between the Earth and the Moon. AI systems will be responsible for navigation, resource extraction, and emergency management, improving the resilience and efficiency of lunar operations.
- **Thermal and environmental technology**: Innovations in material science are likely to lead to new insulation materials and thermal regulation systems by 2030. These technologies will protect sensitive electronic equipment and robotic components from the harsh lunar environment, including extreme temperature fluctuations and abrasive regolith particles. This part of the

[10] Lunar Pathfinder - BSGN (esa.int)
[11] ispace RESILIENCE Lunar Lander Successfully Achieves Testing Milestone in Preparation for Mission 2 (yahoo.com)

process should not be understated, as without advanced materials, many of the robotics advances and AI will be rendered meaningless.

- **Drilling and mining technology**: Adaptations to existing drilling and mining technologies to suit the moon's lower gravity (one-sixth of Earth's) are critical. We anticipate the deployment of lightweight, highly efficient drilling rigs that can penetrate the lunar regolith and ice deposits by late this decade. Rigs will be equipped with sensors to assess the geological properties in real time, guiding the extraction processes with precision.

Economic and policy frameworks:

The developing economic potential of lunar resources is becoming more tangible, and thus, we can expect to see frenetic activity to "control" the environment. However, there is no question that a robust economic and policy framework will be required to develop and support their exploitation:

- **International space resource agreements:** By the early 2030s, we expect a series of international treaties and agreements to be established that outline the legal framework for resource extraction on the moon. These agreements will define property rights, delineate zones for resource exploitation, and set standards for environmental impact assessments.
- **Safety and sustainability protocols:** Protocols to ensure the safety and sustainability of lunar operations will be critical for these frameworks. They should include guidelines for the construction and operation of extraction facilities, waste management procedures, and the decommissioning of outdated equipment.
- **Cooperation and conflict resolution:** As multiple nations and private entities wrestle for lunar resources, mechanisms for cooperation and conflict resolution will be important. These resolutions may include the establishment of an international lunar resource management body, similar in function to the International Seabed Authority that manages earth's seabed resources.

Final word

The extraction of lunar hydrogen is not just a technical challenge; it is a massive step into a future where space resources fuel further exploration and perhaps even permanent human settlement beyond earth. For companies considering investing in this as a mid- to long-term strategy, engaging with these developments means contributing to one of humanity's most ambitious endeavors, establishing a sustainable presence in space. This exciting opportunity not only promises substantial returns but also positions these companies as pioneers in the next step for humans.

Everest Group®
With you on the journey

Everest Group is a leading research firm helping business leaders make confident decisions. We guide clients through today's market challenges and strengthen their strategies by applying contextualized problem-solving to their unique situations. This drives maximized operational and financial performance and transformative experiences. Our deep expertise and tenacious research focused on technology, business processes, and engineering through the lenses of talent, sustainability, and sourcing delivers precise and action-oriented guidance. Find further details and in-depth content at www.everestgrp.com.

For more information about Everest Group, please contact:

+1-214-451-3000

info@everestgrp.com

For more information about this topic please contact the author(s):

Richard Sear, Managing Partner

richard.sear@everestgrp.com

Notice and Disclaimers

Important information. Please review this notice carefully and in its entirety. Through your access, you agree to Everest Group's terms of use.

Everest Group's Terms of Use, available at www.everestgrp.com/terms-of-use/, is hereby incorporated by reference as if fully reproduced herein. Parts of these terms are pasted below for convenience; please refer to the link above for the full version of the Terms of Use.

Everest Group is not registered as an investment adviser or research analyst with the U.S. Securities and Exchange Commission, the Financial Industry Regulatory Authority (FINRA), or any state or foreign securities regulatory authority. For the avoidance of doubt, Everest Group is not providing any advice concerning securities as defined by the law or any regulatory entity or an analysis of equity securities as defined by the law or any regulatory entity. All Everest Group Products and/or Services are for informational purposes only and are provided "as is" without any warranty of any kind. You understand and expressly agree that you assume the entire risk as to your use and any reliance upon any Product or Service. Everest Group is not a legal, tax, financial, or investment advisor, and nothing provided by Everest Group is legal, tax, financial, or investment advice. Nothing Everest Group provides is an offer to sell or a solicitation of an offer to purchase any securities or instruments from any entity. Nothing from Everest Group may be used or relied upon in evaluating the merits of any investment.

Do not base any investment decisions, in whole or part, on anything provided by Everest Group.

Products and/or Services represent research opinions or viewpoints, not representations or statements of fact. Accessing, using, or receiving a grant of access to an Everest Group Product and/or Service does not constitute any recommendation by Everest Group that recipient (1) take any action or refrain from taking any action or (2) enter into a particular transaction. Nothing from Everest Group will be relied upon or interpreted as a promise or representation as to past, present, or future performance of a business or a market. The information contained in any Everest Group Product and/or Service is as of the date prepared, and Everest Group has no duty or obligation to update or revise the information or documentation. Everest Group may have obtained information that appears in its Products and/or Services from the parties mentioned therein, public sources, or third-party sources, including information related to financials, estimates, and/or forecasts. Everest Group has not audited such information and assumes no responsibility for independently verifying such information as Everest Group has relied on such information being complete and accurate in all respects. Note, companies mentioned in Products and/or Services may be customers of Everest Group or have interacted with Everest Group in some other way, including, without limitation, participating in Everest Group research activities.