



Original Article

The Race to the Moon as a Race for Water

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Abstract: The return of humans to the Moon marks a new phase in space exploration, where the availability and use of in situ resources, particularly water, plays a central role. Unlike the Cold War-era space race, current international programs such as NASA's Artemis and the China–Russia-led ILRS aim to establish a permanent and sustainable human presence on the lunar surface, especially in the South Pole region. This area offers strategic advantages due to its extended sunlight exposure and the presence of water ice, a critical resource for life support, oxygen production, and fuel generation. The report explores the technological, scientific, and geopolitical implications of accessing lunar water, detailing its potential sources (regolith and polar permafrost), and the ongoing efforts in ISRU research and development. At the same time, the article emphasizes the lack of a clear and universally accepted legal framework for the exploitation of lunar resources, highlighting the need for coordinated international governance to ensure the peaceful, equitable, and sustainable use of extraterrestrial materials.

Keywords: Lunar exploration, Lunar water, South Pole, ISRU, Artemis program, ILRS, Regolith, Permafrost, Space law, Lunar resources.

1. Introduction

The next major objective in space exploration is the return of humans to the Moon. The Moon has always been part of our collective imagination, inspiring poets, writers, musicians, and artists. Since July 1969, humankind has fulfilled the dream of landing on the lunar surface.

On the night of July 20, 1969, Neil Armstrong and Buzz Aldrin, aboard the lunar module Eagle, separated from the command module Columbia, piloted by astronaut Michael Collins, and descended toward the lunar surface, taking the first steps in the Sea of Tranquility.

In total, during the Apollo program, there were six successful lunar landing missions: Apollo 11, 12, 14, 15, 16, and 17, between 1969 and 1972. Altogether, 12 astronauts have walked on the lunar surface. The Apollo 13 mission failed to land due to a serious in-flight incident that forced the crew to return early to Earth. The subsequent missions Apollo 18, 19, and 20 were cancelled mainly due to budget constraints and changing political priorities.

Current space programs, including NASA's Artemis and initiatives promoted by other international agencies such as ESA and CNSA, aim to return to the Moon with a stable and continuous approach, envisioning the

creation of a permanent base on the lunar surface, conceptually similar to the International Space Station, to conduct scientific experiments and prepare for future missions to Mars.

These types of projects, however, require an analysis of the resources necessary for human permanence on another celestial body, including the availability of food supplies and, above all, water. In this context, water becomes a key and irreplaceable resource: it can be used for human consumption, oxygen production, and as rocket propellant (through the process of electrolysis). Furthermore, the possibility of utilizing in-situ resources (In-Situ Resource Utilization, ISRU) represents a paradigm shift compared to past missions, drastically reducing costs and logistical complexity.

The new race to the Moon is profoundly different from that of the 1960s. Today, the objective is not merely the landing, but the construction of a sustainable and continuous presence. In this scenario, the availability, accessibility, and exploitation of lunar water have become central elements in the strategies of space agencies and commercial actors. Water, located primarily in the permanently shadowed polar regions, is seen not only as a technical resource but also as a geopolitical lever and driver of a future space economy.

This report aims to analyze the centrality of the water resource in the new race for lunar exploration, in relation to the various challenges resulting from this new paradigm of lunar exploration.

2. The Moon, Between Soft Power and Resources

The Moon played a crucial role in the space race during the Cold War, acting as a domain of American comeback after the "Sputnik moment", with the U.S. mission culminating in the first man setting foot on the Moon. This success was strongly pursued by the United States to match the Soviet Union. The powerful impact of the moon landing on American pride is evident in President Kennedy's words on May 25, 1961, in a speech to Congress on the subject of "urgent national needs." In announcing the commitment to the moon landing, he said: "If we are to win the battle that is now going on around the world between freedom and tyranny; if we are to win the battle for the minds of men, the dramatic achievements in space which occurred in recent weeks should have made clear to us all, as did the Sputnik in 1957, the impact of this adventure on the minds of men everywhere, who are attempting to make a determination of which road they should take [...] I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish." [1].

Moreover, in a famous speech at Rice University in Houston, Texas, a year later on September 12, 1962, he declared: "Some ask, why the Moon? Why choose this as our goal? And they may well ask, why climb the highest mountain? Why, 35 years ago, fly the Atlantic? Why does Rice play Texas? We choose to go to the Moon. We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too." [2]

The speeches imbued with national pride by John F. Kennedy gave the Moon a predominant symbolic importance, undeniable in its symbolic value for humankind's space exploration. The Moon, however, beyond the symbolic representation proposed by Kennedy, also assumes a strategic, economic, and political significance. Already in 1958, decorated Brigadier General Homer A. Boushey stated in a speech at the Aero Club of

Washington: “[...] whoever controls the Moon controls the Earth. The Moon offers a retaliatory base with unparalleled advantage.” [3]

Two months later, Lieutenant General Donald L. Putt, in a speech before the House Armed Services Committee, said: “The whole rotating planet could be observed from the Moon with telescopes. In perspective, we must not consider the control of the Moon only to guarantee peace among the nations of Earth. It is the first step towards manned stations on distant planets whose control could be exercised from the Moon. This celestial body seems to be of such importance that we should not allow another nation to establish a military capability there.” [4]. The strategic position of the Moon lies in the fact that it allows for a constant view of the entire planet Earth, due to the synchronization between Earth’s rotation and the Moon’s revolution, as well as in its effectiveness as a base for the execution of future missions to other planets. Such projections for future space missions highlight the necessity of leveraging the geographical peculiarities of selenography, or lunar geography, regarding the resources that can be obtained in-situ. The Moon offers various riches that can contribute to different sectors of the economy, from photovoltaic solar energy to the materials economy. Following the structure adopted by the U.S. Geological Survey (USGS) for the classification of terrestrial resources, lunar resources can also be grouped into three main categories: energy, minerals, and water. This classification is useful for analyzing the availability and potential use of local resources on the Moon, which are fundamental for the long-term sustainability of space activities. The term “resource”, according to the definition shared by the USGS and the U.S. Bureau of Mines (1980), refers to a concentration of natural material in such form and quantity as to allow for economically sustainable extraction. For a long time, one of the main obstacles to the development of technologies for the in-situ use of lunar resources (ISRU – In Situ Resource Utilization) was of a legal nature: the 1967 Outer Space Treaty was interpreted as a prohibition on the extraction of raw materials from the Moon or other celestial bodies. However, in recent years, several nations have introduced legislation that explicitly authorizes the commercial use of space resources: among them, the United States (2015), Luxembourg (2017), and Japan (2021). [5]

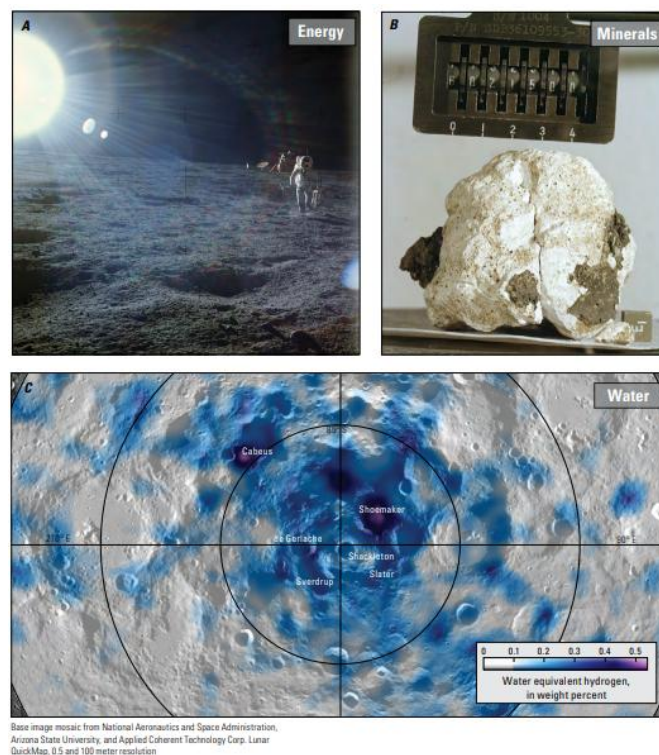


Fig.1 Diagram of the main categories of lunar resources [6]

Technological barriers are gradually giving way to innovation. The use of solar energy on the lunar surface was introduced as early as 1966 with the Soviet Luna 9 mission, marking significant developments. However, the challenges related to the extraction of minerals and water remain more complex. In the early 1990s, the American spacecraft Clementine confirmed the presence of frozen water at the bottom of craters in the lunar South Pole. The launch of the Lunar Prospector probe in 1998 was aimed at mapping the Moon's surface, studying its chemical composition, and identifying formations of frozen water.

In 2009, the Lunar Reconnaissance Orbiter (LRO) created a three-dimensional map of the Moon. The actual extent of water reserves on the Moon is still under investigation, but evidence gathered over the past decades' points to a significant presence of ice deposits in the permanently shadowed polar regions. Data obtained in 2009 from NASA's LCROSS (Lunar Crater Observation and Sensing Satellite) and LRO (Lunar Reconnaissance Orbiter) missions confirmed the presence of useful materials in the shadowed craters of the lunar surface, suggesting that the Moon is chemically active and that a rudimentary water cycle may exist. [7]

NASA, through the Space Technology Mission Directorate, funds large-scale research and development projects on ISRU. One of the main objectives is to create, by 2030, a system capable of extracting at least 15 tons of ice from the lunar south pole, converting it into 10 tons of oxygen and 2 tons of hydrogen, useful both as propellant and life support [8]. Moreover, an Italian experiment conducted in 2021 by a research group from the Politecnico di Milano, led by Michèle Lavagna, successfully extracted water from regolith — the dust of the lunar polar soil — by isolating oxygen from the oxides present in the lunar material [9]. The possibility of accessing water supplies on the Moon therefore stems from two types of sources: lunar regolith and the permafrost of the lunar poles.

On the Moon, small amounts of water and hydrogen are trapped in the regolith, the surface dust of the soil. Part of this hydrogen originates from ancient volcanic eruptions: in the glass deposits of lava fountains, concentrations as high as 1,200 ppm (parts per million) have been detected, although the average ranges around 15–30 ppm. Orbital studies suggest that some areas may contain between 150 and 400 ppm. [10] Another source consists of the solar wind, which carries protons capable of bonding with the oxygen present in the regolith, forming hydroxyl and water. This water is distributed throughout the lunar soil but in low concentrations — about 70 ppm at equatorial levels and up to 500–750 ppm in the polar regions.) [11]. This process has generated a global potential equivalent of tens of billions of tons of water, but at very low concentrations [12].

In the permanently shadowed craters near the poles, particularly the south pole, ice deposits are present. The Lunar Prospector mission of 1998 detected usable hydrogen within the first two meters of depth. The data indicated that a large quantity of water ice, likely around 300 million tons, was mixed with the regolith at each pole — the first direct evidence of permafrost presence at the lunar poles [13].

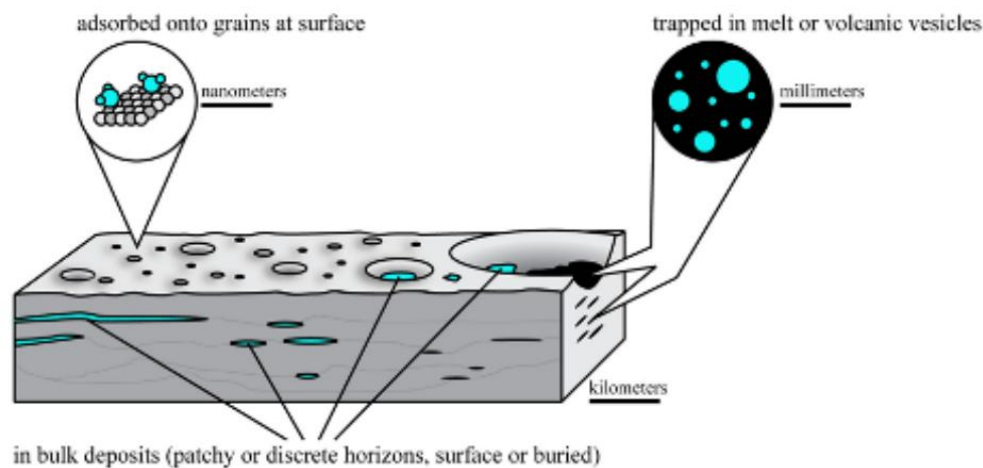


Fig.2 Iconography of the distribution and scale of lunar water reserves. [14]

In 2009, the previously mentioned LCROSS mission impacted the Cabeus crater, revealing greater potential in terms of quantity. Despite these promising indications, the exact size and depth of the ice remain uncertain; some estimates therefore suggest that the volumes may be comparable to those of a small terrestrial lake. [15]

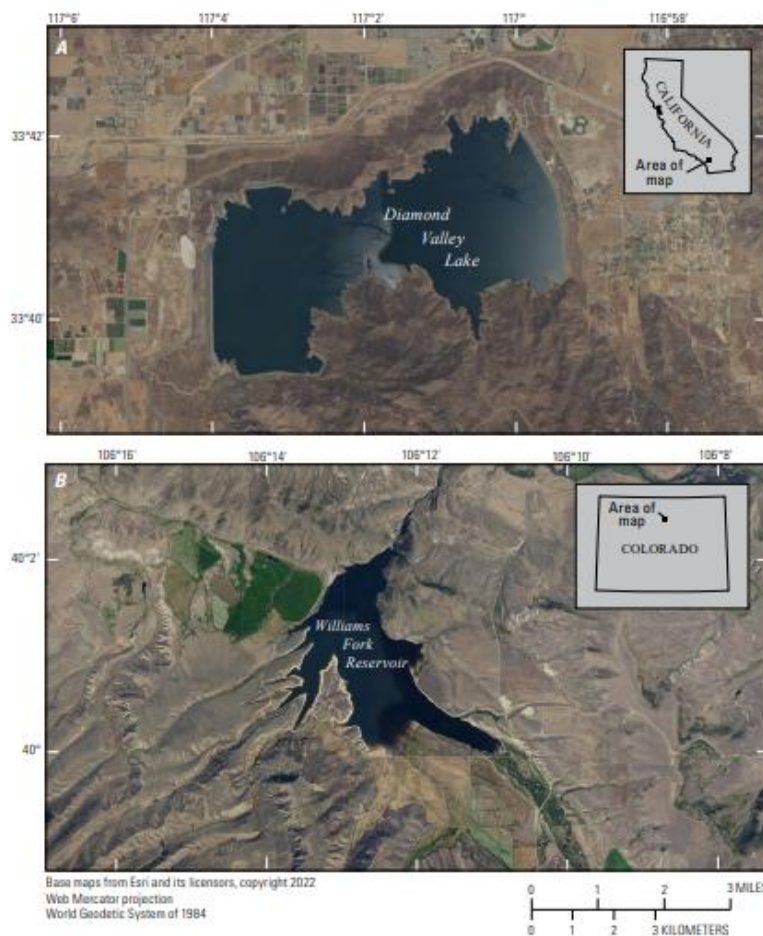


Figure 12. Maps showing examples of reservoirs in the United States that have volumes similar to the total amount of ice estimated to be on the Moon. *A*, Diamond Valley Lake, California, near San Diego has a volume of approximately 1 cubic kilometer (0.2 cubic miles), or 1 billion metric tons of water. *B*, Williams Fork Reservoir, Colorado, near Denver has a volume of approximately 0.1 cubic kilometer (0.02 cubic miles), or 100 million metric tons of water.

Fig.3 Demonstrative map of the potential volume of ice present on the Moon. [16]

Unlike water derived from regolith, the extraction of polar ice would require less processing and offer more readily usable resources, such as drinking water and oxygen for propellant. Particularly useful and explanatory in terms of feasibility studies is the chart developed by the USGS (U.S. Geological Survey), which illustrates the amount of regolith required to produce approximately one liter of water, comparing the two types of water production.

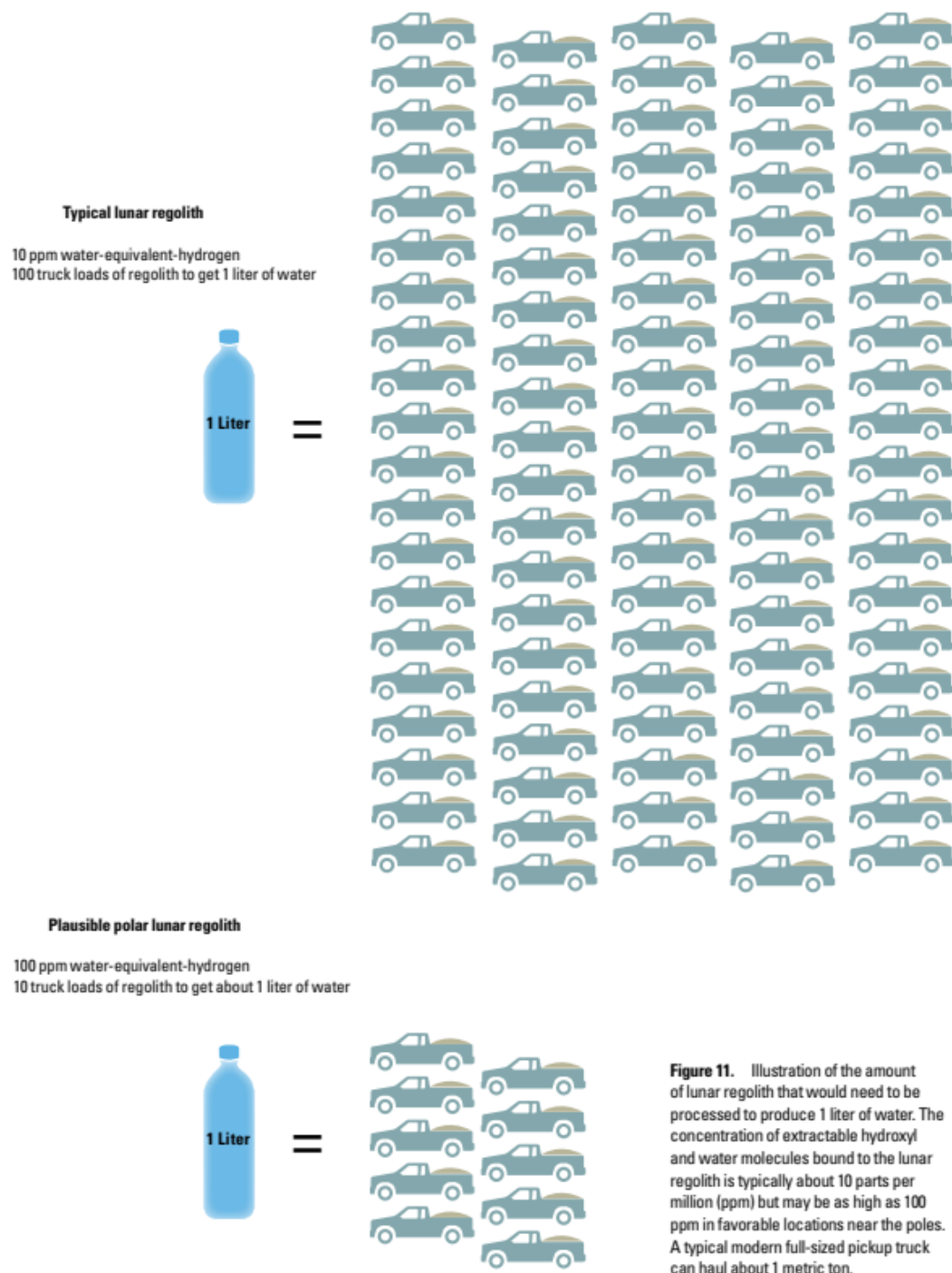


Fig.4 Illustration of the amount of lunar regolith required to produce one liter of water. Each pickup truck represents approximately 1 ton, or 1000 kg, of regolith. [17]

Water in the space environment is a precious and limited resource, and its supply is extremely expensive, just considering that delivering one liter of water to space costs approximately 20,000 US dollars [18].

In addition to the presence of permafrost deposits — that is, reserves of frozen water trapped beneath the surface of the lunar crust — the Moon's South Pole is also notable for its high energy availability, due to its exposure to sunlight. In fact, some areas of this region are illuminated for very long periods, making it a strategic zone for the installation of solar energy-based infrastructure, with significant implications for future lunar missions and the potential establishment of a permanent human settlement.

3. International Missions to the Lunar South Pole

The two main international programs currently focused on establishing a base on the lunar surface are: the International Lunar Research Station (ILRS), led by China, and the Artemis program, led by the United States.

China has made rapid and consistent progress in robotic lunar exploration, culminating in the Chang'e 6 mission, which successfully returned to Earth with the first-ever samples collected from the far side of the Moon. These missions lay the groundwork for much more ambitious objectives, such as a human landing on the Moon by 2030 and the construction of a permanent lunar base known as the International Lunar Research Station (ILRS).

The ILRS is an international research station proposed and led by the China National Space Administration (CNSA) and the Russian space agency Roscosmos. It is to be built near the lunar South Pole, one of the most promising regions for the presence of water ice. The base will initially be unmanned and operated by rovers, robots, and orbiters, but is expected to host astronauts at a later stage. The project is divided into three main phases. The first is a reconnaissance phase (by 2030), involving the Chang'e 7 and 8 missions, which aim to explore the site and test technologies for using local resources such as regolith and water. For example, Chang'e 8 will test a 3D printer designed to work with lunar soil to produce construction materials directly on site. The second phase, scheduled between 2030 and 2035, focuses on actual construction, with the launch of ILRS missions 1 through 5. These missions will aim to install essential infrastructure, including energy systems, communications, mobility platforms, robotics, and scientific laboratories. The final phase, expected to begin around 2045, will mark the operational use of the base. It will include a lunar orbital station for experiments and communications, supported by the future Queqiao satellite constellation dedicated to lunar navigation and telecommunications [19].

The United States, together with a growing coalition of international partners, is advancing the Artemis program, which represents a new frontier in lunar exploration led by NASA. The goal is to return humans to the Moon and establish a sustainable presence on the satellite as an intermediate step toward human exploration of Mars. The Artemis program is centered on building a permanent and sustainable presence at the lunar South Pole — a strategic region, as previously noted, to produce oxygen, water, and fuel. Unlike the ILRS program, which begins with robotic missions, Artemis envisions the direct involvement of astronauts from the very first phases. The project is structured into several phases covering the return of humans to the Moon, the construction of a lunar base, and the development of orbital infrastructure. The initial phase includes the Artemis II mission, which

will bring astronauts into orbit around the Moon for the first time in over fifty years. Artemis III, on the other hand, aims to land the first woman and the second man on the lunar South Pole. The next phase involves consolidating the human presence on the Moon through the creation of the Lunar Gateway, a space station orbiting the Moon that will serve as a staging point for surface missions, along with the development of surface infrastructure: habitable modules, pressurized rovers, and facilities for the extraction and use of in-situ resources (ISRU). The technological cooperation within the Artemis program involves extensive international participation, currently including 55 signatory countries.

The projects foresee a landing zone, the designated area for landing and infrastructure development, at the lunar South Pole. Despite the overlap in the strategic importance of this region, it does not pose a problem for the coexistence of the two missions, due to both the vast geographical extent of the area of interest and the lack of operational overlap between the two programs.

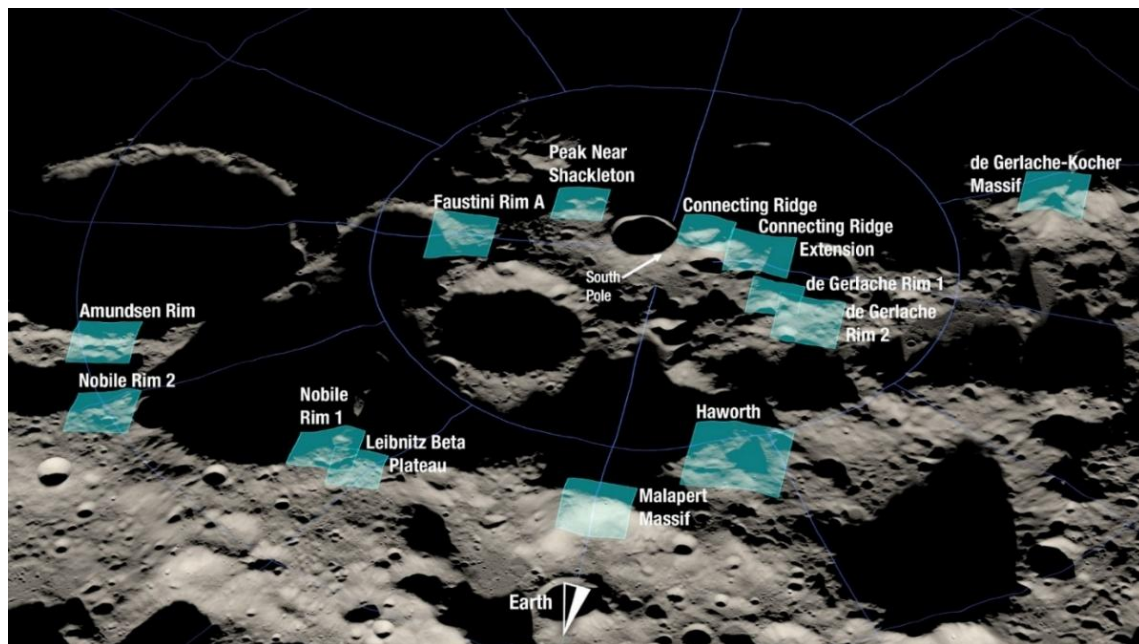


Fig.4 Representation of the potential landing zones for the Artemis III mission. [20]

Both the ILRS and Artemis programs intend to operate in the lunar South Pole region, where the most valuable resources for the development of space missions are located. However, the South Pole is not a single point but a vast area spanning hundreds of square kilometers, with multiple craters and highlands potentially suitable for landings, habitat module installations, and scientific observations. According to official statements, Artemis III has shortlisted 13 potential landing zones, all within the South Pole region, but has not yet designated a fixed, permanent site for a lunar base [21].

ILRS, on the other hand, although it has not confirmed a specific landing zone either, aims to establish its station near the Amundsen crater, also in the southern region, but in a different area from those most frequently cited by NASA [22].

4. Conclusions

Despite technological progress and the initial legislative opening by individual states, the definition of a clear and shared international regulatory framework remains one of the key issues to be addressed for the exploitation of lunar resources.

To date, the main legal framework is represented by the 1967 Outer Space Treaty (OST), which establishes fundamental principles such as the non-appropriation of celestial bodies, the peaceful use of outer space, and international responsibility for activities conducted beyond Earth's atmosphere. [23] However, the OST does not comprehensively regulate the economic use of space resources, nor does it provide operational mechanisms for their management. The lack of specific references to the ownership of extracted materials or to an international regime for their utilization has led some countries to adopt national laws governing the commercial use of extra-terrestrial resources [24].

In this context, the 1979 Moon Agreement aimed to complement the provisions of the OST by introducing principles for the common management of lunar resources and envisioning a possible international regime for their future regulation. [25]. Although it was not ratified by the major space powers, the treaty contains elements that could have provided a foundation for addressing disputes related to access and the use of in-situ resources. The interest in the presence of water in the polar regions of the southern lunar hemisphere drives the main international lunar exploration programs, making it the strategic resource for human missions to the Moon.

The localization, extraction, and distribution of this lunar ice raise additional legal questions, particularly concerning access rights, the sustainability of exploitation, and the sharing of scientific data. Considering these developments, there is a growing need to address the legal framework in a coordinated manner at the international level. This need arises from the importance of defining usage rights, establishing mechanisms for cooperation, preventing conflicts between public and private actors, and protecting the lunar environment.

In particular, the management of lunar water deposits could become one of the first real tests for the effectiveness — or inadequacy — of shared legal instruments. The absence of a recognized and operational legal framework within the international community currently represents a significant factor in assessing the long-term sustainability of lunar activities.

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