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Open Lunar Foundation – Input to the Working Group on Legal Aspects of Space Resource Activities

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The Open Lunar Foundation

Submission to the Chair and Vice-Chair of the UN Working Group on the Legal Aspects of Space Resource Activities

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This document is submitted by the Open Lunar Foundation in its capacity as permanent observer to the United Nations Committee on the Peaceful Uses of Outer Space in response to the invitation for submissions by the Chair and Vice-Chair of the UN Working Group on the Legal Aspects of Space Resource Activities.

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OPEN LUNAR FOUNDATION

Summary

The recovery, exchange and use of natural resources have always been foundational to the development and maintenance of any human society. Yet history also shows that uncoordinated access can create conflict and unfettered development can grow to the detriment of people, places and intentions. As humanity seeks to establish new roots in the vastness of space, the technical, economical and legal ability to make use of available natural resources will thereby play a crucial role in determining our failure or success.

The present submission features highlights from Open Lunar's body of work relevant to the topics mentioned in the invite released by the Chair and Vice-Chair of the UN Working Group on the Legal Aspects of Space Resource Activities. The first part (pages 1 - 5) presents the Open Lunar Foundation, our guiding values, and our expert assessment of five resource systems within the lunar environment. The second part (pages 5 - 10) suggests policy recommendations and governance mechanisms that the working group may wish to take into account in the course of its deliberations.

By sharing a more substantial package of research, this report seeks to highlight the richness of this new domain, emphasize the value of developing shared frameworks to inform specific answers, and the importance of dialogic approaches to policy-setting and coordination.

A non-exhaustive list of Open Lunar's main policy positions and documents can be found at the end of this document. We hope this submission may be of help to the Working Group and we stand ready to provide further information and assistance.

The Open Lunar Foundation

The Open Lunar Foundation is a U.S. non profit organization dedicated to the peaceful and cooperative development of the Moon, for the benefit of all life. Since the year 2021, Open Lunar has been an Observer to the Committee on the Peaceful Uses of Outer Space.

Open Lunar combines institutional research with intentionality and values to develop applied policy proposals and commercial partnerships for the Moon. As a non-profit we identify leverage points and take risks in service of peaceful and cooperative lunar futures. We see the Moon as part of a developing Earth–Moon system, and want to make sure that when we look up at the Moon, we all see something we can be proud of. We work towards this goal through the pursuit of intentional precedents around issues such as resource management, externalities, jurisdiction, transparency and access, and surface coordination protocols.

We hypothesize that enacting policy, instrumentation and coordination mechanisms in concert will accelerate the uptake and incentivise behavior change in the industry, towards a holistic new approach to lunar development. Our key values are polycentricity, plurality, experimentation, accessibility, inclusiveness, accountability, clarity, and adherence to the Outer Space Treaty. As such, our policy work aims to co-create guidance and guardrails with foresight and thoughtfulness, proactively designing responsive, innovative and iterative policy and coordination frameworks. In our documents we address critical issues of resource allocation, rights, jurisdiction, and more, in a way that supports and accelerates lunar development priorities, while also contemplating ethics, benefit sharing, and positive evolution.

At Open Lunar we also promote the development of new initiatives in support of peaceful and cooperative lunar development. In 2021, Open Lunar established the Breaking Ground Trust as an independent legal entity prototyping policies for sustainable, lawful, and multilateral management of lunar resources. In 2023, Open Lunar will support the conduct of preliminary research for the establishment of a global, multi-stakeholder Lunar Policy Platform dedicated to support and promote the cooperative development of the Moon through the investigation and solution of key policy, operational and coordination issues.

Guiding Values

Over the past three years, at Open Lunar we have been reflecting on a set of key values for lunar resource management that can enable the flourishing of a thriving lunar economy while avoiding the mistakes of our past and present. Considering the important precedent setting opportunity and the broadest goals of different actors to be accommodated, we believe the following values should guide the formulation of policies and norms in support of peaceful and prosperous lunar resource activities.

Cooperation and Interdependence

Cooperation is not only a firmly established principle of international space law, it is one of the most powerful drivers of positive human behavior. Because of the high level of interdependence determined by the features of the lunar environment, our ability to use space resources in a cooperative manner will play a crucial role in the development of a sustained and sustainable presence on the Moon.

Plurality and Diversity

In furtherance of Article I of the Outer Space Treaty, plurality and diversity should be embedded in all policy and norms governing access to and use of lunar resources. Only with the participation of a diverse pool of actors, public and private, scientific and commercial, space and terrestrial, developed and developing, societal and indigenous, will it be possible to unlock the full potential held by space resources.

Learning and Experimentation

If space is hard, space resources will be even harder - especially on the lunar surface. Understanding how to recover, process and use space resources in a safe and sustainable manner will require several iterations through time. This reality calls for the development of adaptive governance mechanisms capable of reflecting factual, economic and technological changes.

Openness and Transparency

The significance of space resources extends far beyond the limited pool of actors that will be concretely capable of recovering and using them. Openness and transparency will play a key role in holding space resource operators accountable towards those communities and stakeholders that will not be directly involved in their activities.

Lunar Resource Systems

Space contains a variety of natural resources, and each celestial body presents a different composition. For example, our natural satellite is a highly heterogeneous place featuring different geographical areas and resources: peaks of eternal lights, permanently shadowed craters, lava tubes, radio-quiet areas, “seas” of regolith, trapped oxygen and deposits of water ice. Although the Working Group is discussing broad topics of “whether” or “if” to establish coordination or governance mechanisms for lunar resources, the answer may be different for different resource systems. Applying insights about these differences may allow for focus that would otherwise be elusive and simplify the resulting work necessary for multilateral approaches.

Driven by the goal to develop a thorough understanding of the types and distribution of lunar resources, in collaboration with the Space Generation Advisory Council (SGAC) Open Lunar gathered a group of 15 researchers to identify distinct lunar resource systems and assess their natural and socio-ecological features. The full details of this work are explored in a report titled “Res Luna”, whose main results and implications are condensed below.

Identifying Resource Systems

The lunar ecosystem, as it develops, will consist of complex webs of interactions. Although specific use cases for lunar resources have yet to crystallize, the *Res Luna* working group identified over 20 lunar resource systems. The following pages provide selected extracts discussing features and governance approaches to the following systems: Permanently Shadowed Regions, Radio-Quiet Zone, Peaks of Eternal Light, Lunar Lava Tubes, and Lunar Regolith.

<u>Permanently Shadowed Regions</u>

Permanently Shadowed Regions (PSRs) are topographic depressions and impact craters located at lunar poles and permanently shielded from sunlight. Coupled with the lack of an appreciable atmosphere, the temperature conditions - as low as about 40 Kelvin - allow for primitive outer solar system objects that are rich in volatiles to be delivered and retained over time as potential frozen ore deposits. The rare combination of sufficient depths or crater wall heights, latitude and longitude, and temperature make PSRs scarce and unique resource systems. Further, their volatiles

are nonrenewable on human timescales and as such can be classified as finite, subtractable resources.

The PSRs are of interest to diverse stakeholders. The expected use cases include extraction and collection of water, scientific research, and manufacturing. The PSR volatiles will be essential for the production of key commodities such as O2, H2, and H2O used in the production of rocket propellant, consumables to support a sustained human presence on the surface, chemicals and binders for use in mineral processing and additive manufacturing pipelines, and for various scientific reasons.. All stakeholders will likely have a high dependence on resources found in the PSRs, making it potentially extremely rivalrous.

Radio-Quiet Zone

The Radio-Quiet Zone is an area on the lunar far side shielded from radio frequency (RF) interference originating on or within a distance of 100,000 km from the center of the Earth because of the size and geometry of the Earth, the Moon, and their respective orbit and spin. This provides a unique physical resource that is particularly suited to radio astronomy in the low-frequency range used for investigating the universe's early evolution, the habitability of exoplanets, and other science areas that can only be accessed from the lunar far side.

However, radio astronomy is not the only contender for RF lunar far side. As missions begin to operate in that region, they will require the RF spectrum both locally for scientific payloads on landers and rovers and to relay signals back to lunar orbit. The use case for radio astronomy is rivalrous, but non-excludable. The curvature of the Moon provides natural shielding, but this will change with increased lunar activity. Although frequency-sharing is possible for non-astronomical use cases, benefiting from the ''quiet'' needed for astronomy will require a monopoly in the relevant frequency bands. Because of the region's uniqueness and the difficulty of achieving these observations otherwise, the possibility for contention is high. Interest heterogeneity also exists since the envisioned use cases for each stakeholder group are competing with one another, but the challenge lies more in coordinating access than contention over the radio quiet zone itself. As a governance challenge this is distinct from many other resource systems.

Peaks of Eternal Light

The phrase ‘‘peaks of eternal light’’ (PEL) is a colloquialism that refers to a terrain with relatively high illumination near the lunar poles. These exist due to a combination of local topography and the low tilt angle of the Moon, resulting in a solar ground trace at the lunar poles that continuously ‘‘bobbles’’ around the horizon. Although they are not truly eternal in their illumination, the fraction of time with solar exposure can be in the 80%–90% range, even just a few meters off the ground. Because the sun is constantly so close to the horizon, the actual illumination at any given location is highly dependent on the ground height, where even tens of meters can change the illumination quotient by tens of percentage points, and large shadows will be cast.

These naturally forming phenomena offer a valuable source of solar power as well as thermal consistency. Many PEL exist in raised areas formed at the rims around impact craters. As discussed earlier, these are also believed to be likely sites for cold traps containing water ice and other important volatiles. This makes the PEL of additional interest as future sites for rover missions and surface infrastructures such as habitats and power stations. Because the PEL are estimated to cover only about 0.00000000001% of the surface area of the Moon, they are considered an extremely scarce, naturally occurring resource. Technical substitutes may exist in the form of constructed towers as well as thermonuclear power sources.

The system heterogeneity is high, varying significantly in size, extent, and local features such as crater slope and mineralogical content. Although the stakeholders themselves are diverse, there may be a convergent interest in using these sites for power stations, which potentially motivates shared infrastructure as well as coordination for access to their valuable services.

Lunar Regolith

The particles constituting the Moon’s regolith are a product of millions to billions of years of continuous impacts from meteoroids, the steady bombardment of solar wind and cosmic radiation, and thermal cycling. The regolith’s composition ranges from anorthositic to basaltic, comprising several minerals in different forms, with the most abundant being calcium-rich plagioclase, pyroxene, olivine, ilmenite, and spinel. The relative abundance of these minerals is highly variable depending on location and what fraction of the regolith is being sampled (i.e., particle type, grain size).

The bulk lunar regolith has been considered as a potential feedstock for the production of oxygen and alloys for the construction of roads, habitats, radiation protection, and glass making, whereas others have targeted specific components (e.g., ilmenite, volcanic glass) within the lunar regolith for specific purposes such as oxygen production or horizontal construction. The regolith ‘‘soil’’ (<1 cm fraction) from the highlands may be targeted as a raw material for further beneficiation to produce a feedstock upgraded in aluminum and calcium. In contrast, mare-derived soils may be targeted for iron, titanium, oxygen, and sulfur. The potential resources and use cases of lunar regolith are clearly heterogeneous. Thus, a diversity of stakeholders from commercial, public, and scientific sectors will be present.

The bulk lunar regolith itself is quite abundant. Some individual components (e.g. volcanic-derived glass, ilmenite) are quite scarce relative to the bulk composition, whereas others such as anorthite are not. Lunar regolith naturally renews on geologic, not human, timescales. The regolith as a whole is not easily excludable, for it exists nearly everywhere. In this sense the bulk regolith can be treated as essentially a public good,non-rivalrous and non-excludable due to its abundance and scale, with the possibility of extracted materials becoming private goods, policy permitting. Due to the lack of system-wide knowledge about regolith composition in specific areas, to the extent that access and use is widely available and widely distributed, the resource system is likely more suited to a first come first served arrangement than other lunar resource systems. A permission system for making bricks from lunar regolith is arguably a lower priority than international agreements for landing sites.

Lunar Lava Tubes

Lava tubes are natural ‘‘roofed’’ channels that likely formed from the extrusion of low-viscosity basaltic magma. Over time, the outer lava in a flow solidifies to form a shell, whereas the inner lava continues to flow, carving a channel. Eventually, the lava flow subsides, creating an empty void space. Lava Tubes formed under Lunar conditions (LLTs) are believed to be tens or hundreds of meters wide, hundreds of meters deep, and tens of kilometers long.

The LLTs are heterogeneous resource systems, and thus their classification depends on their use case. Although the difficulty of accessing LLTs suggests they are unlikely as a short-term destination, their medium to long-term use cases might include natural shielding for habitats, data centers, and natural refrigeration and

temperature control for food, supplies, machinery, feedstock, and waste storage. Their value is based on protection from the harsh lunar environment (e.g., dust, solar particle radiation and galactic cosmic radiation, micrometeorite impacts, and severe temperature fluctuations). The LLTs may also be sources of pristine materials from the Moon's early formation period such as mantle-origin rocks and volcanic and cometary volatiles, which might not otherwise be preserved if they were exposed to the harsh lunar environment. Such materials would make enticing targets for scientists and economic geologists.

If used for science, shelter, and storage purposes, LLTs can be restored and made available to other users, making them renewable. However, if they are transformed or destroyed through extraction of resources, LLTs would be non-renewable and subtractable. Because knowledge about the abundance and internal characteristics of intact LLTs is still limited, the extent of demand remains unknown. The LLTs may be classified as a public or club good, depending on their use case. If LLTs are used for shelter, transport, and storage, their use may be excludable, but the scale of LLTs implies it may also be possible to share use of the resource. In the case of non-destructive use, policy efforts might emphasize coordination rather than restrictions. However, if the primary use case involves the destruction of natural features, a more conservative approach may be warranted.

The Importance of Understanding Scarcity

With as many different resource systems existing on the Moon, the development of appropriate tools to identify their level of scarcity will play a fundamental role in developing appropriate management strategies. In simple terms, scarcity occurs when the demand for something is greater than the availability of it. Without logical mechanisms to effectively manage lunar resources (i.e. water, physical space, valuable minerals, orbits) the Moon may become vulnerable to the many problems that can arise from resource scarcity, and actors operating in space will be left to fend for themselves. A general approach to classifying scarcity could be adopted to prioritize which resources must be conserved first. One possibility is creating a type of "score card" of indicators, such as the estimated supply of the resource or their level of renewability, and generating a "Scarcity Score" that designates which resources are most vulnerable to negative outcomes of unmanaged use.

Policy and Governance

On the Moon even more than on Earth, one size hardly fits all. The various features of lunar resource systems, with special emphasis on their different levels of scarcity, have several policy and governance implications. In our work we distinguish between governance and policy implications in the sense that a governance arrangement is a policy resulting from active ongoing coordination and decision making among actors with distinct knowledge and experience specific to that system. Based upon our studies of the lunar environment, the following pages provide an overview of key governance implications and policy recommendations for lunar resource activities.

Governance Implications

One Size Does Not Fit All

We have seen that, practically, the Moon consists of numerous different resource systems, each with their own unique features, use cases and governance needs. As such, a single governance regime or organization is unlikely to coherently or efficiently address them all. Water ice and oxygen deposits might be found in numerous locations, and their management may involve a simple notification process. However, prospecting and extraction of these resources in the PSRs might be better served by an international system of prioritization and sharing. The radio-quiet region could involve a system of timesharing. The scarcity of PEL, their general utility for power provision, and potential interference due to shadowing suggests international coordination of their use rights. On the contrary, the bulk regolith may be sufficiently abundant that access and use do not need to be coordinated at all. Finally, conservation and heritage designations for scientific or cultural purposes may warrant a dedicated group of professionals evaluating proposals in an adaptive fashion, rather than a strict set of firm and generic rules imposed from the top down.

The Benefits of Polycentricity

Although all lunar operators will be stakeholders in global issues such as large-scale dust mitigation or spectrum allocation, regional considerations for shadowing at the PEL or access coordination for specific PSRs will more likely involve a subset of them. As such, frameworks that allow for diversity and subsidiarity of governance systems should be researched and considered for lunar governance. One such potential framework is polycentricity. In polycentricity, a shared set of goals and institutions

empowers local management by semi-autonomous decision makers. Polycentricity leverages localized synergies and deep system knowledge for high social-ecological and governance congruence. Through subsidiarity and diversity, polycentric governance enables institutional experimentation and exchange in uncertain and complex environments. In a polycentric lunar governance system, the different lunar resource systems can be managed locally and individually while conforming to universal norms and principles such as transparency, sustainability, peace, cooperation, and justice. Thus, we recommend further investigation of the applicability and operationalization of polycentricity to space resource management.

Policy Recommendations

Create a Catalog of Scarce Resources

Not all space resources are equally accessible or exist in large quantities. Specific resources or regions may be affected by inherent conditions of scarcity, such as the "peaks of eternal light" at the lunar poles or the "radio quiet zone" on the far side of the Moon. To ensure appropriate management regimes, we recommend developing and updating a living list of resources and regions involving conditions of scarcity. States, operators and other interested stakeholders should involve themselves in this definitional process and publicly commit to recognizing and respecting the list.

Develop Different Types of Resource Management Regimes

The existing variety of space resources should be reciprocated by the corresponding development of different approaches to resource management systems. The discussion of property rights is often assumed to imply *private* property rights; but private property is only one of an array of different approaches each of which may include, the rights of use, withdrawal, exclusion, management, and alienation. We thus recommend reflecting on differentiated resource management approaches to be applied to different resource systems. For example, extracting resources from a permanently shadowed crater in the lunar south pole may come with obligations for sharing or coordination that do not apply to a research outpost at an equatorial region. Landing at a site abounding in scarce resources as listed in the catalog may involve an internationally agreed upon approval process, whereas landing at the less differentiated equatorial regions may simply involve an expectation of transparency and information sharing.

Leverage Participatory Policy and Deliberative Processes

Determining how to allocate access to and use of space resources naturally involves multiple fields of expertise as well as a diverse range of stakeholders. To unravel the complex web of factors impacting these determinations, we recommend leveraging participatory processes ensuring high-learning, high-empathy decision making. The output produced as a result of these deliberative processes could be used to provide expert, pragmatic, community-driven inputs to traditional policy-making efforts both at the national and international level. Participatory policy and deliberative processes may also be conducive to stakeholders' commitments towards minimum standards of behavior for safe and sustainable operations, promoting positive precedents and increasing predictability and accountability.[1]

Scaffolding Towards Shared Frameworks

Wishing to ensure that emerging lunar regulations truly enable a plurality of societies, parties and activities, while not over-specifying institutional structures based on past approaches, a foundational document could be adopted which focuses on guiding principles and shared agreements rather than specific resource management and coordination approaches. Such a document could emphasize commitment to peace, cooperation and accessibility while protecting the ability for adaptive learning and evolution.

[1]Over the last two years, Open Lunar incubated the Breaking Ground Trust (BGT) and Moon Dialogs (MD) initiatives to demonstrate the benefits of participatory policy and deliberative processes for space resources and lunar governance. In 2023, the results of these initiatives will be leveraged to conduct the first community-driven demonstration of a safety zone, and spearhead the establishment of a unique global and multi-stakeholder Lunar Policy Platform.

Relevant Documents

A non-exhaustive list of Open Lunar's main policy positions and documents include:

- Lunar Resources Policy (September 2020)
- Space Tenure: The Policies of Sustained Lunar Presence (October 2020)
- Polycentricity For Coherent, Timely, Effective, And Equitable Governance Of Lunar Activities (June 2021)
- "Breaking Ground": A Lunar Resources Trust (June 2021)
- Safety Zones for Lunar Activities Under the Artemis Accords (January 2022)
- Res Luna: Resource Systems and Governance Approaches (January 2022)
- Deliberations On Our Resource Rights (DOORR) (January 2022)
- Scarcity of Lunar Resources - Policy Brief (March 2022)
- Scarcity of Lunar Resources - Scorecard & Case Study (March 2022)
- Res Lunae: Characterizing Diverse Lunar Resource Systems Using the Social-Ecological System Framework (May 2022)

Further documents on specific topics can be found on our website.