BEYOND EARTH INSTITUTE

Toward A Cislunar Ecosystem With Human Presence

The Underpinning For Permanent Lunar Communities

The paper was prepared as background for a panel of the same name presented at the **Beyond Earth Institute**. The content of this paper is not meant to represent the views of any of the speakers on the panel or their employers.

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I Sustainability

Space can be considered a new frontier, a free and open domain for humanity to create and innovate for the betterment of Earth and humankind. As we travel outward, we bring with us our human values. Governments have a responsibility to promote the values they wish to preserve and propagate beyond Earth. This is especially true as the international community expands en masse to our nearest celestial neighbor: the Moon.

Timing is key. Government responses to technological development tend to be ill-timed. Top-down systems often struggle to keep up politically and technologically as the world changes more rapidly than governmental institutions can react to such change. As much as is feasible, policies should be created from the bottom-up rather than top-down with multiple stakeholder involvement from governmental and non-governmental entities alike.

Similarly, policies can also be created too soon, leading to stifling growth, limiting potential, or driving direction the wrong way. As mentioned, timing is crucial in policy implementation, and this is a reality that is only exacerbated in the space domain.

Sustainability is one of the main goals of NASA's Artemis program[1]. Space sustainability is often defined as political, economic, and environmental. Sustainability needs to be proved in the short term before it can be assessed in the long term.

Whereas former NASA Administrator James Bridenstine defined sustained lunar exploration as the ability to access the Moon anytime we wish to[2], we of the Beyond Earth Institute believe the US should strive for more. It should be noted, however, that former Administrator Bridenstine was working within budget and government constraints that limited what is actually feasible regarding space endeavors. Bridenstine would have likely advocated for much more in the way of sustainability without such constraints. That said, the US can and should commit itself to the goal of creating and nurturing a cislunar ecosystem with a permanent human presence.

[1] NASA's Plan for Sustained Lunar Exploration and Development, https://www.nasa.gov/sites/default/files/atoms/files/a_sustained_lunar_presence_nspc_report4220final.pdf
[2] The Space Foundation's Symposium365, Space Matters, July 14, 2022

II Political Sustainability

Until recently, change was a constant at NASA's human exploration directorates from presidential administration to administration. The George W. Bush administration's Vision for Space Exploration[1] was discarded in favor of the Barack Obama administration's Journey to Mars[2] and Asteroid Redirect Mission[3] which was later discarded in favor of the Donald Trump administration's Artemis program, with numerous examples of earlier transitions.

The cycle appears to have been broken with the Joseph Biden administration. The current administration has largely kept the course, promoting and funding the Artemis program it inherited from the previous administration. This has allowed NASA to save time and resources by not needing to greatly modify its plans, mission architectures, and hardware to fit a new goal.

Political sustainability is obtained with bipartisan support. Only by establishing an enduring national interest and articulating the "why" of space exploration in general and the Artemis program, in particular, can NASA and the White House maintain political sustainability. This stated national interest may be in the form of economic, political, or security priorities. Congress can support political sustainability by passing NASA authorization bills and matching appropriation bills.

Programmatic sustainability can augment/bolster political sustainability. Whereas Apollo was not programmatically sustainable, Artemis can be designed to be so. This may be accomplished by gradually extending Artemis' mission from shorter six-day expeditions to six months or one year, similar to International Space Station expeditions.

Commercial partners should be used to a maximum extent for cislunar and lunar infrastructure and operations. For example, SpaceX's super-heavy-lift vehicle Starship could be used to create surface infrastructure to allow for longer lunar expeditions. NASA has contracted SpaceX to modify Starship to carry astronauts to and from the surface of the Moon for Artemis 3. Its volume and carrying capacity are large enough to transform into a significant piece of Moon base infrastructure. Government missions can benefit technologically and financially by leveraging what the commercial sector is already doing or proposing to do.

III Economic Sustainability

The Artemis program will probe whether lunar activity is economically sustainable, that is, whether it is affordable and profitable for the private sector. This will largely depend on whether there is a market for cislunar commodities and services and if in-situ local resources can be used primarily or instead of relying on Earth resources. Investor commitments and private sector activities will also depend on the clarity of policies, regulations, and norms of behavior, especially regarding the safe and responsible use of cislunar space and lunar resources.

The US-led Artemis Accords[4] are multilateral agreements with 21 countries (at the time of this writing) on acceptable norms of behavior in space, largely based on the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space[5] (hereafter called the Outer Space Treaty). However, these agreements are still high-level. There is still work to be done to gain consensus on many topics outlined within the Artemis Accords.

Technology to enable a permanent presence and safe operations on the Moon, such as the development of landing pads or tracking capabilities for cislunar space situational awareness, should be encouraged.

The US may need to develop and fund additional missions for lunar mapping and resource prospecting, especially to better understand regions of great interest to the wider scientific and commercial space community.

Article II of the Outer Space Treaty forbids "national appropriation by claim of sovereignty, by means of use or occupation, or by any other means." Some nations interpret this article as forbidding ownership of property, including mined or collected lunar resources. Other nations, such as the United States, have recognized celestial property rights in law.

Although this issue is settled within US law, it may need to be addressed in more detail to develop a global consensus. This will especially become important once mined lunar regolith or processed lunar regolith materials become a commodity to use in space or return to Earth for commercial purposes. For example, the completion of NASA contracts with three companies to purchase collected lunar regolith on the lunar surface may lead to additional policy and legal discussions on lunar property rights.

Certain lunar locations may be more desirable for mining and in-situ resource utilization (ISRU) operations. Disputed locations of interest may be the lunar south pole, where there are higher concentrations of water, permanently shadowed craters where water ice is less likely to have boiled off, and peaks of eternal light, which may be beneficial for solar power facilities.

A better understanding or consensus must be developed to understand how these regions of interest may be used. A "first come, first use" or "finders, keepers" mentality may not be looked upon favorably by the global community. Agreements between the international community on the use of these special regions may need to be better defined.

Additionally, there may be disagreements between the scientific community, who prefer a more pristine or underdeveloped lunar environment for surface research and deep-space radio astronomy, and the commercial space community, who prefers more lunar development.

Archaeologists and historians may also desire to protect areas of human heritage on the Moon. These heritage sites are protected under the Artemis Accords, and a proposal has been submitted for protection under the United Nations (UN)[6]. Which areas are set aside for protection and what this protection entails, as well as enforcement, need to be better defined.

Gaining a better understanding of cislunar space domain awareness is important for safe operations and national security. Improved satellite registration, coordination, tracking, trajectory analysis, and data verification are needed so proper conjunction analysis can be performed.

The UN maintains the Register of Objects Launched into Outer Space[7]. Some states are slow to provide information to the UN to update this registry after launches. It will become increasingly important to maintain a list of space objects in cislunar space as activities increase and the area becomes more congested, as we've seen with activities in Earth orbit.

Similar to the diplomatic work underway regarding Earth orbit operations, norms of behavior need to be developed and followed for cislunar and lunar operations. It is essential for all parties, especially adversarial states, to understand which maneuvers or close-approach operations are acceptable, for what reasons, and under what circumstances, as well as when to share information about these maneuvers and operations.

1 Vision for Space Exploration, Feb. 2004, https://www.history.nasa.gov/Vision_For_Space_Exploration.pdf
2 NASA's Journey to Mars: Pioneering Next Steps in Space Exploration, Oct. 2015, https://www.nasa.gov/sites/default/files/atoms/files/journey-to-mars-next-steps-20151008_508.pdf
3 Asteroid Redirect Mission Reference Concept, https://www.nasa.gov/sites/default/files/files/Asteroid_Redirect_Mission_Reference_Concept_Description.pdf
4 https://www.nasa.gov/specials/artemis-accords/index.html
5 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205
6 https://www.forallmoonkind.org/
7 https://www.unoosa.org/oosa/en/spaceobjectregister/index.html

Cislunar space domain awareness is also vital to mitigate the proliferation of space debris. Unlike Earth, the Moon does not have a true atmosphere. Atmospheric drag allows for deorbit burns of satellites and other space objects in low-Earth orbit (LEO), which are then burned up in Earth's atmosphere. Larger space objects that survive atmospheric reentry are often targeted to hit an area unpopulated by humans, such as the ocean.

In lunar orbit, there is no atmosphere to burn up space debris and other objects. Although the Moon is currently unpopulated, impacts onto the lunar surface can spray regolith widely and may even send ejected particles into lunar orbit, posing a danger to other objects in the vicinity or in orbit. Accidental and purposeful creation of space debris in the cislunar and lunar environment should be avoided where unintended consequences could cause harm.

The Moon's low-gravity and vacuum environment allow disturbed regolith to spread widely. Surface operations may eject enough regolith to disturb unrelated operations elsewhere on the surface of the Moon or in lunar orbit. The concept of "safety zones" or "keep away zones" has been proposed but undefined. More work may need to be done to reconcile protected lunar areas of activity with Article II of the Outer Space Treaty's prohibition of national appropriations.

Safety zones could be established based on technical, physical, and operational considerations rather than arbitrarily defined. For example, safety zones with landing pads and other mitigation measures could be based on the minimum safe distance that regolith or rocks of a specific size might be ejected outward from a landing vehicle or an area of surface activity. The technical community, rather than a governance body, could develop the criteria to assess safety considerations and set boundaries. Basing safety zones on physical properties and the promotion of responsible operations may increase the international community's willingness to accept zoning precautions as a norm.

The Outer Space Treaty calls for the avoidance of harmful contamination of the Moon and other celestial bodies. NASA classifies most areas of the Moon in its lowest protection classification, Category 1[1]. However, the lunar polar regions (north of 86 degrees north latitude and south of 79 degrees south latitude) and areas around human heritage sites are classified as Category 2, a classification that requires documentation.

With this in mind, the US Government may need to develop more robust and/or broader payload registration and review processes and trajectory tracking requirements. Under Article VI of the Outer Space Treaty, the US has certain obligations for authorization and continuing supervision of non-governmental US entities operating on or near the Moon.

IV Environmental Sustainability

To keep the Moon as a destination and resource for all humanity down through the generations, environmental sustainability must be considered and planned for from the start. This includes mitigating against the creation and proliferation of cislunar space debris and surface trash due to wasteful or careless operations.

Regulations may be needed to lessen the creation of waste on the lunar surface due to industrial processes and other activities and to avoid specific materials that may be difficult to recycle or dispose of.

We have the opportunity to create a Moon base or larger human habitats with more efficiency than typically seen on Earth. Excessive surface infrastructure can be minimized with advanced planning and new technology. For example, developing power beaming technology may be more efficient than laying power lines.

The Federal Communications Commission (FCC) has proposed a new rule requiring US and US-market-operating satellites in LEO to deorbit within five years of the completion of the satellite's mission[2], down from the non-binding 25-year guideline. A similar rule may need to be put in place in lunar orbit, with the added challenge of how to safely deorbit satellites onto the lunar surface or raise satellites into a lunar "graveyard orbit." Enforcement of these rules and guidelines is another area to be explored.

The US Government should evaluate the need for defunct space object salvage laws and/or support such laws should international partners propose them. This is of particular interest for the recycling or reuse of objects in Earth orbit. However, such laws could also benefit the cislunar and lunar environment by allowing for a potentially profitable way for companies to assist in the cleanup of cislunar and lunar objects no longer in use.

The lack of ability to dispose of near-Moon objects in an atmosphere may make near-Moon human-made object salvage rights even more of an imperative to keep the lunar and cislunar environment free of space debris and allow for safer and more sustainable cislunar operations.

V United States Leadership to Create a Cislunar Economy

The US has taken the lead to return to the Moon with a human presence, this time sustainably. Through NASA's Artemis program, supporting defense initiatives, and the Artemis Accords, the US is leading the way to creating a cislunar economy with a human presence.

NASA is a US tool of diplomacy. The Artemis program may be the right opportunity to promote a more open, transparent sharing of data, especially scientific data or data that might benefit scientific missions. Although the Wolf Amendment prohibits direct cooperation between NASA and China, some exceptions have been made over the past decade when it comes to sharing data for scientific purposes or scientific missions. The US may be able to use this period of renewed lunar exploration as a means of creating additional diplomatic bridges between the US, China, and other adversarial nations.

[1] https://planetaryprotection.jpl.nasa.gov/missions

[2] FCC Chairwoman Proposes New Rules to Address Growing Risk of Orbital Debris, Sept. 9, 2022, https://docs.fcc.gov/public/attachments/DOC-387071A1.pdf