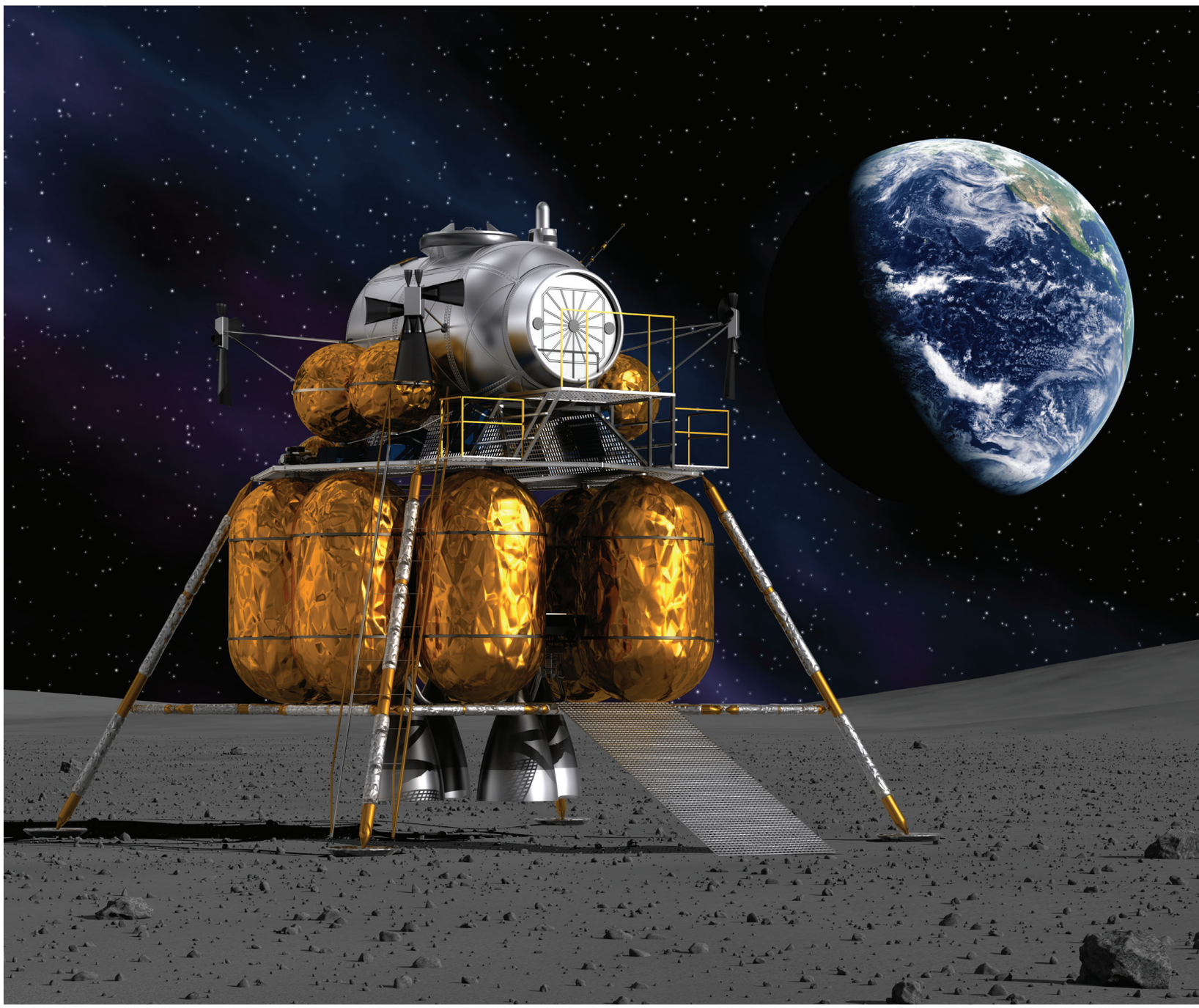
SPACE FOUNDATION

THE SPACE REPORT

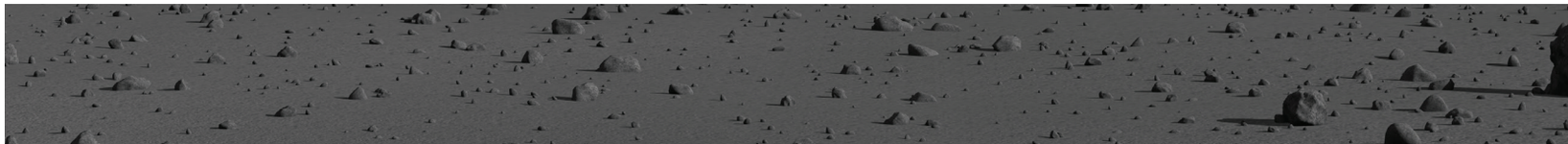
THE AUTHORITATIVE GUIDE TO GLOBAL SPACE ACTIVITY

2021

THE 36TH ANNUAL SPACE SYMPOSIUM SPECIAL EDITION



2020 COMMERCIAL REVENUE | LUNAR SUSTAINABILITY | SMALLSATS AND LAUNCH VEHICLES



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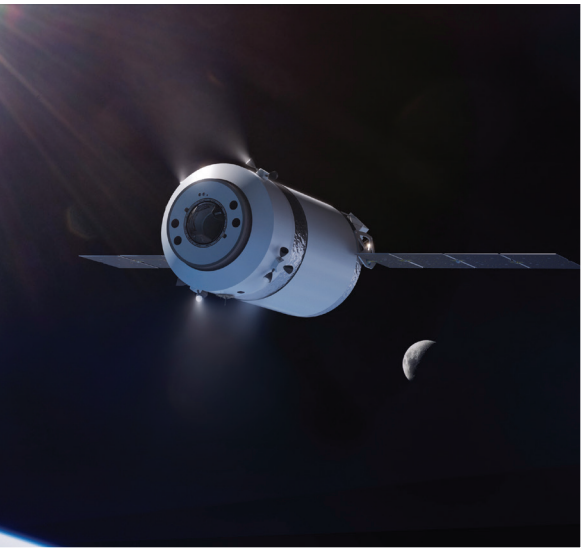


Introduction | *The Moon is re-emerging as a focus for global space exploration activities at a level and tempo that will surpass the peak of lunar activities during the space race of the 1960s and 1970s. Governments and commercial entities across the globe are investing in a suite of lunar missions. As this occurs, the sustainability — across multiple dimensions — of those activities comes into question.*

Illustration of the SpaceX Dragon XL as it is deployed from the Falcon Heavy's second stage in high Earth orbit on its way to the Gateway in lunar orbit.
Credit: SpaceX via NASA

Three Dimensions of Building Toward a Sustained Lunar Return

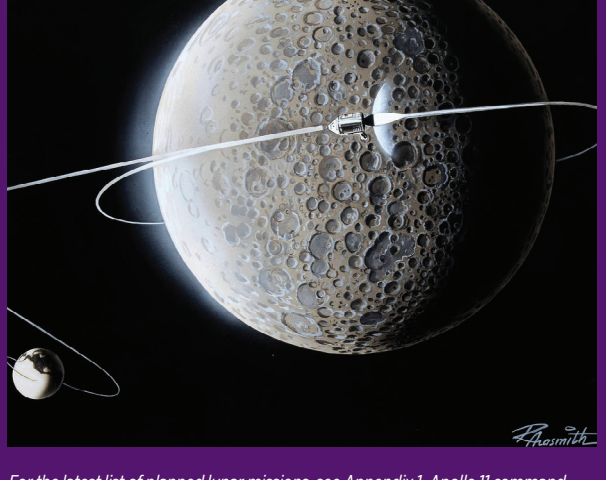
> *The United States shall lead an innovative and sustainable program of scientific discovery, technology development, and space exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities.*
>
> - National Space Policy of the United States of America, December 2020[1]

Government and private stakeholders across the planet are describing visions and plans for a sustained presence on the Moon — a presence that will require multiple users, uses, and activities to interact and develop in a sustainable fashion. Broadly speaking, the sustainability of continued lunar activities might be thought of in three dimensions: exploration, environmental, and economic:

- Sustainable lunar exploration: including activities, capabilities, and infrastructure
- Sustainability of the lunar environment: including environment impact, heritage and cultural considerations, and safety of operations
- A sustainable lunar economy: including public and private investment; the government's role as a customer; and making a market.

These dimensions frame the most crucial issues about how renewed forays to the Moon must be achieved, matured, and expanded to provide for economic, environmental, and scientific outcomes to the benefit of humankind.

Upcoming Lunar Missions



For the latest list of planned lunar missions, see Appendix 1. Apollo 11 command module orbits the Moon.
Credit: NASA

The Different Dimensions of Lunar Sustainability

> *Most agencies have become increasingly interested and committed to exploring the Moon's polar regions and in implementing long-term sustainable exploration missions based on international cooperation and commercial participation.*
>
> - Global Exploration Roadmap Supplement August 2020[2]

The sustained activities and possible economic expansion envisaged in current planning will not be achieved without efforts to address these three dimensions. How we do as a spacefaring community understand these dimensions of lunar sustainability? How embedded is the connection to sustainable practices in planning for the lunar future? Can we identify and track the types of investments and activities being made to achieve it?

Dimension 1: Sustained Lunar Exploration

In August 2019 then-U.S. Vice President Mike Pence directed NASA to submit to the National Space Council a plan for "sustainable lunar surface exploration and development, including necessary technologies and capabilities to enable initial human exploration of Mars." The resultant Artemis Program Plan for Sustained Lunar Exploration and Development[3] describes a high-level philosophy towards building a sustained lunar presence in which increasingly capable and complex capabilities are developed and fielded in lunar orbit and on the lunar surface. These capabilities include robotic and crewed systems. The International Space Exploration Coordination Group (ISECG), a forum of 26 space agencies, has identified 31 technologies as "critical for future exploration missions."[4]

Achieving sustained lunar (and Martian) activities will require development, maturation, and fielding of these technologies. One method to track or measure activity in sustained lunar exploration is to look at the activities and infrastructure government is funding. Space is still a government-driven market and in this early stage of defining a sustainable lunar presence, government investments will likely drive where private business is applying effort. The types of government investment being made, and its magnitude, will indicate which type of lunar activities will be initially dominated. Government data purchases and exploration science priorities may influence the commercial viability or knowledge for space resources utilization activities.

In this new era of lunar missions, full transparency of government spending from many of the participating nations, including China, Turkey, and the United Arab Emirates, is difficult to obtain. Public records and media reports provide a limited scope of the government investment by other nations:

Global Exploration Roadmap Critical Technologies

The International Space Exploration Coordination Group (ISECG) in 2018 identified these 31 technologies as critical for future exploration missions.

Propulsion, Landing and Return
In-Space Cryogenic Acquisition & Propellant Storage
Liquid Oxygen/ Methane Cryogenic Propulsion
Mars Entry, Descent, and Landing (EDL) (Lunar lander applications too)
Precision Landing and Hazard Avoidance
Robust Ablative Heat Shield Thermal Protection
Electric Propulsion and Power Processing
Mid-and High-Class Solar Arrays
Autonomous Systems
Autonomous Vehicle System Management
AR&D, Proximity Operations, Target Relative Navigation
Beyond-LEO Crew Autonomy
Life Support
Enhanced Reliability
Closed-Loop Life Support
In-Flight Environmental Monitoring
Crew Health & Performance
Long-Duration Spaceflight Medical Care
Long-Duration Behavioral Health and Performance
Microgravity Counter-Measures
Deep Space Mission Human Factors and Habitability
Space Radiation Protection
Infrastructure and Support Systems
High Data Rate (Forward & Return Links)
Adaptive, Internetworked Proximity Communications
In-Space Timing and Navigation
Low Temperature and Long-Life Batteries
Comprehensive Dust Mitigation
Low-Temperature Mechatronics
Low-Temperature Mechatronics (with the Moon as a test bed)
Fission Power (Surface Missions)
EVA/Moblity/Robotic
Deep-Space Suit
Surface Suit (Moon and Mars)
Next Generation Surface Mobility
Tele-robotic Control of Robotic Systems with Time Delay
Robots working side-by-side w/ crew

- Russia announced in May that its Oryol, or Eagle program, would require 1.7 trillion Rubles (US$23 billion) to provide a super-heavy launch carrier, related infrastructure, a landing module and rescue means for its crewed lunar space flights.[5] Its Luna orbiter program will require another 15 billion Rubles (US$195 million) a year for that initiative.[6]

- India has estimated that Chandrayaan-3 will cost 6.15 billion rupees ($86.4 million), compared to the 9.7 billion rupees that Chandrayaan-2 cost. Both estimates include the cost of the spacecraft and its launch.[7]

- The United States, for the Artemis program, has obligated funding through FY2020 of $37.2 billion, with $6.6 billion allocated for FY2021 and another $41.7 billion projected through FY2025.[8] That funding includes expenditures for launch vehicles, human landing systems, habitats, and research and exploration missions.

- Japan has promised 51.4 billion Yen (US$472 million) toward the Artemis program,[9] with funding directed toward technologies for the Lunar Gateway, a resupply vehicle, and a lunar lander.

- South Korea pledged in February to put a robotic lander on the Moon by 2030 and will spend 615 billion Won (US$553 million) this year on that goal and broader space technology.[10]

- Canada joined the Artemis Accords and pledged to spend CAD$2 billion (US$1.4 billion) with NASA on the Lunar Gateway project, including CAD$150 million for a Lunar Exploration Accelerator Program to help develop new technologies to be developed in orbit and on the Moon's surface and will develop a new Canadarm3 to help repair and maintain the Gateway.[11]

- Australia has committed to Artemis as well, agreeing to spend AUD$150 million to support the Moon to Mars exploration program.[12]

Eventually government-developed or -funded systems may provide the basis for shared lunar infrastructure; and operations might be transferred to the private sector. A similar challenge is unfolding in low Earth orbit, as the eventual phase out of the International Space Station, and transfer of capbilities to the private sector, is considered.

Dimension 2: Sustainability of the Lunar Environment

While sustained lunar exploration refers to the activities that will be conducted in a future of continual lunar presence, the Moon's unique physical environment will impact our ability to conduct those activities. And the activities themselves will have impact on that lunar environment — in its physical and cultural aspects. As activity increases in the cislunar environment there is need to develop practices for safe and responsible operations in this domain — both to protect the Moon itself and to enable beneficial science, exploration, and development.

Efforts have begun throughout the space community to identify these practices. In July 2020 NASA updated its planetary protection guidelines for the Moon in anticipation of increased activity and in the interests of sustainable exploration.[13] The Moon Village Association has published a set of Best Practices for Sustainable Lunar Activities and is facilitating a Global Expert Group on Sustainable Lunar Activities (GEGSLA)[14] to develop recommendations to the international community. (See the accompanying article in this edition's Space Policy section for details on this initiative.) The Open Lunar Foundation, under a theme of sustainable governance, has published research on several aspects of lunar environmental management practices.[15] The Aerospace Corporation published a paper in June 2020, Cislunar Stewardship: Planning for Sustainability and International Cooperation, emphasizing the need to develop space situational awareness capabilities and space debris mitigation practices specific to the lunar domain.[16]

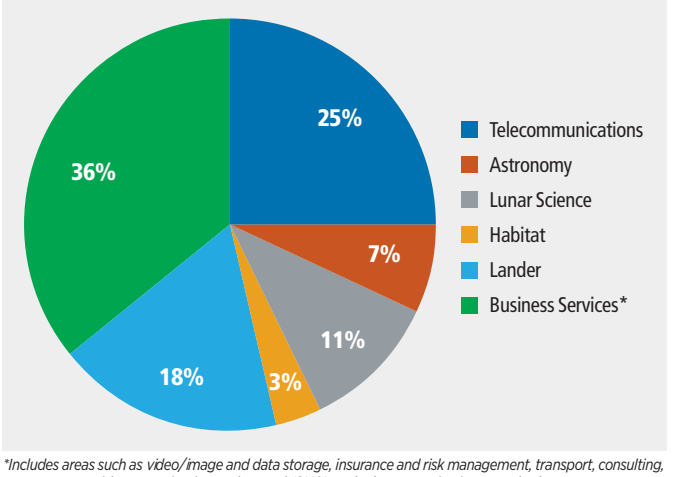
Collectively these analyses begin to identify the environmental management practices that will be necessary to sustain lunar activities. These risks and practices include: space situational awareness, space debris mitigation, lunar dust mitigation, safety zones, interference risks, management of historical and cultural sites, and protection of sites of scientific interest.

Dimension 3: Sustainable Lunar Economy

Many stakeholders see this new wave of lunar activity as a key enabler for the emergence of a larger cislunar economy. United Launch Alliance CEO Tory Bruno has articulated a vision for a "trillion-dollar cislunar econosphere." In this vision, lunar resources, sustained government investment in exploration, the emergence of on-orbit servicing assembly and manufacturing, lead to a multi-trillion dollar in-space economy by the 2040s. Stakeholders within China's state-owned space enterprises have described a vision to develop an Earth-Moon economic activity zone, with some stakeholders describing a potential to create up to $10 trillion in economic benefit value by 2050.[17] While neither of these statements indicate concrete plans or official government policy, they are indicative of the potential space stakeholders see in the cislunar domain.

Developing a sustained lunar economy entails understanding the potential economic activity that might be generated through, and in, the use of the cislunar domain, not as extension of government activity, but by moving from a government-driven market to a business-to-business or business-to-consumer-driven market, in which governments are but one customer type in the marketplace. This entails developing an understanding of the activities and resources that will support sustained growth in profitable space activities, the supplier and customer relationships involved in addressing those market activities, and the policy, legal and regulatory steps necessary to develop a functional market framework.

Survey Results for Distribution of Intended Primary Lunar Services



**Includes areas such as video/image and data storage, insurance and risk management, transport, consulting, autonomous guidance, navigation and control (GNC), and telecommunications standards*
Source: CommStar Communications

Numerous industry, government, and academic studies have attempted to estimate and forecast the potential size or value of the lunar or cislunar economy (or elements thereof). For example, a 2018 market study commissioned by the Luxembourg Space Agency forecasts that "the space resources utilization industry is expected to generate a market revenue of up to 170 billion EUR over the years 2018 to 2045."[18] An April 2020 market study by the consultancy Northern Sky Research "forecasts 140 Moon Missions launching over the next decade to generate $42.3B," with an emphasis on crewed missions.[19]

Each of these studies takes different methodological approaches, different assumptions, or different definitions — and are difficult to meaningfully compare. They all point to considerable potential and considerable uncertainty in development of a cislunar economy. However, most are consistent that government customers will be of key importance in the initial development of commercial capabilities, and that a private market will only emerge following from sustained government investment. Navigating this transition will be a key challenge in achieving a sustainable lunar (or cislunar) economy.

One company, which plans to deliver the first private cislunar communications satellite into orbit in 2023, recently conducted a user survey in coordination with Space Foundation. CommStar Space Communications culled responses from an initial survey pool of more than 4,000 companies, institutions and individuals to ask about planned lunar missions, their communications needs and targeted lunar landing site.

Respondents were allowed multiple responses to mission purposes, with clear majorities presenting for telecommunications and lander activity. In terms of timeline, 50% of respondents plan their missions between 2024-2026, followed closely by 46.4% planning a more immediate goal of a lunar mission before 2023. An expected mission arrival between 2027-2029 was the third-most frequent survey response. Respondents represented businesses in the United States, Europe, Asia-Pacific, South America, and Africa. More than 65% estimated doing five or more missions, followed by 11.5% estimating three or more missions.

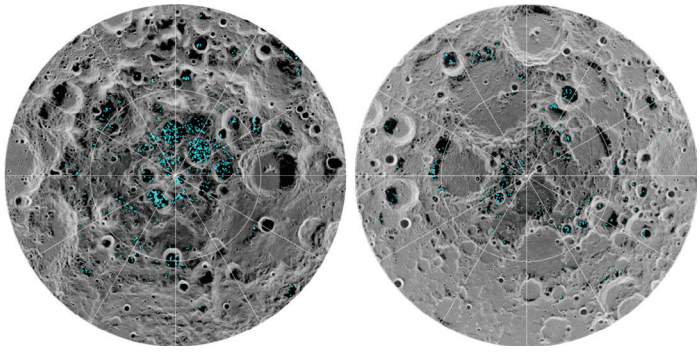
Progressing Toward Lunar Sustainability

> *A "new wave of lunar explorations has been emerging in the world, with participants aiming to make sustainable missions to deepen knowledge of the moon and exploit resources there."*
> - Zhou Yanfei, deputy general designer of China's human spaceflight program, September 2020, Quoted in Space News[20]

If the global space sector is to be successful in achieving a sustained return to the lunar surface, elements of each of these dimensions must be incrementally understood and invested in. All dimensions of lunar sustainability are interdependent: What are we doing on the Moon? How are we doing it? What will it achieve and produce?

Resources vs. Reserves

One of the key resources necessary to support sustained lunar activates is water. Water is of course a critical requirement to support crew operations. Water is also a key resource that can be used to create rocket fuel and potentially catalyze a range of in-space commercial and scientific activities. For example, a 2018 study commissioned by United Launch Alliance identifies "a near term annual demand of 450 metric tons of lunar derived propellant equating to...$2.4 billion of revenue annually."[21] Academic analysis has shown that viable business cases — with positive economic return — can emerge based on lunar sourced propellant. Public-private partnerships with government are shown to be likely to produce greater returns of economic value, however purely commercial business cases are also shown to be possible.[22]



The image shows the distribution of surface ice at the Moon's south pole (left) and north pole (right), detected by NASA's Moon Mineralogy Mapper instrument. Blue represents the ice locations, plotted over an image of the lunar surface.
Credit: NASA

Since 2008 — via data from India's Chandrayaan-1 lunar mission — scientists have known that water ice exists in shadowed craters on the lunar surface.[23] Subsequent missions have provided further analysis. NASA estimates that more than 600 million metric tons of water is present in the polar regions of the Moon, predominately in ice in lunar craters.[24] In October 2020 NASA announced the discovery of water in the lunar regolith, at concentrations "roughly equivalent to a 12-ounce bottle of water trapped in a cubic meter of soil spread across the lunar surface."[25] This finding indicates water exists not only in shaded craters but also in sunlit lunar soil. Yet, as remarkable as the discovery may be, that concentration is less than that of water in the soil of the Sahara Desert.

Just because water exists on the Moon does not mean that the water can be effectively used to support exploration or commercial activities. The terrestrial mining sector refers to "resources" and "reserves." Broadly speaking, "resource" refers to amount of a commodity that exists in in-situ deposits (both known and unknown); a "reserve" is the known part of the resource that can be accessed and used in an economically viable manner.[26] Currently when we speak of water on the Moon, we are speaking of resources, not necessarily reserves.

Efforts are underway to develop further detail on lunar resources. The United States Geological Survey (USGS) has published a Unified Geologic Map of the Moon, which integrates a range of existing lunar geological data to produce a map of the geological surface of the Moon.[27] This map might serve as the basis for further detailed mapping of lunar resources. USGS has already verified that its quantitative methods for conducting resource assessments on Earth can be applied to asteroid mineral resources.[28] The commercial lunar exploration firm iSpace, working with government and academic partners in Australia and Europe, is leading the development of a set of standard terminology and classification categories to describe potential lunar reserves — Lunar Ore Reserves Standards 101 (LORS-101).[29] Based on existing standards in the terrestrial mining sector LORS aims to create a "standard code for reporting space and lunar exploration results, mineral and non-mineral resources (e.g. water), and ore reserves."[30] Such a standard ideally would be used by scientific and industry actors to describe and classify lunar reserves in a manner that promotes transparency and supports a functional marketplace.

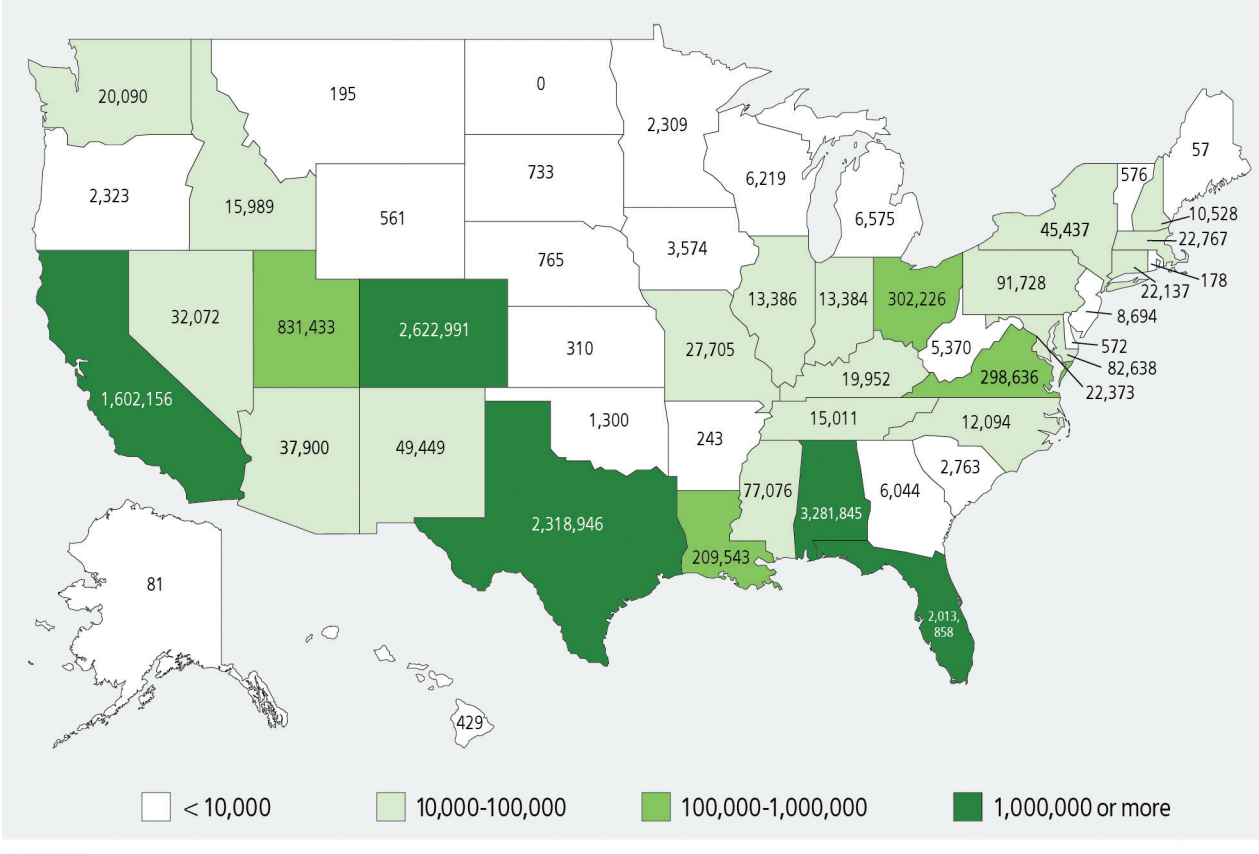
Further efforts to characterize water resources and reserves on the Moon will be necessary to address all three dimensions of lunar sustainability. The locations and sizes of water deposits on the Moon already are influencing the choice of lunar missions and landing sites, and the need to further characterize those deposits will be a key driver of future exploration missions. The presence of water ice in the lunar environment — on the surface and in the regolith — will require balancing scientific and commercial interests, and specific sites of interest or competition may require specialized protection or regulatory practices to manage priority in use or exploration.[31] Efforts to characterize, describe, and access lunar water resources will be necessary to demonstrate economically viable uses, and build business around those uses. Similar efforts will be required for other lunar resources of potential interest — including mineral resources.

Infrastructure Needs for Lunar Operations

Returning to the Moon in a sustained manner requires developing operational capabilities to support continued operations — a different model than the mostly one-off missions that have characterized lunar exploration to date. In July 2020 the U.S. National Space Council noted that "the next lunar explorers will use longer-lasting and more reliable means of habitation, life support, power generation, transmission, storage, surface transportation, and resource extraction and utilization. Surface mobility will enable broader exploration, and reusable vehicles will ferry astronauts and cargo…"[32] Governments are making investments in developing these — and other aspects — of lunar infrastructure. For example, the European Space Agency (ESA) has initiated a set of projects, under an initiative known as Project Moonlight, to provide lunar communications and navigation services. The project aims to provide dedicated telecommunications and navigation infrastructure in lunar orbits and reduce the need for individual missions to dedicate resources and payload space to those services.[33] A pathfinder satellite — Lunar Pathfinder — is under development at Surrey Satellite Technology Limited (SSTL) as public-private partnership with ESA. Due for launch by the end of 2023, Lunar Pathfinder will provide communications relay services for lunar missions and also carry an experimental payload designed to demonstrate the operations of a satellite navigation receiver in lunar orbit.[34] In May 2021 ESA awarded contracts to two competing commercial consortia to conduct concept of studies of lunar satellite networks that might provide communications and navigation services. These networks might ultimately be operated as a commercial service.[35] Since May 2018, China has operated the Queqiao relay satellite in lunar orbit to support its Chang'e-4 lunar mission.[36]

In 2019 Canada established the Lunar Exploration Accelerator Program (LEAP), under the Canadian Space Agency, with a $150 million budget over five years with the purpose of supporting a broad range of lunar exploration related science and technology. In the United States, NASA's Space Technology Mission Directorate has established the Lunar Surface Innovation Consortium (LSIC) under NASA's Lunar Surface Innovation Initiative. The mission of LSIC focuses on communication and collaboration among primarily U.S., commercial, government, academic and nonprofit stakeholders to advance technology capabilities necessary for "successful lunar surface exploration."[37] LSIC has identified six focus areas, indicating key needs for lunar operations: in-situ resource utilization, surface power, dust mitigation, capability to operate in extreme environments, surface access and navigation technologies, and excavation and construction approaches.[38] Addressing each of these areas is complex. For example, an effort under the ISECG has identified an extensive list of Strategic Knowledge

Moon to Mars (M2M) Output Impacts by State (in $ thousands), 2019



Source: NASA
Based on FY2021 Federal Budget

Gaps (SKGs) related to ISRU that must be addressed to enable successful long-term lunar (and Martian) exploration.[39] Sustained funding across a broad base of capabilities will be necessary.

The United States' Moon to Mars (M2M) program, which includes Artemis, represents a significant amount of the current government investment in lunar exploration and its potential for far-reaching economic impact on businesses large and small. Corporations such as Lockheed Martin and SpaceX have won contracts valued at $4.6 billion[40] and nearly $10 billion[41,42] respectively, but a Space Foundation review of nearly $30 billion in NASA contracts shows smaller businesses have won contracts, and NASA procurement officials say more than 2,000 businesses[43] have been awarded subcontracts for products and services ranging from cryogenic propellant management to payload integration and delivery support.

NASA has assessed the economic impacts that result throughout the U.S. national economy from M2M activities,[44] including:

- The total amount of employment generated by M2M activities across the U.S. is more than 69,200 jobs. NASA directly employs 5,563 civil servants to support the M2M program, paying more than $520 million in annual wages and benefits — an average wage of $93,474.
- The M2M program supports labor income of $5.2 billion per year and total economic output of $14.1 billion annually.
- For each million dollars of labor income earned by M2M-assigned NASA employees, an additional $9 million in labor income is generated in the U.S.

This base of contracting investment contributes to economic and exploration sustainability by introducing more participants to lunar activities and working to build an industrial base. These contracts, while not all related to infrastructure, indicate activity in a broad range of capabilities necessary to enable sustained lunar operations. Not all of these contracts will result in successful and long-term viable technology, products, or services. However, tracking the government investments being made across the entirety of the industrial base supporting the lunar program will provide some indication of whether the necessary breadth of capabilities are being developed and supported.

This infrastructure may provide the initial foundation of a sustainable lunar economy — as government investment in a suite of technology developments transitions into government acting as a customer and eventually into a marketplace of private services. In some areas the development of the necessary capabilities to provide the infrastructure for sustainable lunar operations will also help to responsibly manage and protect the lunar environment.

Operational and Environmental Challenges

The Moon is a unique operational and physical domain. Many of the infrastructure investments being pursued are in response to this unique nature — for example, lunar dust mitigation studies or efforts to develop systems capable of withstanding the lunar night. In the context of sustainable lunar operations — operating safely in the context of this unique domain must be a key consideration, including the safety of individual missions and the need to avoid harmful interference with other missions and activities. The Moon also has cultural and historical significance, which increased human activities might disrupt or otherwise affect. As multiple stakeholders become more actively involved on the lunar surface, the need will increase for coordination mechanisms to ensure potentially overlapping and competing uses are balanced. Collectively this group of challenges has led to calls for development of lunar environmental management practices and policies.[45]

This challenge begins in lunar orbit. As more operators become active in lunar orbit, and on the surface, need increases to develop space situational awareness, space traffic coordination practices, and orbital debris mitigation practices specifically for cislunar space.[46, 47] Existing space situational awareness capabilities are challenged to cover cislunar space. A 2020 Memorandum of Understanding between NASA and the U.S. Space Force notes that both organizations are "at current capability limits for extending Space Domain Awareness beyond geosynchronous orbit."[48]

On the lunar surface, management and mitigation of lunar dust is a key challenge. Lunar activities — in particular landings of spacecraft — will create ejecta of lunar regolith and dust. Elements of this ejecta — in particular the dust — can travel long distances in the low gravity environment of the Moon and be potentially harmful to other operations on the lunar surface (and even in lunar orbit).[49] Mitigation of lunar dust as a result of increased activity will be essential in achieving sustainable operations. NASA and other space agencies are funding research into mitigation approaches. One potential approach that has been suggested is the construction of hardened, shared landing pads.[50]

The issue of lunar dust is one example of how lunar activity might pose risk of harmful interference with other activities on the Moon. Other types of harmful interference might occur as well. Some initiatives — including the U.S.-led Artemis Accords and the Hague International Space Resources Governance Working Group — have proposed developing safety zones around specific lunar activities as a means towards reducing the risk of harmful interference and promoting lunar safety.

The suggestion of safety zones points to a broader need to develop practices for deconfliction of activities between stakeholders on the lunar surface. Scientific, commercial, historical, and cultural significance of the Moon must be balanced in an increasingly multistakeholder environment. Practices for doing so will include a mix of policy, legal, and technical approaches, including registries of activities, regulatory and licensing provisions, and information sharing practices. As the Moon is better characterized through exploration efforts — our collective understanding of where overlapping activities and interests emerge will be improved.

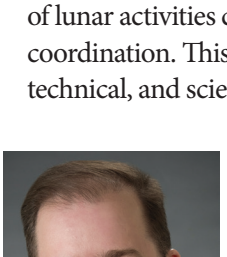
Conclusion: Toward a Functional Market

The three dimensions of lunar sustainability and the initial investments and activities in related areas demonstrate the overlapping interests and stakeholders that are a key feature of a sustained return to the Moon. Sustainability itself can be a key driver – and requirement – in international and multilateral discussions of the governance of lunar activities.[51] In many ways the Moon resembles an economic commons, in particular with regard to its resources and uses.[52] The Moon is a shared resource — under the sovereignty of no state, and theoretically accessible to any government, business or entity capable of reaching it. Yet reserves extracted from the Moon may be utilized and owned. Freedom of use is a principle of the Outer Space Treaty, and several states have recognized the ability to utilize space resources (including lunar resources). Yet at the same time, the Treaty establishes that no state can claim sovereignty over the Moon, and by extension cannot unilaterally grant claim to any part of the lunar surface.

There is need for international coordination and policy to enable a functional and sustainable market on the Moon — that will achieve a balance in all three dimensions of lunar sustainability. Managing rights and access to lunar resources (including regolith, physical sites, and energy) is key toward achieving balance. The legal means to provide certainty to lunar resources utilization claims, to enact protection of cultural and scientific sites of interest, and perhaps to enact safety zones all relate to a central question around priority and access rights to areas of the lunar surface.[53]

The U.S. Council of Economic Advisers, a policy advisory organization in the Executive Office of the President, has argued that establishing private property rights in space is a key enabling factor for growing the size of the space economy, increasing investor certainty, and producing further benefit from space activities.[54] Private property rights in the lunar context might cover extracted resources, enabling their sale and tradability. It is also suggested — based on evidence from terrestrial extractive industries — that establishing a private property and secure claims system might result in more sustainable environmental practices by reducing the likelihood of a rush to extract reserves under an unclear or uncertain rights regime.[55]

However, the realm of private property rights is not the only system for managing usage and ownership rights. Economic theory provides for approaches to management of common areas through common pool resources and rights in the public domain. These theories address the governance and use of resources in the context of a wider range of stakeholders and interests. The applicability of commons management principles regimes to the lunar context is unclear, and efforts are underway to evaluate approaches.[56] What is clear is that a method to balance stakeholders' interests across the range of lunar activities cannot be implemented by a single country or state alone — it will fundamentally require international coordination. This policy and legal coordination will need to be continued areas of investment — along with business, technical, and scientific investments — to enable a truly sustainable lunar future.



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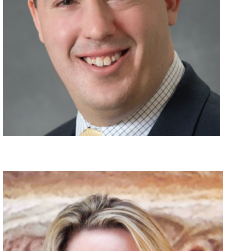

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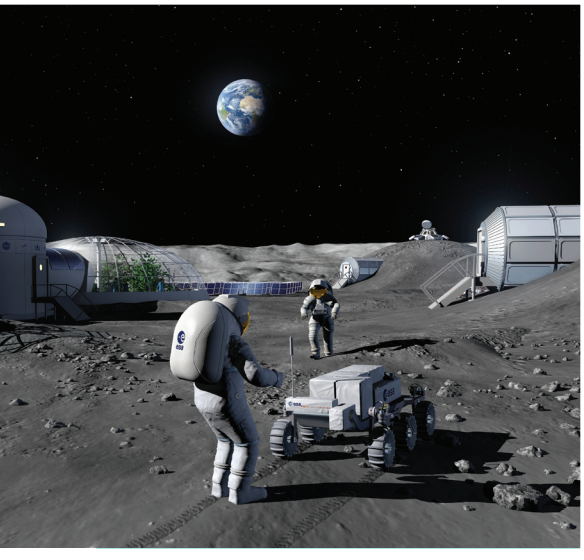
Appendix 1 – Upcoming Lunar Missions

COUNTRY	NAME	EXPECTED LAUNCH	TYPE	AGENCY/COMPANY
Canada	STEM payload	2021	TBA	Canadensys via Astrobotic's Peregrine
	Lunar Exploration Accelerator Program	2022	AI flight computer	Mission Control Space Services via iSpace
	Lunar Exploration Accelerator Program	2022	Lunar camera payload	Canadensys via iSpace
	Lunar Exploration Accelerator Program	2022	Autonomous navigation system	NGC Aerospace Ltd via iSpace
	Robotic Lunar Rover	2026	Polar Rover	Canadian Space Agency/NASA
China	Chang'e 6	By 2030	Robotic probe	CNSA
	Chang'e 7	By 2030	Robotic probe	CNSA
	Chang'e 8	By 2030	Robotic probe	CNSA
EU/Japan/Canada	Heracles/EL3	2027	Robotic transfer/lander	ESA
Germany	DHL	2021	TBA	DHL via Astrobotic's Peregrine
	ALINA	2021	Landers	PTScientists
Germany/Israel	Lunar Surface Access Service	2022	Lander	OHB/IAI
Hungary	Team Puli	2021	Rover	Puli Space Technologies via Peregrine
India	Chandrayaan-3	2022	Lander and rover	ISRO
India/Japan	Lunar Polar Exploration (LUPEX) for water	By 2024	Lander and rover	JAXA/ISRO
Israel	Beresheet 2	First half of 2024	2 landers, 1 orbiter	Space/IL
Japan	Yaoki	2021	Rover	Dymon via Astrobotic's Peregrine
	Hakuto-R	2022	Lander	iSpace
	SLIM	Jan. 2022	Lander and rover	JAXA
Mexico	COLMENA	2021	Micro-rovers	ICN via Astrobotic's Peregrine
Russia	Luna-25	Oct. 2021	Lander	Roscosmos
	Luna-26	2024	Lander	Roscosmos
	Luna-27	2025	Lander	Roscosmos
	Luna-28	2027-8	Lander	Roscosmos
	Oryol (Orel)	2030	Crewed Orbiter	Roscosmos
South Korea	Unnamed	2030	Robotic lander	Korea Aerospace Research Institute
	Korea Pathfinder Lunar Orbiter	Aug-22	Orbiter	Korea Aerospace Research Institute
Turkey	Unnamed	2023	Rocket launch	UAE
	Rashid	2024	Rover	UAE MBRSC via iSpace
UK	Mission 1	2021	"Spider" lander	Spacebit UK via Astrobotic's Peregrine
	Mission 2	End of 2021	Lander	Spacebit UK
USA	CAPSTONE	Early 2021	Navigation cubesat	Advanced Space
	Artemis 1	Nov. 2021	SLS, Orion capsule test	NASA/Boeing/Lockheed Martin
	Peregrine	2022	Lander/ NASA equipment	Astrobotic
	Nova-C	2022	Lander	Intuitive Machines
	PRIME-1	By Dec. 2022	Ice mining equipment	Honeybee Robotics/INFICON/NASA
	Masten Mission-1	Nov.2023	Lander/NASA equipement	Masten
	VIPER	Late 2023	Water explorer	Astrobotic
	Artemis 2	2023	first human-crewed test	NASA/Boeing/Lockheed Martin
	HALO/PPE	2023	Gateway modules	Northrop Grumman/Maxar
	SpaceX dearMoon	2023	Tourism orbit	SpaceX
	CommStar-1	2023	Communications satellite	CommStar/Thales Alenia
	Artemis 3	2024	Human Moon landing	NASA/Boeing/Lockheed Martin

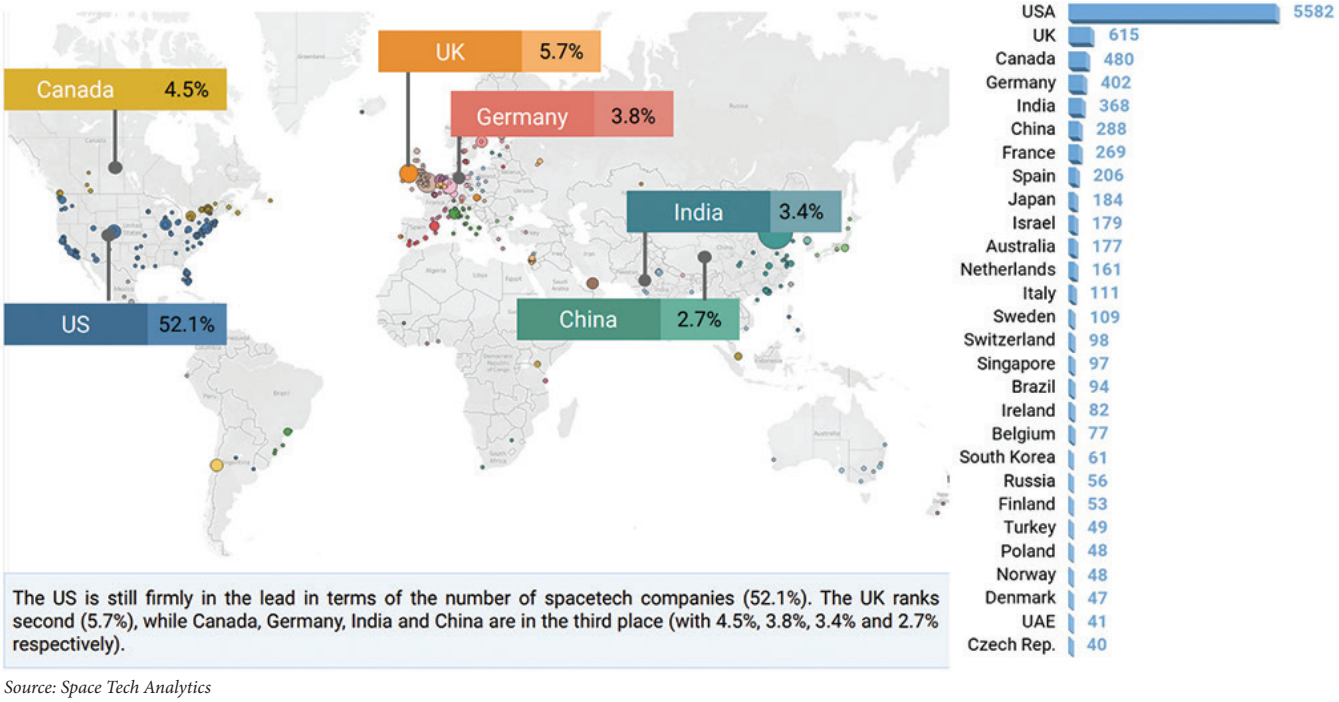


Introduction | *By 2024, NASA intends to land astronauts including the first female on the Moon. The Artemis program is an exciting opportunity for the space industry and all humankind to settle in deep space within the next decades. Even more exciting, the United States is not the only nation venturing into this expanding frontier. 13 other countries have plans for missions to Earth's natural satellite. An international organization is working on recommendations to the United Nations to develop cislunar policies.*

This artist's impression shows a multi-dome lunar base, based on the 3D printing concept. As nations develop plans to explore and eventually inhabit the Moon, there are increasing calls for international policies to determine government regulation and commercial rights. *Credit: ESA illustration*

Getting Along on a Busy Moon

The current $447 billion global space economy[1] is expanding fast. In 2019, before COVID, projections of the UBS Swiss Investment Bank saw it doubling by the end of the decade. Morgan Stanley anticipates that by 2040, the industry will grow beyond US$1 trillion.[2] That growth is pushing developments beyond Earth, making the Moon a very attractive destination for visionary businesses. As shown below, the number of companies sharing that budget and receiving public investment is also increasing exponentially. In the United States alone such enterprises already represent more than 50% of the industry internationally measured by number of companies.



The US is still firmly in the lead in terms of the number of spacetech companies (52.1%). The UK ranks second (5.7%), while Canada, Germany, India and China are in the third place (with 4.5%, 3.8%, 3.4% and 2.7% respectively).

Source: Space Tech Analytics

This increasing number of national projects and private business plans are tracing out a vision of intense human and robotic activities on the Moon for the near future. That interest is not trivial. To leverage the potential of a profitable lunar economy sustainably, the Moon Village Association has proposed and hosted a forum for all major lunar stakeholders

to interact, think out loud, and discuss what procedures and working methods may be required to permit maintaining smooth operations for all on and around the Moon. With 36 members and almost 140 observers, the Global Expert Group on Sustainable Lunar Activities (GEGSLA) was launched in February 2021 to serve as a platform of information exchange. The group will operate for two years until it makes its final recommendations to the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS).

Since 1968, when the Outer Space Treaty (OST) went into effect, there has been no recognized sovereign authority over territory in outer space. As a result, no sovereign state can grant territorial title nor decree legislation that applies to everyone inside a defined set of physical boundaries. Although this probably has prevented a mad scramble to claim pieces of celestial territory by the most powerful of Earth's countries, it also leaves a lot of unanswered questions about how people representing different nationalities, cultures, and institutions are going to interact productively as they pursue scientific and profitable activities on the Moon.

Addressing these unanswered questions is the goal of numerous conversations focused on a word that can bring shivers to the spines of some of those pursuing either private business plans or focused national interests: governance. Although used quite frequently in analyzing decision-making processes and operating procedures in both for-profit corporations and not-for-profit institutions, "governance" often awakens fears of "global government" or excessive regulation. For GEGSLA, the term addresses the processes and methods of engagement that show promise for minimizing conflict and mutual interference among those pursuing activities on the Moon. It is in this context that GEGSLA brings equilibrium among governments, established corporations, and entrepreneurs alike seeking some promise of orderly interactions and predictability on the Moon.

Why GEGSLA?

Forums such as GEGSLA provide immensurable sources of information on how multiple stakeholders plan to operate in space. They create a strong sense of community by identifying not only the basis for soft and hard regulatory regimes on technology and policy, but also on several other key issues that will play a role in human interaction in lunar activities. Many stakeholders, for example, have the potential of creating a large number of problems: Space debris on the Moon, and unintentional interference to interoperability are just a few. Therefore, such forums are essential for mitigation and providing a glimpse on how exploration and fair use of the natural resources available in situ on celestial bodies can be monitored and regulated. Although regulation raises concerns among many potential operators of business activities involving the Moon, the lack of regulation keeping erstwhile competitors from doing whatever they want whenever the want is also grounds for substantial worry.

Because everyone working on the Moon would continue to be subject to the laws of their home country, projects involving people from several different nations will need to reconcile potential difference in the legal obligations faced by team members. If it were to occur on the International Space Station (ISS) this kind of issue might be resolved by the Intergovernmental Committee, but no such group exists to address the potentially far more complicated issues presented by the highly varied activities envisioned for the lunar surface and cislunar space.

In this contest, GEGSLA has begun pursing the objective of outlining guidelines for interaction on the Moon that can reduce the number of conflicts and identify agreed-upon procedures for resolving those that do occur. With no delusion of being the decision-making body on such guidelines, GEGSLA seeks to assemble a well-reasoned collection of principles and practices that can be turned over to COPUOS in time for it to begin consideration of them during its 2023 session. With 93 members, COPUOS represents a broadly diverse group of countries with interests in space ranging from ground station operations to interplanetary missions.

As a private initiative with public participation, GEGSLA is following a political trajectory that has proven effective in several previous processes leading to the adoption of space policy principles with broad international support. Some examples may help establish this point: Current guidelines for planetary protection were developed by the Committee on Space Research (COSPAR), which continues to update them. These guidelines have been endorsed by the United Nations General Assembly and are widely followed. Second, space debris guidelines developed by the Interagency Space Debris Coordination Committee were submitted to COPUOS and greatly influenced the text of the guidelines endorsed by the U.N. in 2007. Third, in 2005, a completely private initiative of the Association of Space Explorers gathered a Panel on Asteroid Threat Mitigation that worked for four years to prepare recommendation for addressing threats to Earth posed by Near Earth Objects. Their report was delivered to COPUOS in 2009 and contributed substantially to the General Assembly's endorsement of two new institutions — the International Asteroid Warning Network and the Space Mission Planning Advisory Group. Both have provided the mechanism for coordinating evaluation and contingency planning for addressing asteroid impact threats. Most recently, the Hague International Space Resources Governance Working Group (SRGWG) concluded its work in 2019 and forwarded a set of recommended policy building blocks and a detailed legal commentary on the group's rationale to COPUOS. Both documents are being reviewed as part of informal consultations on space resources within COPUOS's Legal Subcommittee.

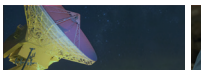
Because these expert group processes get attention and political traction, they are an important part of policy making at the international level. Whether it be for adapting business plans to advocating for one's government to take a particular position for or against, being aware of the existence, progress, and eventual recommendations of expert groups is an essential component of addressing the evolving international policy environment in which space commerce will operate in the decades to come.

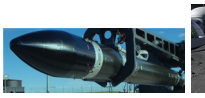
GEGSLA: The Beginnings

GEGSLA began as an initiative of the Moon Village Association (MVA), a not-for-profit organization established in Austria with an international membership. Although a completely independent organization, MVA was inspired by the idea of Jan Wörner, the former director general of the European Space Agency who used the Moon Village image to emphasize the need for community, productive interaction, and mutual support as a foundation for successful operations on the Moon. After conversations with the U.N. Office of Outer Space Affairs to confirm that expert group input on unresolved questions of international relationships on the Moon would be welcomed, MVA put out an open call for volunteers to serve on GEGSLA.

The call specified that volunteers should express their preference for being members of the group or observers. Members have priority when speaking in GEGSLA sessions with the ultimate responsibility for deciding what recommendations and suggestions will be included in documents to be forwarded to COPUOS. Observers are allowed to view all online meetings of the expert group, comment real time through the chat function, speak with permission of the chairman, and volunteer for service on such working groups as might be established for advancing GEGSLA's progress between regular monthly sessions. As GEGSLA voting procedure is done by consensus, the number of members has been limited to 36 with the goal of facilitating eventual decision-making. No limit has been placed on the number of observers. All countries that volunteered to participate were guaranteed a membership seat at the table unless they expressed a preference for observer status. By the time the two-month period of open call ended in January 2021, 174 people had expressed interest in membership or observer status.

The task of selecting 36 members from this list was assigned to a five-member international evaluation committee. This committee began meeting in January and settled on its final list in February. In the course of its work, members sought






a diverse group of selectees not only in terms of gender and geographic connections, but also in terms of professional perspective. Following the approach used by the SRGWG, the committee specifically sought to include members with roots in the commercial sector. To that sector, they added several other categories: government/space agencies, academia, and civil society. Ultimately, the selection included 35 people representing 13 governments, nine commercial endeavors, 10 academics, and three from civil society. In all, 22 countries from six continents were included in the selection. Two important international organizations, UNOOSA and the ITU (International Telecommunication Union) have chosen to participate as observers. Leadership of the expert group was elected during GEGSLA's first meetings, with former Romanian astronaut and UNCOPUOS chairman Dumitru-Dorin Prunariu as presiding officer and Alice Gorman of Australia, Raji Rajigopalan from India, and Kyle Acierno of Canada as deputies.

First Deliverables

On April 19th, 2021, the MVA, as an observer member of the COPUOS, presented its first report on GEGSLA titled "Report of the Moon Village Association on the Global Expert Group on Sustainable Lunar Activities" to the COPUOS Scientific and Technical Subcommittee. The report states that the two most important deliverables of GEGSLA will be a main document titled "Recommended Framework and Key Elements for Peaceful and Sustainable Lunar Activities," and second "Guidelines for Lunar Activity Implementation and Operations" addressing issues such as lunar debris mitigation, benefits sharing, sharing of information, registration of activities, and regulating access to natural resources.

In the main proposal of the report, the MVA also asks for the support of all members of the committee in adopting a new permanent agenda item on the topic of sustainable lunar activities. The adoption will ensure continuity of the efforts. The participation of all COPUOS members will leverage the solid response humanity needs to address the issue of sustainability on the Moon.

The plan is to provide a preliminary draft of both deliverables by early 2022 and the final document by the end of that same year, which is when GEGSLA will complete its activities. The two texts intend to bring forth to the United Nations the needs of the space community and propose solutions for considerations. They are very promising contributions, given the high level of expertise of the members. Hence there is much expectation that the proposals may be incorporated into future guidelines of the committee through the permanent agenda item and a dedicated working group. It is no exaggeration to say that GEGSLA will play a fundamental role in humanity's quest to extend intelligent life beyond Earth, starting on the Moon.

Besides informing COPUOS about the creation of GEGSLA, the report also mentions the early efforts of the MVA for Moon governance, such as the first edition of its Best Practices for Sustainable Lunar Activities, released in March 2020.[3] The edition contains 13 recommendations that reiterate the peaceful utilization of celestial bodies, which is a stated objective in U.N. space treaties, and makes substantive remarks regarding avoiding interference. An example of MVA's perspective is reflected in its recommendation No. 5, Avoiding Harm:

"Space actors are encouraged to take measures to the extent possible:

- To avoid causing adverse changes to the lunar environment or cislunar space, including the harmful contamination of the Moon in contravention of planetary protection policies;
- To mitigate the creation of lunar orbital debris;
- To avoid causing harmful interference with existing or planned lunar activities; and
- To avoid causing adverse changes to internationally endorsed sites of significant scientific or historical interest."[4]

Avoiding harmful interference with existing or planned lunar activities, whether intentional or unintentional, will be crucial for maintaining peace and productive activity beyond Earth. Protecting internationally endorsed sites will assure that areas of scientific and historical interest are distinguished from those for commercial exploration and exploitation. Lunar actors will need to pay careful attention to the four points above to assure a long-lasting, sustainable use of lunar resources and to promote fair competition. Inattention to avoiding harm could lead to major incidents on the lunar surface and might compromise entire space missions and deep space exploration as a whole in the long-term.

While avoiding harm is the core issue being addressed in the MVA document on sustainable lunar activities, Recommendation 8 on space resources and Recommendation 10 on sharing information are also worth attention as they facilitate the understanding of how new ventures on the Moon can be carried out while respecting individual and national rights. The document states that utilization of space resources does not inherently mean appropriation, emphasizing how these activities are in accordance with current space legal frameworks. As such it is reasonably friendly to the foundation of space commerce. Moreover, the report highlights the importance of sharing information about such activities not only to avoid interference but for promoting international cooperation among various stakeholders.

The MVA recommendations for sustainable lunar activities can be downloaded from the association's website and can provide useful insight to the core perspectives behind MVA's interest in launching GEGSLA.

GEGSLA: Work Structure

The MVA's and GEGSLA's first efforts speak much about the way forward with the goals ahead for the next two years. The draft of GEGSLA main document "Recommended Framework and Key Elements for Peaceful and Sustainable Lunar Activities" has three main phases, and members have been divided into four main subgroups. Meetings have occurred monthly and online since February this year.

In the ensuing 10 months, they will work on a large number of pressing topics that ultimately comprise the two most concerning issues already mentioned: avoiding harm and sharing information.

Subgroup 1 – Information Sharing. Within this first subgroup, four topics of discussion have been proposed: Monitoring activities on the Moon to avoid dispute and conflicts of operations; information exchange of activities to promote coordination; the development of a registry of lunar assets, activities, frequencies, etc. (reflecting the Registration Convention of 1976 and Article 5 of the Moon Agreement of 1979); identifying common techniques, common landing zones and spaceport areas.

Subgroup 2 – Safe Operations and Lunar Environmental Protections. This subgroup contains 21 topics, which will subsequently be reduced. Some propose fundamental definitions for "harmful contamination" and "lunar heritage," allowing the further development of codes of conducts. Other topics concern biological waste, pollution, and debris mitigation. Proposal 21 finalizes by fundamentally asking: "decide who will decide which satellites will operate on the Moon (and occupy certain orbits)?"

Subgroup 3 – Compatibility and Interoperability. With eight topics, it is the most technical of all subgroups. It is about developing interoperability standards for mechanical and electric interfaces, shared common stations, and resilience guidelines for the far deep world of cybersecurity. Moreover, it proposes a topic to support the work of the ITU to identify the volume of frequencies on the Moon, signaling this way a possible contribution of the entity on answering proposal No. 21 above.

Subgroup 4 – Responsible Governance. Its nine topics gather regulation proposals for businesses, investments, the public and private sector, the commoditization of space, and the concept of "Moon Commons." It explores the subject of responsible governance and ethical principles based on corpus juris specialis for commerce on the Moon.

A lot is at stake in each single topic, especially with respect to sovereignty. Sharing data of commercial activities may give away information that is often protected by national commercial law on Earth. Countries and companies are not obliged to cooperate on the Moon more than they do on Earth because such a set of binding laws simply does not exist.

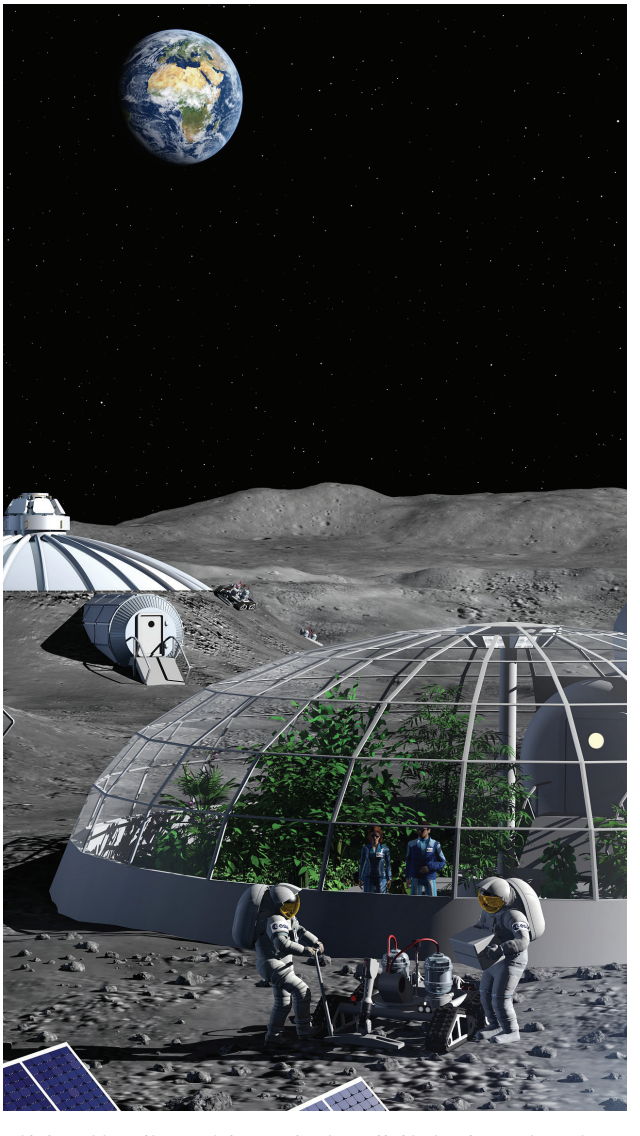
At first, it seems the group is trying to overaccomplish its call. However, the reality is otherwise. GEGSLA has no delusion of being the decision-making body on such guidelines nor does it desire to replace dedicated efforts at the COPUOS. It seeks to add to its contributions. Its means of work, findings, and limitations will be referenced for the development of governance for extraterrestrial commerce for the next decades.

The Moon Is Open For Business

Life on Earth is already very dependent on space applications, and that reality seems destined to increase in the future. Space-based solutions have been expanding across agriculture, transportation, communications, education, and many industries. Exploring and exploiting celestial bodies are part of the drive that will help agencies, companies, and all space actors solve Earth problems. It is with that mindset that Lockheed Martin, Off World, the Luxembourg Space Agency, and the Institute of Space Commerce have sponsored GEGSLA, while representatives of dozens of space agencies, universities, and thinktanks have also committed to the expert group's work.

One company in particular, ispace, has turned its business model toward the Moon, taking a major lead at GEGSLA with its U.S. CEO Kyle Ancierno serving as one of three deputy chairpersons. ispace has been on the top of the Google Lunar XPRIZE competition, raising US$120 million.[5] The company is working to become the first private lunar exploration program with two space missions on its schedule. The missions of ispace to land a rover on the Moon and send high-definition images back to Earth are part of the building blocks of the commercial efforts to spin off developments and provide new products, services, and solutions for society.

With eyes on the future of space commerce on the Moon and beyond, the Institute of Space Commerce (ISC), a North American thinktank affiliated with the International Space University (ISU), and a partner of the International Institute of Space Commerce in Europe, has collaborated with GEGSLA to make space business open for youth. It is the goal of the ISC to



With the anticipated increase in lunar exploration and habitation, there are increasing calls for international law regarding usage rights.
Credit: ESA illustration

make the complex world of space more accessible and manageable to those who will in the next decades take the lead of what has been started. The ISC's goal is another true example of how high-technology is driving education, commerce, and leadership back on Earth, changing lives of youth.

Therefore, even after the work of GEGSLA, the Moon shall remain open for business. The legacy of bringing predictability and governance will continue through the MVA, its sponsors, partners, and participants.

Opportunities for Input

Expert groups are inevitably comprised of a small fraction of those with expertise or interest in the topic under discussion. For those not at the table, this can be frustrating. Fortunately there are ways to be involved with GEGSLA and the issues about which it seeks to make recommendations that don't require a seat at the table.

First, there is the opportunity to become an observer. The number of observers is not limited and participation in this capacity provides immediate insight into the direction that discussions are going and provides an avenue for feedback in near real time. Although observers can be allowed time to speak during meetings, their large number makes that unlikely. Written feedback through Zoom chat or Slack is thoroughly reviewed by the GEGSLA secretariat and its content briefed to the members. Second, with a geographically diverse membership, many people will find one or more GEGSLA members with whom they already have professional relationships. Direct communication with such contacts can ensure ideas and perspectives are not overlooked.

Finally, never lose sight of the fact that any policy decisions emerging from GEGSLA's work will require agreement among governments. That agreement could emerge through the United Nations system or it might take the form of agreements negotiated outside of it. Although broadly supported agreements would provide the most certainty and predictability for business planners and investors, the art of the possible in setting the stage for sustainable lunar activities is not yet clearly understood. This means that traditional paths of advocacy through one's own government will be important once GEGSLA's work is delivered as a final report in 2023.

Conclusion

The next decades can be very promising for space exploration and development if current efforts can find the balance between agreed productive practices and excessive limits. Although much attention will focus on interactions among commercial activities for which there is very little precedent, the deliberations will be extremely important for government-sponsored missions as well.

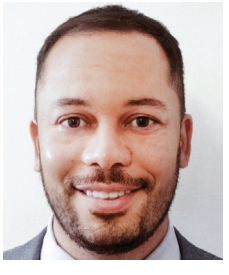
The recent history of space policy development demonstrates that remaining attentive to the progress of expert groups such as GEGSLA is justified by the impact they have demonstrated, especially in the international arena. This attention is also usefully applied to sponsoring groups such as the Moon Village Association, as in GEGSLA's case, because they often shape substantially the direction of the discussion, especially in its early stages. In the case of GEGSLA, MVA's greatest early impact may be in its commitment to create a group that is diverse in terms of gender, perspective, and geography.

The fact that GEGSLA's deliberations occur in a fishbowl where observers can see ideas emerge — whether worthy of applause or criticism — provides an opportunity to see ideas emerge before they are fully vetted and long before they are solidified into rules or expectations. This provides many opportunities to support or oppose the adoption of recommendations as agreed policy.

For the space commerce community GEGSLA has already proven fundamental for the future of ventures on the Moon. The group is a pioneer of its kind for governance of commercial exploration and exploitation on Earth's natural satellite. Simply by insisting that commercial representatives be present at the table, the group has moved away from the practice of earlier groups that relegated business to its own fora or to groups where international representation of governments was absent to restricted.

As with other similar working groups with high-level experts, there is great anticipation and expectation for the outcome of its main document. Unlike the case with some expert groups, GEGSLA seems to present less cause for anxiety to those who pay attention to its progress.

Michael K. Simpson is managing director of the International Institute of Space Commerce and executive director emeritus of Secure World Foundation. He served on the advisory committee that selected the members of GEGSLA.



Elias de Andrade is deputy director at the Institute of Space Commerce. He is an official observer of GEGSLA.

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Section 3 | Space Infrastructure

Three Dimensions of Building Toward a Sustained Lunar Return

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Section 4 | Space Policy

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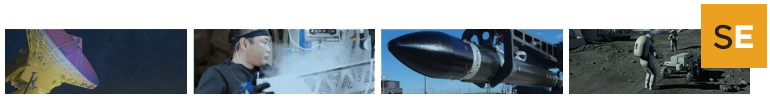

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