Opinion

Where are we on the journey to a lunar economy?

by Giuseppe Reibaldi and Chris Bosquillon March 12, 2025

A view of the moon from low lunar orbit by Blue Ghost 1 before its landing attempt March 2. Credit: Firefly Aerospace

Former NASA Administrator and LogiQ co-president Mike Grif n framed it best: "the question about the vision for space exploration boils down to whether we want to incorporate the solar system in our economic sphere or not." To live off the land within the solar system, not depending on Earth for the necessities of life, requires in-situ resource utilization (ISRU). Some moons of Saturn and Jupiter may be candidates but, with current propulsion technologies, remain off-limit for commercial round trips. For accessible ISRU, we draw a line in the vicinity of Mars and the Main Belt asteroids. Mars is a settlement project self-funded by governments and individuals, with opportunities for privateers. At the other end of the inner solar system, excluding Mercury, Venus may be habitable in its upper atmosphere.

But it is in between that we might have a business case in the making: Greater Earth, comprising of Earth orbits, cislunar space, the moon, and near-Earth asteroids (NEAs), is the piece of real estate that enables propellant depots, with logistical and industrial opportunities. This cislunar perimeter is meant to act as an ISRU hub toward the Solar System. Public funding of lunar political commitment stems from such common sense understanding. Private sector contracts and investors are working hard to make it happen: Intuitive Machines was among the top four best performing space stocks of 2024. But is a cis/lunar economy even a thing at all, if meant as a sustainable market economy on the moon, in its vicinity, and the cislunar space that starts beyond the currently occupied Earth orbits? In a nutshell, we aren't there yet. What follows is a pathway for what it would take to get there.

Cis/lunar commercial development: a clear and pragmatic vision

The moon is the closest planetary body on which to practice ISRU, which would allow humanity to build value chains within the greater Earth perimeter. Moving beyond Flags and Footprints missions, establishing Antarctic-style research stations, producing propellant and setting up industrial pilots would enable a market based on manufacturing and trading industrial goods and consumables, all while developing space habitats in various locations. For the industrialization of space the investment and trade in high-value goods for Earth markets is paramount: dumping unprocessed raw materials from space back on Earth makes no economic sense. Over time, mineral resources from NEAs may be integrated in these Greater Earth value chains. Cis/lunar closed systems and power generation may be used to solve terrestrial environmental issues. This does take decades. Yet, self-sustaining lunar stations may emerge post-2050, invested by international civil and commercial stakeholders with sustained political will and sustainable resources. The biggest market opportunities are cis/lunar transportation, infrastructures, habitat and ISRU, with various power generation options (such as solar and nuclear). Next come essential supporting activities such as communications, agrifood production and consumable supplies.

From speculation to validation

Potentially extractable lunar resources include volatiles such as ice water and oxygen (to be used for propellant, life support systems and radiation shields) and platinum group metals (valuable to tech markets). Helium-3 recently made a comeback with a use case as a cooling device for quantum computers, rather than for the elusive albeit increasingly invested-in nuclear fusion. A rst principle of resources extraction economic realism is to go through the motions of increasing geological (or here, selenical) con dence from resources to reserves: from inferred to indicated to measured mineral resources, it is crucial to precisely quantify mineral reserves, or the techno-economically mineable part of these carefully measured resources — the ground truth. We don't have lunar ground truth yet, so we need to explore, map, measure and extract. That's a lot of missing data, but that is only a rst step.

Next, ISRU needs to not only work but scale up at a reasonable level of industrial production for commercial exploitation. That depends on technology readiness in-situ, not with a prototype on Earth. The subsequent requirement is affordable shipping of a marketable output to a customer in space or on Earth. With capital expenditures, cis/lunar shipping, and the cost in treasure and human health, if the commercial invoice math doesn't add up, you've built yourself a white elephant.

On Earth, a potash mine for fertilizers markets, or an offshore liquid natural gas platform might require dozens of billions of dollars in capital expenditures, and high operational costs. But despite market fluctuations, investors can bet on short to long term markets with anchoring mechanisms: spot, mid-; and long-term contracts, pricing control and production adjustments. With lunar ISRU, there is no market yet; no mechanism to anchor classic debt and equity nancing, derivatives and sustainable insurance models. Public and private partnership models are mostly a g leaf for depending on government backup for decades to come.

So what can be done about this? This may require some creative hybrid model blending seemingly-opposed arrangements such as a command economy versus market-driven private sector capitalism. As made-on-the-moon propellant nears the tipping point of getting cheaper than imported-from-Earth supplies, this may justify long term contracts. Anchor customers for these contracts could be government agencies and departments or ministries of defense, defense industry majors, but also space primes and — why not — industrial majors, such as the mining and energy sector. The model applied to propellant could be adapted for Helium-3 and other validated mineral resources. To juggle pricing would remain an issue, but the point here is that a hurdle would be solved by guaranteeing a steady state of balanced supply and demand, while steadily scaling up at both suppliers and buyers ends.

The market for cis/lunar propellant depots

The techno-economic disruption that would best enable the emergence of a cis/lunar economy would be the decrease in the cost of space transportation in cis/lunar space. Launchers and landers require reusability and the availability of propellant depots in cis/lunar space. Propellant made on the moon or from NEAs makes sense, provided its cost is past a tipping point where it is cheaper to ship it from the moon or NEAs to the depot, compared with the constantly decreasing cost of bringing that propellant from Earth. That tipping point remains a clear catch-22 for the economy of space refueling. Furthermore, there is the cost and there is the market price. A space transporter having decreased costs by over 90% might still charge signi cantly higher market price margins to ensure its own return on investment, and depending on competition.

Overall, assuming that, at least in the next two to three decades, most of the activity will remain supported by government contracts, there is room for commercial transporters and the value chain of private contractors to make deals. But whether their nances are sustainable without recapitalization or consolidation remains to be seen. Companies of all sizes and market positions, from SpaceX and Blue Origin to Intuitive Machines, Astrobotics, ispace, Qosmosys and others, are better off spreading risks across several segments of lunar value chains: by providing, besides transportation, a service platform that supports the above key markets, and transacting high-value data.

Energy needs and nuclear commercial opportunities

Cis/lunar infrastructures require massive, affordable, and sustainable amounts of energy. This is a major bottleneck preventing habitat, infrastructure and industrial production. Space-based solar power has yet to gain traction for Earth rst, but could play a role for the moon. Nuclear power generation is getting renewed traction on both the moon and Earth. NASA wrapped up its Fission Surface Power Project initial phase with Lockheed Martin, Westinghouse and a joint-venture between Intuitive Machines and X-Energy named IX, aiming at a lunar nuclear reactor in the early 2030s. The China-led International Lunar Research Station (ILRS) is cooperating with Roscosmos to set up an automated nuclear reactor by the time the ILRS comes online in the mid-2030's. In the European region, a Rolls-Royce-led consortium aims to develop micronuclear reactors for lunar exploration ahead of the 2030s with funding from the U.K. Space Agency. While waste and security issues loom large and require responsible handling, nuclear comes across as a sustainable space energy solution.

Because the moon lacks any infrastructure, everything has to be built from scratch, generating commercial demand globally for the next two to three decades. Some early stage activities in this sector are just now starting.

The U.N. should de ne the rules for cis/lunar commercial activity

For all these commercial markets to develop in a pro table and sustainable way, there is a need for clarity and agreement between friends and foes on how to proceed. Today, we do not have this for the moon, as the Outer Space Treaty approved in 1967 was not conceived to frame commercial space activities. These are deemed to operate within a non-sovereign domain, somewhat comparable to shing in international waters. What is required is convergence between international public space law and private commercial law. While enabling public lunar policies, this balancing act should secure private interests and not constitute a showstopper for investors. Since lunar "territory" can't be appropriated, it boils down to property rights on extracted materials, priority in exploration and other contentious issues. When it comes to intellectual property rights, regulatory clarity is missing as well.

Furthermore, many missions from commercial and government stakeholders will be aiming to the same location: the lunar south pole. This will create risks of accidents and therefore political problems, underscoring the need for political and legislative solutions. Safety zones could be established around landing sites, but these should not become exclusion zones, which would entail de facto territorial appropriation. The United Nations as a whole, with its Committee on the Peaceful Uses of Outer Space (COPUOS), is the established organization where discussions on de ning how to behave on the moon can and are taking place, albeit at a slow pace. Currently, COPUOS has more than 100 member countries and about 50 Permanent Observers. In 2022, to de ne a much needed implementation framework for lunar resources utilization, a Working Group on Legal Aspects of Space Resource Activities was created within the COPUOS Legal Subcommittee. The output and deliverables of this working group that involves mainly states, but also industry and Non-Governmental Organizations, will be available in 2027. In 2024, COPUOS held the rst Conference on Sustainable Lunar Activities and approved the creation of the Action Team on Lunar Consultation Activities (ATLAC). MVA, as a permanent observer at COPUOS, where it promotes activities to increase cooperation and consultation between countries, previously incubated the creation of ATLAC by working for a few years with the Global Expert Group on Sustainable Lunar Activities) producing a reference framework.

Since ATLAC will become operational in 2025, it will be the focal point for operational discussion between delegations related to how to behave on the moon, in areas such as information sharing, safety zones, lunar debris mitigation, etc. While we agree it will take several decades for signi cant lunar ISRU-driven activity to consolidate into a sustainable cis/lunar market economy, we recommend immediately tackling issues and friction that are bound to happen in this decade. High on the agenda are cis/lunar space situational awareness and traf c management, and protection of human, material and intangible assets. These functionalities, likely driven by governments and militaries, provide numerous opportunities for commercial sector involvement. We recommend speeding up regulatory clarity to accelerate involvement of the commercial sector in this decade. Speci c points of uncertainty and confusion remain, such as property rights for resources and material assets, data and intellectual property rights, priority rights and safety zones since operating in a non-sovereign domain, etc. That should be performed in adaptive fashion with regulations that are t for the purpose of lunar ground truth.

From Flags and Footprints to staying, investing and expanding

No one denies the signi cance of Flags and Footprints. But even more signi cant is who stays, invests, builds, trades and expands. Furthermore, there is no mutual exclusion nor incompatibility between Mars and the moon: these are distinct projects that are already planned to be run in parallel by several countries. Assuming Mars settlements missions will start in the future with flight windows every two years, they shouldn't have to wait for cis/lunar industrial development. Once available though, consumables produced in cis/lunar space may be cost competitive for delivery to Mars. The same goes for orbital and cislunar propellant depots compatible with Mars flight con gurations. Whatever the moon can provide as a test-bed and rehearsal for speci c Mars environments will be useful, which is the rationale behind "moon-to-Mars" programs. While the moon and Mars environments do strongly differ (they have different gravity, atmosphere, temperature, radiations and regolith) they may support each other's self-suf ciency by testing and producing equipment and consumables. Human health and medicine training for long term duration space missions can also be scaled from the moon to Mars.

To expand on Mars and beyond is about the quest for human survivability and the spirit of exploration, before it becomes a business case across the solar system in the coming centuries. But today, the debate over whether it is worthwhile to invest in, build, trade and expand logistic and industrial activities in cis/lunar space also raises questions about economic development, space assets security, and leadership positions that both bene t Earth and enable access to the solar system. Granted, the business case is yet to be fully validated, but it is also about leading with a robust industrial and trading culture, or falling behind technologically.

Today, India, China, Korea and Japan all sustain moon programs with cis/lunar space technology as the strong home of their solar system expansion. This requires globally engaging new-to-space industries, especially those in the Indo-Paci c. Australia, New Zealand and ASEAN are thriving. Thailand balances partnerships with both Artemis and ILRS. The Indo-Paci c region's terrestrial dominance in natural resources, energy, shipping, industrial trade and investment stems from value chains that sustain large scale resources and industrial project nancing. With decades of practice in such elds as a resident within this region, we see this industrious collective as a segway to an ISRU-driven cis/lunar economy: an Indo-Paci c t to lead a Solar System economic expansion. By supporting entrepreneurship, this region acts as a reliable cis/lunar economic development partner for Latin America, the Middle-East, Africa and Europe.

It is time to understand that, not only is the moon not a distraction, it is clearly seen as strategically relevant by major industrial powers in ways that warrant stakeholder investment into economic expansion and security. And even though it takes decades to close the cis/lunar business case for a realistic market economy, it would be a mistake not to start investing in the sustainability of commercial cis/lunar activities. Not after 2050. Now.

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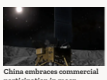

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