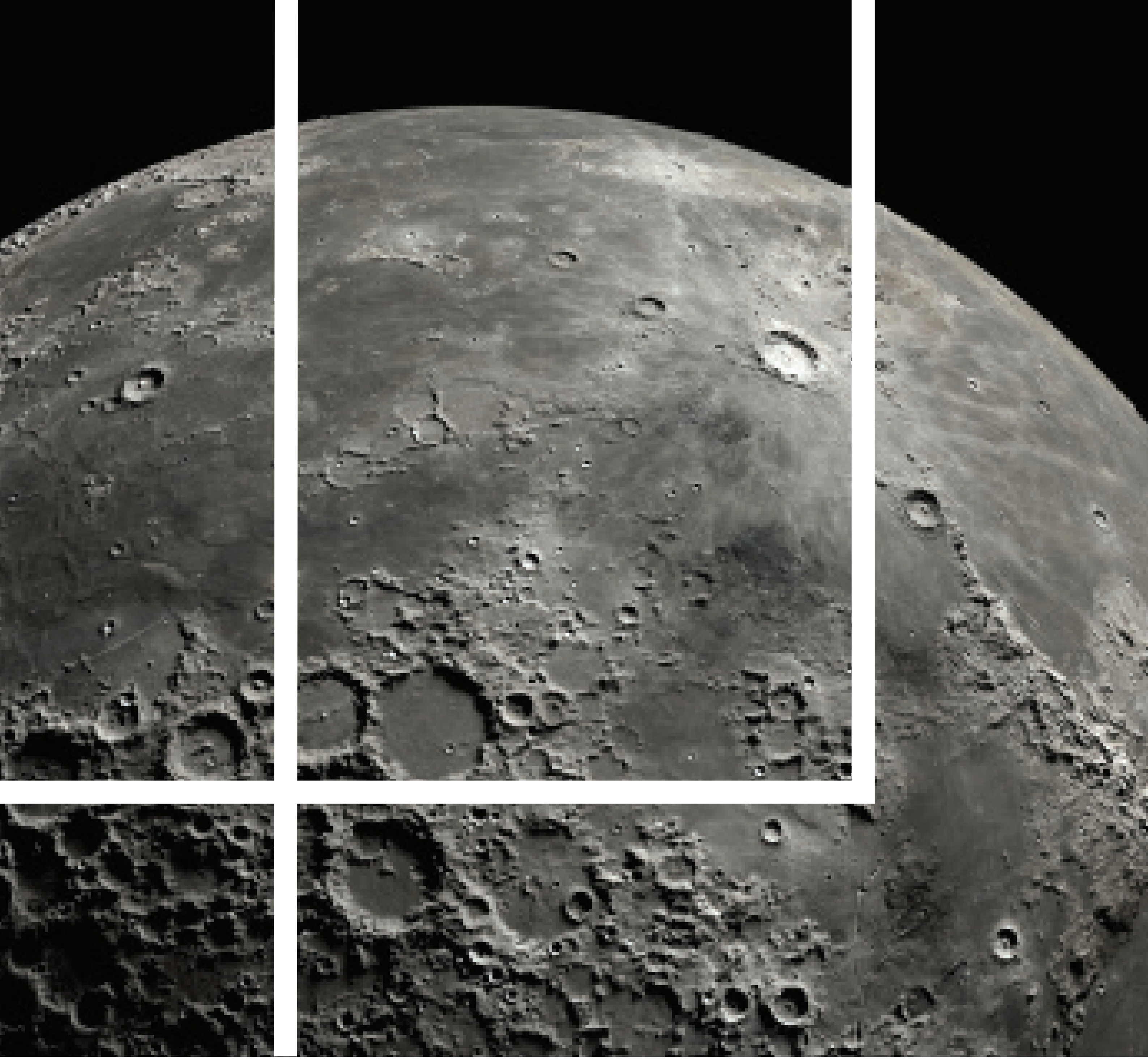

Lunar market assessment: market trends and challenges in the development of a lunar economy

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Prepared by PwC

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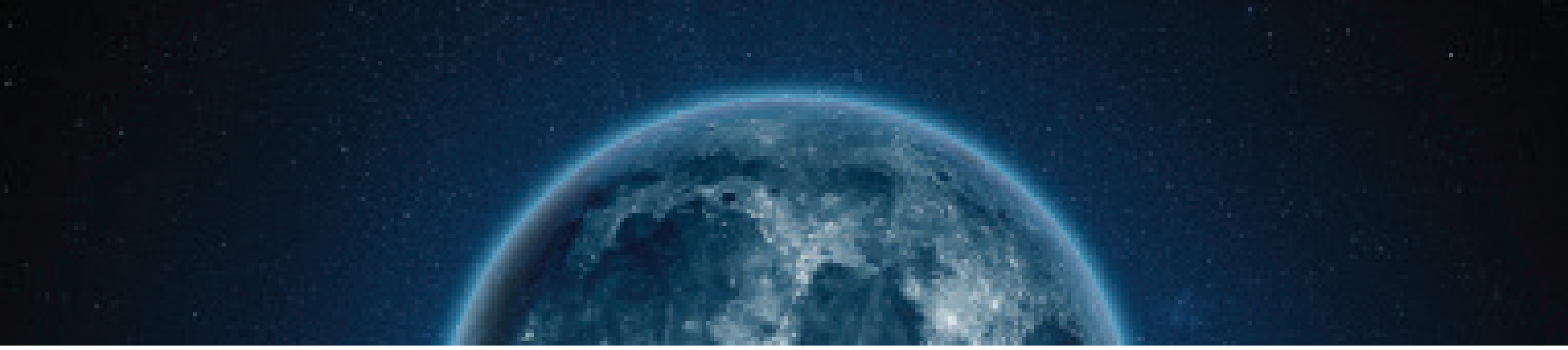


1 Introduction

The three main types of activities considered in this lunar market assessment

As humankind's space odyssey continues, the next chapter sees a target of returning to the Moon and establishing a permanent presence there. Success in this venture would lay the foundation for the beginnings of a lunar economy. A lunar economy encompasses all general economic activity associated with the production, use and exchange of lunar resources on the Moon's surface, in lunar orbit and on Earth. While there are a huge variety of potential activities that fit into the definition of a lunar economy (in particular for what concerns the support activities to human presence on the Moon), this paper focuses on three types of lunar activities: transportation, lunar data and in-situ resources utilisation (ISRU).

The first, transportation encompasses both cislunar space and lunar orbits, including the travel routes between Earth and the Moon, and is driven mainly by the ferrying of humans and resources to and from the Moon in order to develop our presence in the Moon's vicinity and on its surface. The second, commercialisation of lunar data, covers the exploitation, on the Earth, of different types of data gathered during lunar missions. It mostly includes technical data associated in general to the preparation of space missions or research on space resources, and is completed

to a smaller extent by entertainment

data for various leisure applications on Earth. The third, exploitation of in-situ resources, includes mining and extracting resources, manufacturing products, building infrastructure, as well as exporting goods and materials – for scientific purposes, to support human presence, or as commercial activities in the medium and long term. These activities, almost identical in nature to their terrestrial counterparts, are the basic building blocks of establishing a self-sufficient lunar economy.

The lunar exploration ecosystem extends beyond space agencies, involving private actors and non-space industries

space entities stand to benefit from its development. Space entities, such as providers of space transportation infrastructures and technology or manufacturers of space equipment, will profit from a surge in demand for spatial capabilities and services. This demand will be stimulated not only by increasing lunar economic activity, but also by the future opportunities that will be unlocked and created from a self-sufficient lunar economy, such as markets for deeper space exploration to other planets. Non-space entities are the less obvious beneficiaries of a functioning lunar economy; however, they stand to benefit greatly from its growth nonetheless. These terrestrial industries (mining, automotive and construction companies) with nascent connexions to space technologies might constitute a driving ecosystem for the lunar economy, as they become downstream beneficiaries of spillover effects created by space innovations.

As of today, many private companies have taken initiative and are very well positioned to offer transportation, data or in-situ technologies in support of future lunar missions. In parallel, national agendas have become even more space-focused, with particular attention given to the Moon, setting ambitious goals and coherent roadmaps. To create and sustain a full-fledged lunar economy, a crucial factor will be a strong, continuous collaboration between public and private entities – through the thick and thin of dynamic market forces. Over time, particularly in the short-run, markets will need to adjust to disruptive innovations, fluid political agendas and other external forces. Existing collaboration between private and public entities in other space domains should play a decisive role in the context of such risky and capital-intensive endeavours, for instance through co-financing, support to R&D and establishment of anchor customers for first commercial providers involved. Such collaboration would drive the success rate and increase the pace of lunar ambitions, to ultimately unlock the transformative potential of a lunar economy.

The high stakes of a lunar economy call for a close monitoring of the drivers and challenges ahead

A lunar economy will undoubtedly have far-reaching effects on various aspects of society; primarily touching the economic, political, and scientific spheres. First, the main drivers leading economic transformation should be observed in technological innovation, the creation of new industries and markets, and high levels of public investment., These three factors will in turn have positive effects on the growth rates of terrestrial industries. Second, a growing lunar economy will be closely intertwined with political agendas and the complex web of international relations. The Moon and all its potential represent undeniable strategicand nationalistic opportunities, which terrestrial super-powers are sure to covet. Finally, there is an equally important scientific element. The research conducted on Earth to enable the feasibility of establishing a lunar economy, paired with the potential spatial knowledge which will be gained from time spent on the Moon will be invaluable to the furthering of science.

Today, the different activities and markets under consideration are in their nascent phase, with a renewed dynamic from the recent re-focus from various space agencies. There are still several unknowns which remain, regarding the pace at which markets will mature, the success of technological demonstrations, or how much business potential can be expected in the coming decade. It is important to pinpoint and monitor the drivers for these markets and identify the early signs of success and challenges in the current roadmaps announced by various space actors. In that vein, this paper provides a state-of-play analysis across lunar transportation, resources exploitation and data commercialisation activities, in order to support the identification of present and future business opportunities associated to these markets.

2 Lunar transportation market

2.1 State of play

2.1.1 Introduction of the transportation market

Today, there are many different types of actors aiming for the Moon, either as a final destination (for research and exploration, or preparation of a sustainable presence for instance) or as a new source of data to conduct experiments in support to other activities. These end customers include institutional players (such as space agencies) as well as private actors (space companies or companies involved in terrestrial activities) who wish to exploit the obtained data and services for their own needs or commercialise it. Depending on their needs and the activities they hope to conduct, these actors rely on different profiles of vehicles (including orbital payloads), landers to descend to the lunar surface, and rovers to explore different areas of the Moon.

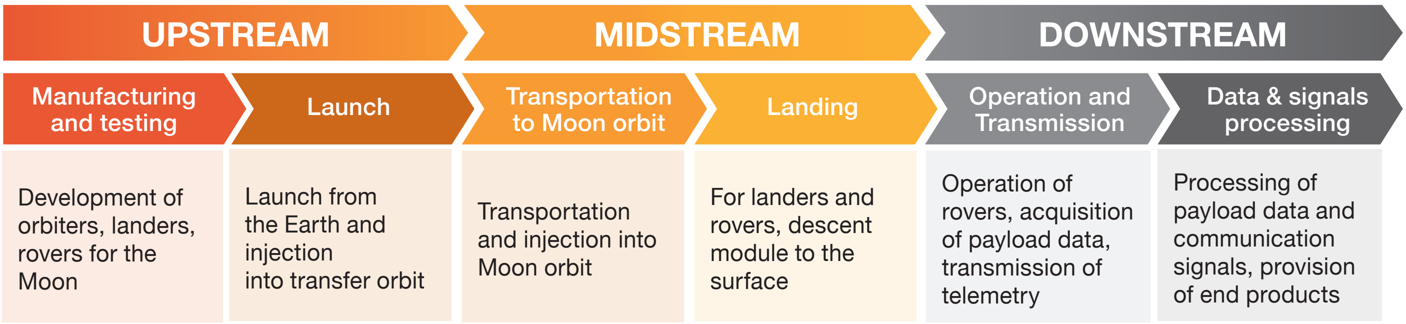


Figure 1 - Value chain for Lunar transportation market

These actors all face a common challenge of accessing the Moon, from its orbits or landing on its surface. Some actors are choosing to develop their own vehicles as means to reach the Moon, while others are focusing on their payloads and outsourcing their transportation needs. In addition to the journey itself, payloads for the Moon also rely on means to communicate with Earth, both for telemetry and control, and for the downlink of the data.

As needs vary greatly by actor, so do the masses of their payloads - with some payloads weighing just a few kilograms to others weighing more than a ton. As the complexity of the mission also differs based on the vehicles' main purpose, the price per kilogram also varies substantially on a case by case basis.

2.1.2 Supply and demand Characterisation

2.1.2.1 Public sector

Traditionally, the public sector has predominantly been the only customer for space exploration applications, with very little involvement from the private sector. This is mainly due to the fact that such activities have been driven by national strategic, scientific or academic motives, and commercial opportunities had not yet been explored.. Today however, the status quo is changing, as governments and their space agencies are dedicating more and more resources to developing a self-sustaining private space ecosystem, Some examples of public sector interest to explore the Moon are,

USA

USA's efforts are dedicated to creating a sustainable commercial lunar economy for the future, which will culminate in landing the first woman and the next man on the moon by 2024, as part of the Artemis program. During the initial years of this program NASA will be the anchor customer via the CLPS programme.

European Union

ESA has a clear lunar vision stated in the European Exploration Envelope Programme (E3P, now Terrae Novae), in the Science programme and in the Moon and SRU strategy, that together set mid-term goals for 2030. The European Commission is working hand in hand with ESA in space exploration but has also directly supported initiatives via the H2020 programme (e.g. LUVMI lunar rover). In addition, the EC represents EU countries at the International Space Exploration Forum (ISEF) and will be organising the third edition in 2021.

Russia

Russia has strongly cooperated with ESA as part of the Luna Programme (Luna 25 and 27), but very few with other space agencies. It is currently making efforts to cooperate with NASA (space exploration on Artemis Accords) and Luxembourg (Russia is awaiting Luxembourg's decision to become part of the Multilateral Agreement for Mining in Space).

China

China released a three-phase roadmap in the early 2000s for their Chang missions. Phase 1: achieving lunar orbital missions of probing and studying the surface of Moon. Phase 2: demonstrating lunar landing capabilities using landers and rovers. Phase 3: achieving sample return missions to study lunar materials. Phases 1 & 2 have since been achieved and phase 3 is in-progress. The Chang missions of this program also serve to support China's longer-term objectives and milestones.

Japan

Japan has set high ambitions regarding lunar exploration activities including manned missions by 2029. In 2020, Japan launched a new lunar exploration roadmap that details their high level objectives between 2020 and 2050.The 2020s will focus on technology demonstrators of ECLSS, transportation and lander & surface exploration etc. The 2030s will shift focus to ISRU activities, then to sustainable exploration in the 2040s up to private sector led exploration in the 2050s.

India

ISRO has developed 2 Lunar missions thus far, including a lander and a rover. However, the failure of Chandrayaan-2, has been a small set-back for India in terms of its lunar exploratory endeavours. Nevertheless, ISRO is already planning the development and launch of chandrayaan-3 in 2022.

South Korea

The Korean Lunar Exploration Programme (KLEP) is a two-phase KLPO (Korean Pathfinder Lunar Orbiter) developing orbiter, lander, rover and ground control infrastructure.

Canada

Canada is fostering relations with other space agencies notably ESA and NASA, Theyalso signed the US Agreement on resource mining on the Moon.

United Arab Emirates (UAE)

While the UAE via its MBRSC has been dedicated towards developing a sustainable Martian society by 2117, recently the nation has announced its plan of sending a rover to the Moon by 2024.

2.1.2.2 Private sector

2.1.2.2.1 Space Sectors involvement in Exploratory Activities

Significant steps were moved by the private sector into the wider space exploration domain (in lunar exploration, in Space Resources Utilization, or in the commercial exploitation of Low Earth Orbit). The demand (and associated spending) for space exploration activity remains substantially institutionally driven, but a fundamental shift in the role of space agencies and governments from developing agencies to service procurement agencies ("Moon as a service") have moved the capability developments and risk-taking to the private sector (in a similar fashion to what happened within the Launcher segment with the raise of privately developed launch vehicles propelled by public procurement contracts for launches).

Thus, a growing number of private companies have been honing capabilities for space exploration, including spacecraft design, payload transport capabilities, launcher capabilities, resource identification and mining, astronaut shuttling, and more. The involvement of commercial actors remains primarily supported by government contracts and investments even in the development phase, but by delegating the development of these capabilities to the private sector, governments and space agencies are ensuring they receive the best end products, at competitive prices, while simultaneously helping foster growth and success in their respective private space sectors.

United States

In the United States, the private space sector is playing an increasingly greater role in the future of lunar exploration. There are myriad examples of public sector initiatives and programmes (primarily from NASA) which are driving the growth of private firms (such as SpaceX, Boeing, and Blue Origin). For example, NASA's super heavy lift Space Launch System (SLS) is being built by Boeing for the Artemis Program (returning humans to the Moon by 2025) – with payload capacities reaching 45,000 kg. Another example is the Orion Multi-Purpose Crew Vehicle (MPCV), co-designed by Lockheed Martin and Airbus Defence & Space, to house and shuttle a crew of up to six NASA astronauts into outer space. In the frame of Artemis Human Landing Systems, NASA doled out three bid contracts to SpaceX, Blue Origin and Dynetics (recently awarded to SpaceX), to develop human class landers for astronaut landings on the Moon. In parallel, the VIPER mission planning saw NASA award three contracts to Astrobotic Techology, Intuitive Space Systems, and Masten Space Systems, to develop lunar landers that will transport a specialized rover to the Moon, to survey and map the lunar surface in anticipation of human landings. Another illustration of private actors' involvement is the contracting by NASA of Firefly Aerospace to deliver a package of 10 science and technology missions to the lunar surface in 2023, using Firefly's Blue Ghost lander. These examples are few in many of PPPs between the NASA and an ambitious, growing private sector.

Japan

Japan is another nation with strong lunar ambitions and an efficient PPP framework, which is helping foster the growth of its private space sector. For example, Japanese company Mitsubishi was contracted by JAXA to build the H3 launcher and HTV-X ship, to deliver payloads and cargo directly to the Moon by 2025 at competitive costs. Another example is automotive company Toyota, who is co-designing and building an electric human-driven rover called the Lunar Cruiser alongside JAXA, for future use on the lunar surface. Another example is the space start-up iSpace, who recently raised around $90 million in funding, in part from important government-backed companies, and is developing a lander and rover for lunar exploration. Furthermore, in 2018 the Japanese government established a $940 million venture capital fund to support space-related start-ups. These different examples of commitments and agreements between public institutions and private companies is helping take the Japanese private space sector to new heights.

Europe

In Europe, ESA has consistently been seeking out and supporting commercial services for lunar exploration. For example, one of the most notable PPPs in Europe is the Lunar Pathfinder project, a satellite that will orbit the moon and offers communication services to different assets on the lunar surface. The Lunar Pathfinder project is backed by ESA and co-developed alongside private space firms Surrey Satellite Technology Ltd and Goonhilly Earth Station. Another example is ESA selecting private companies ArianeGroup and PTScientists to collaborate on a future lunar exploration mission. ArianeGroup is responsible for the launch and ground control services, while PTScientists are developing a lunar lander, in the hopes of landing on the Moon in 2025. European actors are also involved in international programmes, for instance through ESA's long-term involvement in the NASA-led programmes. As such, ESA awarded Airbus Defence & Space with a contract to build three additional Orion MPCVs, while Thales Alenia Space is developing two key modules for the Lunar Orbital Platform Gateway, a small space station designed to orbit the Moon and support human presence on the Moon. The European private sector is rapidly expanding in the field of SRU, with growing private firms such as Maana Electric (specializing in In-Situ Lunar Resource Utilization) and OffWorld (developing AI-powered robotics for lunar resource extraction).

China

China has proven its commitment and capabilities in space – such as achieving the first landing on the far side of the Moon – and has made no secret of its desire to return to the Moon. However, China's missions to date have all been state-backed and state-operated ventures, and the country has only recently opened its space sector to commercial entities, albeit maintaining strict limitations to what private firms can develop and manufacture. Despite these restrictions, a little under 150 Chinese firms have already registered to integrate the growing Chinese space sector – such as space exploration company OriginSpace – and more are sure to follow. China's model may differ from the United States' and similar nations for now, but the government will certainly want to tap into the creativity and innovation of the private sector in the near future (as witnessed in other space domains such as micro-launchers), as the scale of space activities ramp up and the Moon becomes more and more accessible.

Russia

In Russia, missions are predominantly state-operated and state-backed projects. Roscosmos, Russia's national space agency, does employ the technologies and capabilities of subcontractors and subsidiaries such as NPO Lavochkin and RKK Energiya, although these companies are state-backed and rely heavily on Roscosmos contracts to operate. Despite the lack of a strong private sector however, Russia has, and continues to be a major player in space, and hopes to land humans on the Moon by 2030, with a permanent lunar base established by 2035 – which will most likely spur private sector growth in the future, and make the current firms more self-sufficient.

2.1.2.2.2 Non-Space Sectors involvement in Exploratory Activities

Space agencies and the public sector have recognised the role that the terrestrial industry could play in space exploration and have deployed strategies to encourage their participation. While it remains unlikely in the short term that non-space companies will launch collaborative missions with space entities (public or private), many non-space organisations have demonstrated their interest in observing and supporting some of the developments of space technologies, through partnerships with space agencies or other space companies. They are expected to contribute through co-funding, mission support or by acting as co-developers of technology. The growth of terrestrial industries in the space exploration is extremely dependent on government action and policy. As this market evolves, non-space actors could potentially become direct customers of the space transportation market. Among the main non-space industries that demonstrated some interest in space exploration, automobile, O&G and mining, construction and energy are all expected to influence the exploratory market by approximately USD$ 4-5B for the coming two decades (2020-2040). Some examples of the involvement of organisations from these sectors within the exploratory market are listed below:

Automotive Sector

GM — In 2015, NASA partnered with GM to develop a faster, more dexterous and more technologically advanced robot, Robonaut 2

Audi — In 2016, PTS partnered with Audi to help build and launch a 3D printed rover.

TOYOTA — In 2019, JAXA and Toyota announced their collaboration on international space exploration.

The automotive industry is actively involved along space actors, as illustrated by actors such as GM in the US, Toyota in Japan and Audi in the EU. The automotive market provides expertise in the development of lunar rovers, or in the development of technologies required for automated vehicles, efficient power supply, and vehicle resistance to harsh environments. The investment from the automotive sector is expected to leverage the spin-along capabilities that could be envisioned between the space sector and the automotive sector. The involvement of this industry in the lunar economy is concrete, as exemplified by Toyota's cooperation with JAXA targets the Moon exploration and particularly manned missions as early as 2029.

Mining Sector

Caterpillar undertook several research programmes related to remote-operating systems to minimize the danger in hazardous environments on Earth or in space.

Rio Tinto collaborates with ASA to valuate how its mining technology and drills an be used to extract space resources.

Woodside Energy and ASA have signed an agreement on technology transfer between the space sector and the O&G industry mainly for: robotics, advanced sensors, AI.

The O&G and mining industry is also expected to play a significant role in advancing the potential opportunities available on the Moon, Mars and other celestial bodies, stimulated by the synergies in resources extraction and exploitation. The involvement of O&G and mining organisations will involve spinning off terrestrial mining and drilling technologies and applying them in space, enabling several components within the SRU value-chain. Companies like Caterpillar, Rio Tinto or Woodside exemplify this phenomenon, as they all are engineering their technologies to apply them to the SRU sector. As SRU beings to take shape and technologies mature, the advancements achieved in space technologies relating to mining equipment could also have positive effects on the terrestrial mining sector, such as improving the capabilities of these technologies on traditionally harsh terrestrial environments where current robots are limited.

Construction Sector

Foster + Partners is part of a consortium ESA developed (around 2013) to explore the 3D printing of lunar habitat using in-situ resources. Monolite, another earth-based company that is part of this consortium provides the D-shape printer.

The construction industry is expected to support the development of modern techniques that would enable building lunar habitats and structures in space while simultaneously facilitating the terrestrial industry in advancing 3D printing (additive manufacturing) capabilities.. Here too, the construction sector is expected to grow alongside the space industry, more specifically with the development of the lunar economy.

Energy Sector

Skyre partnered with Meta Vista USA LLC, to develop a system that makes propellant from permanently frozen water located at the Moon's poles, including processes to separate the hydrogen and oxygen, store them in cryogenic conditions and hydrogen as a refrigerant to liquefy oxygen.

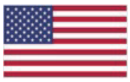
OxEon Energy worked with the Colorado School of Mines to integrate an electrolysis technology to process ice and separate the hydrogen and oxygen on the Moon. The molecules could then be cooled to produce fuel for cislunar transport.

Robotics Sector

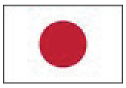
Robotics start-ups have partnered with JAXA since its Avatar X project launch with ANA holdings (2018). They are developing advanced human like robots that would replace astronauts in operations such as construction in space or maintenance.

The energy industry and **the robotics industry** will also play vital roles in investing and developing lunar exploratory activities. The energy sector is expected to leverage the development of cleaner and efficient technologies required for space applications, while the robotics industry is expected to participate in the development of automated technologies and robots that are able to perform the tasks required in space. Both these industries are expected to be driven by the USA, with Japan playing an important role in the robotics industry.

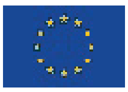
2.1.3 Overview of regional dynamics



The Space Policy Directive-1 (SPD-1) signed in 2017 mandated NASA to land the first American woman and next American man at the South Pole of the Moon by 2024, followed by a sustained presence on and around the Moon by 2028. However, NASA is yet to submit its Artemis budget breakdown, cost structure, and development architecture to the US congress. Its previous administrator, Jim Bridenstine, estimated the cost of the Artemis missions (until 2024) to be between $20-30B, thus requiring an additional $4-6B on top of NASA's current Artemis budget. Moreover, cost overruns are also becoming a point of concern:it is estimated that NASA has already invested approximately $12B between 2011 and 2019 to develop the SLS, which is 24.6% more than the programs development baseline. Additionally, the SLS was expected to be operational by 2017 but has been delayed until 2021.

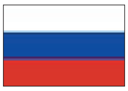


In 2007, Japan developed an exploration roadmap that set high objectives and expectations for the 2007 – 2030 period. Unfortunately, many of the planned missions were delayed and cancelled, ultimately weakening the roadmap. Additionally, JAXA's budget has been relatively flat for the past few years, seeing an increase in 2020 of only 2.2% from 2019 (pre-COVID-19-19) for a total of $1.73 billion Nonetheless, Japan is making significant efforts towards developing a private space sector, illustrated by the aforementioned $940 million VC fund from the Japanese government to support space start-ups. Prior that that, Japanese start-up iSpace announced a $90 million funding series from large Japanese companies with government backing, and Astroscale also announced a fund raise of $ 25 M on the same year.



In Europe, the ESA has long shown interest in lunar missions following the SMART-1 in 2003-2006. However, since then, only few direct missions have been planned (e.g. Heracles, Lunar Pathfinder in partnership with SSTL and GES) and most of ESA's involvement in lunar activities has been on opportunity missions: Luna 25 and 27, European Service Module for Orion (FM1,2 and 3 secured, FM4 to be confirmed), Gateway-related elements (Esprit module and International Habitat). Some missions have not yet been announced but have been cited in the "Science at the Moon" and "Strategy for SRU" reports. Additionally, when it comes to funding, the ESA Ministerial Council of 2019 secured a budget for lunar exploration missions until 2022. The exploration programme of ESA (E3P – €1.65 billion / $1.88 billion for 2016-2021) and ESA's 2030 strategy have secured budget until 2030. Aside from institutional budgets, private funding in Europe is still relatively weaker than the US(e.g. VC activity is limited for space), and EU Member States are trying to incentivise private funding. For example, Luxembourg signed an agreement with EIB to enhance finance access to private actors and created a dedicated fund for space in 2018 ($110 million). There are very few private actors developing projects (e.g. PT Scientists), and future successful initiatives will require support from public investment.

In addition to China's previously mentioned Lunar Exploration Programme, the nation is developing a range of launchers that would enable larger cargo and human spacecraft missions. Long March 5B recently launched a module for the Tiangong space station, and will carry a manned spacecraft. Long march 9 super heavy lift which is expected to offer 50 tons of payload capacity to lunar orbit, is planned to be tested by 2030.. In terms of funding, in 2018 China' space budget was estimated at $5.8 billion with a 5Y CAGR of 9.4%. The Chinese private sector is also gradually developing, both in terms of operators and investors. VC's in China (such as Tencent Holdings Ltd) are not only investing in the local lunar transportation market but are also investing in US commercial space exploration entities such as Moon Express and Planetary Resources.



While Russia's initial plans were aimed at launching humans to the Moon by 2030, the Yenisei launcher necessary for such mission type is still under design phase, with issues of budget availability highly likely. Yenisei's development requires the equivalent of the entire Russian budget for space over 10 years. In terms of technology development, Russia is also developing the Angara 5P, which is being threatened by a new iteration of the Soyuz rocket. In terms of funding, the economic instability in Russia has prevented it from completing all its space objectives. This resulted in a shrinking of the Federal Space Programme budget, reduced by two thirds after 2014, down to $21B for the 2016-2025 time period.

2.2 Future evolution and market for lunar transportation

2.2.1 Market drivers and challenges

2.2.1.1 Market Drivers

A renewed geopolitical interest for exploration

Following a period of about 40 years during which lunar missions were limited to a few scientific endeavours, the last decade has seen a renewed interest shared among space agencies at the international level. This interest is well reflected in the high ambitions of the Artemis programme, the lunar gateway initiative and the return of humans to the Moon, or the Moon village vision, all exemplifying a close collaboration between space faring nations and the dedication of substantial institutional budgets. The USA exploration programme is the main source of funding on the global scene in the short term, with a progressive increase of the weight of other regions expected in the medium and long term.

An increasing share of missions to the Moon surface rather than orbiters

Lunar exploration countries begin their roadmaps by sending payloads into lunar orbits, which is the most technologically simple type of mission. Once they succeeded in doing that, they begin to move towards more complex missions, incorporating landers and rovers, to demonstrate technology and enable larger operations on the lunar surface. This evolution drives the profile of lunar missions towards heavier payloads to be transported in the future.

Ultimately, the mature phase of lunar activities will involve more extensive ground activities and equipment, with an associated logistics chain involving regular heavy payloads being delivered from Earth.

Support to the involvement of the private sector, including non-space companies

There is currently a large majority of public actors taking part in exploration activities, which will be progressively balanced over time with increased involvement from the private sector, both from space companies and non-space companies. Space agencies and the public sector are expected to develop policies, initiatives and programmes that encourage the participation of the private sector. Space actors are increasingly involved along space agencies, as illustrated by NASA commercial procurement for Moon landers and crewed vehicles, or ESA commercial procurement for mission-enabling services for its ISRU demonstrator mission. Non-space companies should also be incentivised in the coming decade to take part in identified business opportunities and synergies, where we expect PPPs to put more risk on private actors. Many opportunities lie in particular in non-space companies which have strong financial profiles and already identified potential areas of technology spin-offs and future spin-ins, mainly around SRU related activities, development of habitat and bases or of advanced technologies (automated drills, rovers etc.).

2.2.1.2 Market challenges

Delays and potential cancellations due to budgets uncertainties

One the main challenges associated with space exploration activities is the (sustainable) availability of institutional budgets over time, as they still constitute the large majority of the demand and funding for space ventures. The recent COVID-19 crisis has increased the risk of revision of space budgets as part of national contingency plans for the pandemic. While near term milestones will likely not be affected (with a majority of the costs already spent), longer term plans are more likely to be affected by new budget restrictions. This will vary on a case by case basis –future missions such as JWST, JUICE or SLS are likely to be affected, while other programme have continued to proceed nominally (Lunar Gateway, SpaceX commercial crew, Chinese launchers etc.).

Uncertainties during still early phases of technology demonstrators

The current involvement of terrestrial industry sectors is still limited in the short and medium term, and remains tied to the demonstration of pre-required space technologies, in particular in-situ demonstrations of scalable solutions. ISRU synergies and potential for spin-offs for the mining, automotive or robotics industries remain bound to the space technology roadmaps that will be pursued by space agencies. While ISRU demonstrators should provide some answers in the coming years, terrestrial actors involvement should remain moderate and limited to opportunistic cooperation in the meantime.

Orbital payloads will remain non-negligible in terms of mass, but negligible in terms of market value

Whatever the stage of maturity of the lunar market, there remains a need for orbital payloads, mainly for activities such as communication relays (although some of it is expected to be handled through the lunar gateway once it is operational) or surface monitoring to support surface experiments and vehicles. In parallel, new entrants to lunar exploration will generally begin by testing small payloads for limited applications (typically for scientific and technology demonstration) and conducting experiments on the lunar surface and orbit (similarly to the current exploitation of the ISS for instance), also addressing small payload masses. The situation should result in a cyclic demand for these small payloads. However, the cost per kg is an order of magnitude smaller for orbital payloads with respect to landers and rover payloads, leading to a very small impact on the final market size.

2.2.2 Market Forecast

2.2.2.1 Approach to the market forecast

The market sizing for lunar transportation is conducted through a bottom-up approach. The different lunar missions are identified and extrapolated for each region up to the year 2040. They represent a combination of known missions (typically in the coming 3 to 5 years) and of expected future missions that have not yet been announced. These future missions are associated to a specific customer profile, which includes the payload mass category and the type of payload transported (orbiter, lander or rover). The revenues of each identified mission are obtained from the mass and price per kg of each individual mission, and the overall market size is obtained by adding up the revenues of the individual missions.

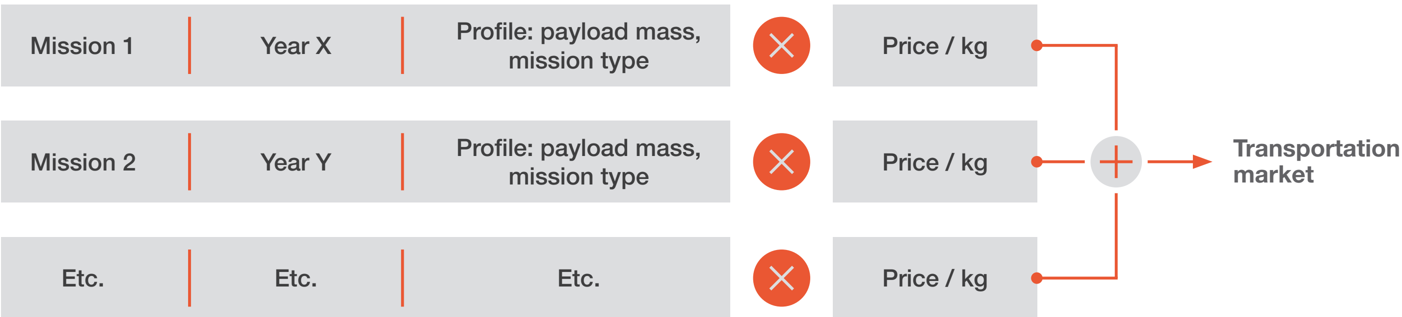
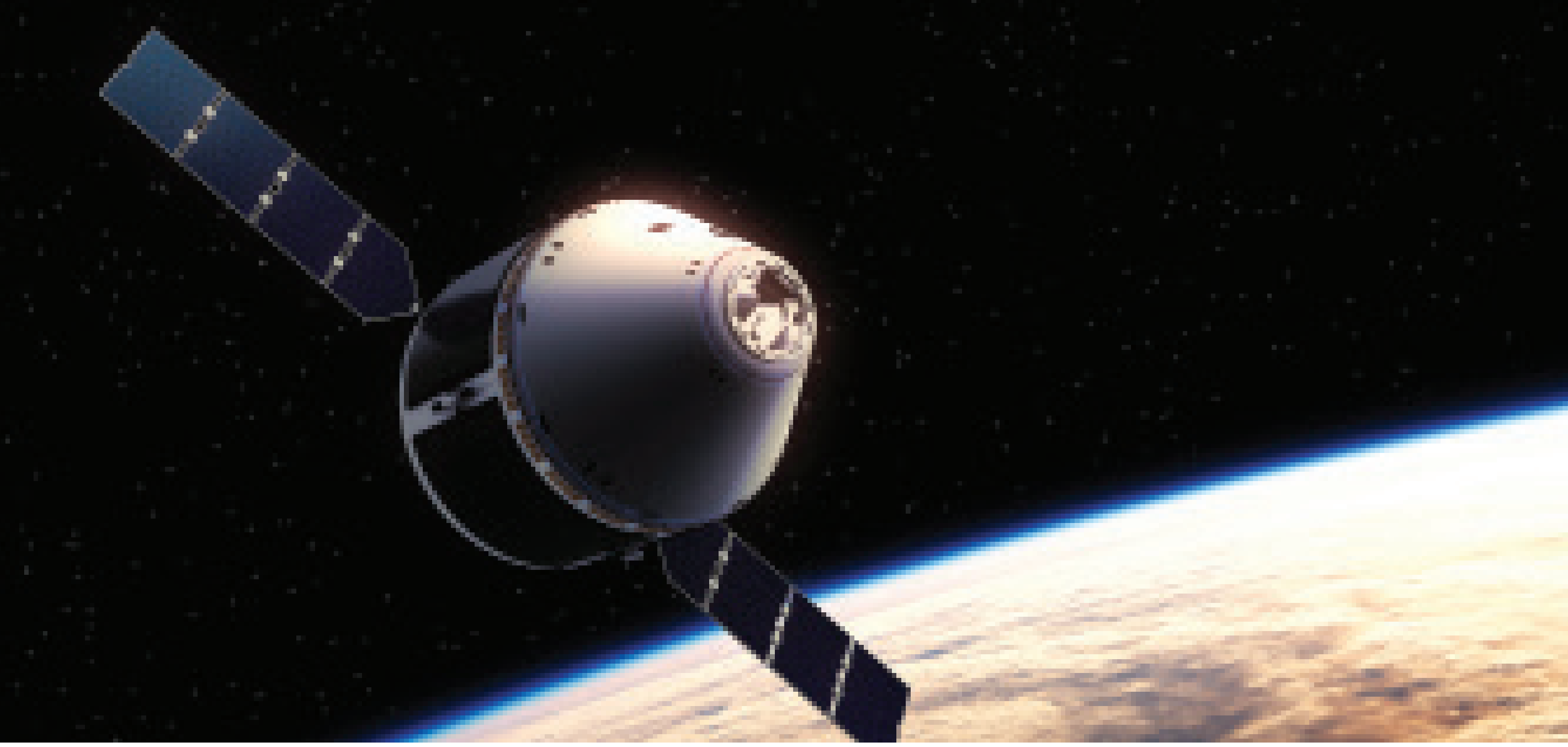


Figure 2 - Approach for the quantification of the lunar transportation market

Thus, the number of missions considered between 2020 and 2040 constitutes the source of the market size. This forecast considers, for each region, the current state of play, the market drivers and challenges described above, and the analysis of four axes: programmes & activities, technology, economy & financing, and politics & cooperation. These four pillars play a central role in defining the acceleration, deceleration, or even cancellation of lunar initiatives. To cope with the uncertainties surrounding these parameters in the next five to twenty years, a scenario-based approach is adopted (conservative / nominal / optimistic), providing the envelope of the realistic market around the nominal scenario.



2.2.2.2 Results for the lunar transportation market

The global lunar transportation market payload mass (cumulative) between 2020 and 2040 is expected to reach 187 tons in the nominal scenario (128 and 230 tons for the conservative and optimistic scenarios, respectively). This leads to a total transportation market size of $79B in the nominal scenario ($55B and $102B in the conservative and optimistic scenarios respectively), with a CAGR of 10% for the nominal scenario. The transportation market increases at a rather regular pace over the time period considered, from $9B over 2020-2025 to $19B over 2026-2030, $32B over 2031-2035 and $42B over 2036-2040 (optimistic scenario).

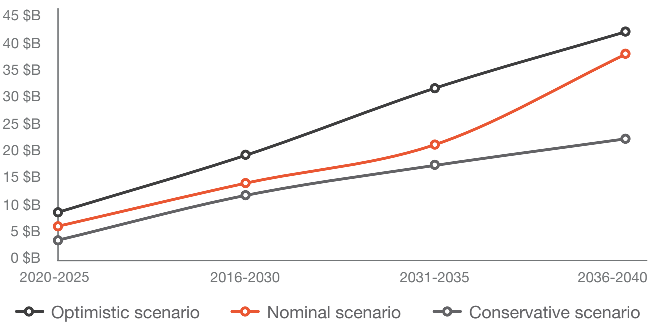


Figure 3 – Scenarios of market size for the global lunar transportation market

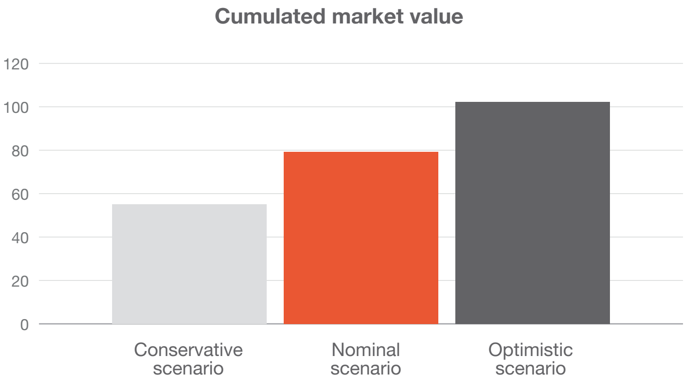


Figure 4 - Cumulated lunar transportation market 2020 - 2040

From a regional perspective, the future evolution of this market is expected to be driven mainly by the USA, which represents between half and two thirds of the total market. This is largely driven by the Artemis Program and the US led efforts towards advancing a sustainable Lunar presence on the Moon. Next, China and Japan represent each around 12% of the total demand, and the EU around 5% of the total. It is interesting to note that the market associated to China may seem quite small with respect to the US and very close to Japan's, while the overall Chinese space programme demonstrated higher ambitions in the recent years. Several aspects should be kept in mind when interpreting these figures. First, this assessment is based on the currently known missions and roadmaps for the Moon exploration, before extrapolating any additional future missions. This information is more difficult to retrieve on the Chinese space programme for the next 10 to 20 years.As a result, we kept a conservative approach and extrapolated on the basis of available information only. Second, the relative isolation of China in the international exploration scene (for instance its non-involvement on the Artemis programme) and the nation's ongoing programme for its own LEO space station Tiangong reduces the relative involvement and weight of China in the aggregate lunar transportation market. In contrast, Japan has set up an ambitious framework around lunar exploration with various landers and rovers companies involved along its national space institutions and other, non-space companies, allowing the country to capture a significant share of the market. In terms of the profile of missions, in the nominal scenario the lander market is expected to be the dominant one across the timeframe, and cumulatively accounts for $47 billion. The rover market is expected to follow with a cumulative revenue of $30 billion, while orbital payloads should represent a marginal part of the market value, with a cumulated value of just below $2 billion.

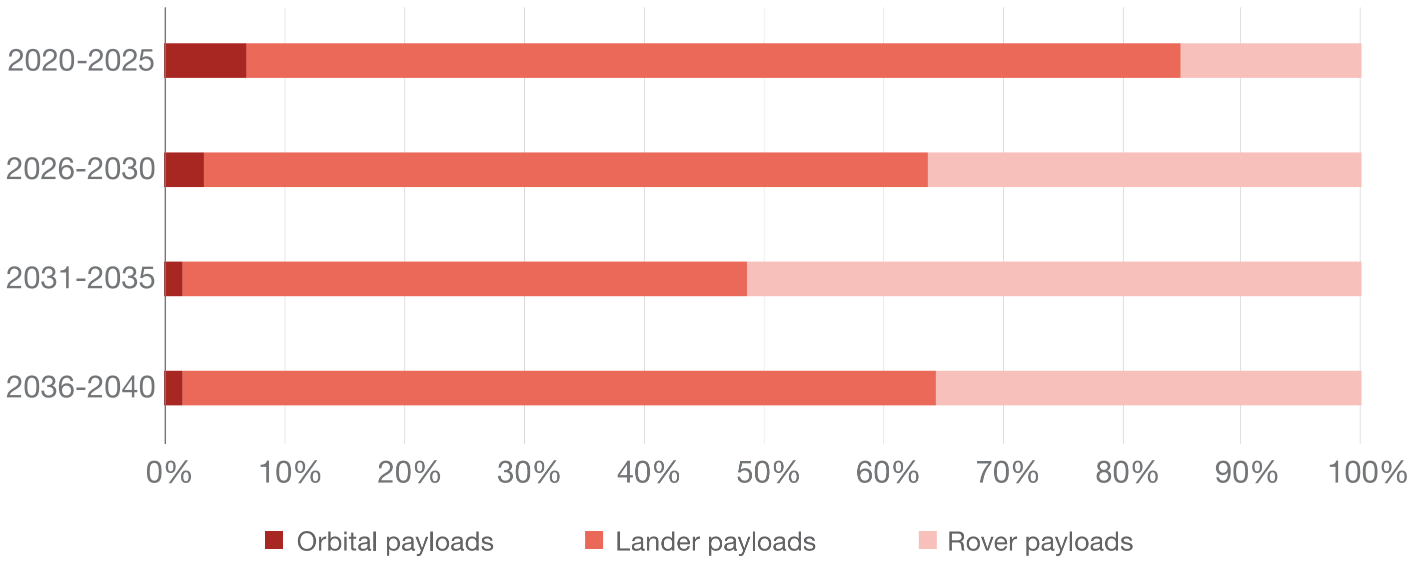


Figure 5 - Distribution of the transportation market value ($) between the types of payloads

It should be noted however, that despite the low market share for orbital payloads, their cumulated mass is expected to be slightly higher than the payload mass on rovers. Indeed, rover payloads tend to be smaller in size and mass due to the limited capacities of rovers, whose own masses already constitute a limitation for near term vehicles. However, in terms of market value, the cost of launching a payload on a rover is much higher than the cost of launching a payload into lunar orbit, leading to a different order of magnitude of revenues per mission.

While in the short term, lunar exploration countries will assign a central role to orbital payloads (as the most affordable and technically accessible type of payload), space agencies and commercial players are expected to additionally rely on more complex missions incorporating landers and rovers to demonstrate technology and enable larger operations on the lunar surface.

Reflecting the market drivers mentioned above on the increasing role of the private sector in the lunar exploration activities, the market share of commercial actors is expected to increase over time. In the coming decade, the market is expected to still be largely institution-driven, as most of the missions to the Moon will be scientific endeavours and experiments towards human sustainability. The role of private customers should increase along the years as space actors increasingly contribute to the sustainable missions on the Moon surface (support services for manned missions, demonstration of autonomous systems, provision of ISRU services etc.). However, it is expected that the growth of the commercial segment will become even more stimulated by non-space actors, which will gain interest in space and increase their opportunities for technology spin-offs and spin-ins, incentivising them to step up their investments in actual space missions.

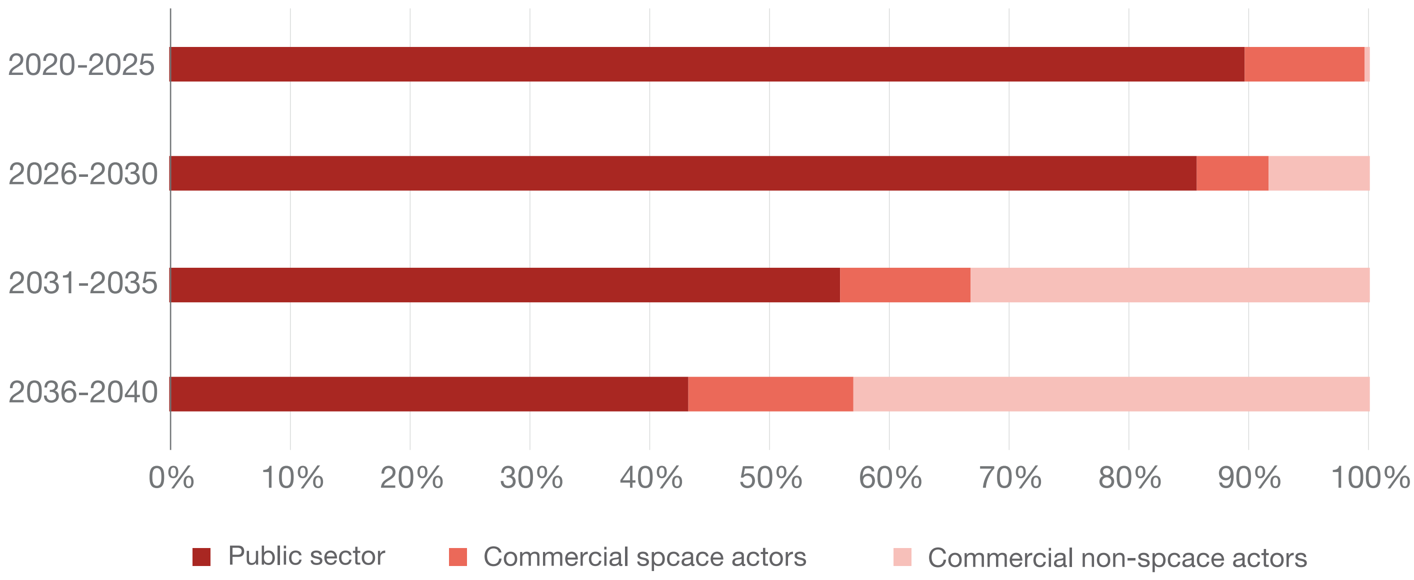


Figure 6 - Distribution of the transportation market value ($) between the profile of customers

As a result, the private sector contribution to the lunar transportation market is expected to increase from just above 10% in the first decade (2020-2030) to more than 50% in the second decade (2031-2040). Within the private sector, the non-space industries are expected to disrupt the picture after 2030, jumping to around three quarters of the overall commercial demand, overtaking the demand from pure space players. Such growth in demand is expectedly driven by the mining industry (leveraging synergies in mining and processing capabilities in harsh environments), the automotive industry (developing rovers, and exploiting synergies in the development of autonomous vehicles, including with respect to their energy autonomy), the energy sector (answering the growing needs for sustainable power sources on the moon surface), and the construction industry bringing their expertise to support the development of sustainable infrastructures and facilities on the surface of the Moon.

Caveats and critical analysis

The lunar transportation market is sized based on several aforementioned assumptions (see figure 2). Per the twenty-year timeframe considered for the analysis, there is an inherent uncertainty on the actual evolution of the transportation landscape. In particular, the modelling shows that there is a strong sensitivity of the forecast to:

 The extrapolated number of missions beyond 2030: the US and China have the potential of quickly changing the global landscape for lunar exploration, which could greatly influence the total number of launches. Japan is also demonstrating a strong dynamism from the private sector, and as lunar exploration is still in the nascent phase of the market, the next 20 years could deviate from the current forecast depending on the short-term achievements.

 The average mass per mission: this approach relied on the categorisation of the payloads into 4 weight classes, ranging from 1 kg to more than 1 ton. While the number of heavy payloads is forecasted to be substantially smaller than the number of small payloads, they constitute a large majority of the cumulated mass, thus having a greater direct influence on the overall market value.

 The price per kg: a number of parameters can influence the evolution of the pricing curve, starting with the average launch cost from Earth, including the current decrease of the cost per kg on heavy launchers and on super heavy launchers in the near future. Technology and market maturation will also affect the pricing of future missions and could therefore affect the market size presented in this paper.

It is therefore important to consider that this market estimate is based on the available information and the current roadmaps of space agencies and commercial actors for the lunar exploration. Considering we are still in the early stages of humankind's current ambitions of returning to the Moon, the coming years will be decisive in confirming the trajectory and adjusting potentially the associated market.

2.2.3 Roadmap gap analysis

2.2.3.1 Principle of the roadmap gap analysis

In parallel to the current roadmaps of space agencies, such as the Global Exploration Roadmap issued by the ISECG, some alternative visions have been expressed by some private organisations on a lunar presence, already in the medium term. In the past years, some companies had expressed such vision, foreseeing 1,000 people living in space or visiting the Moon every year, in a timeframe between 2040 to 2045. While these visions remain in a different order of magnitude with respect to the current institutional roadmaps, a theoretical sizing exercise is conducted to characterise the gap between current market forecasts and a potential up-side scenario of 1,000 astronauts on the Moon in 2040, identifying the drivers that would contribute to the development of such a scenario and the resulting transportation market.

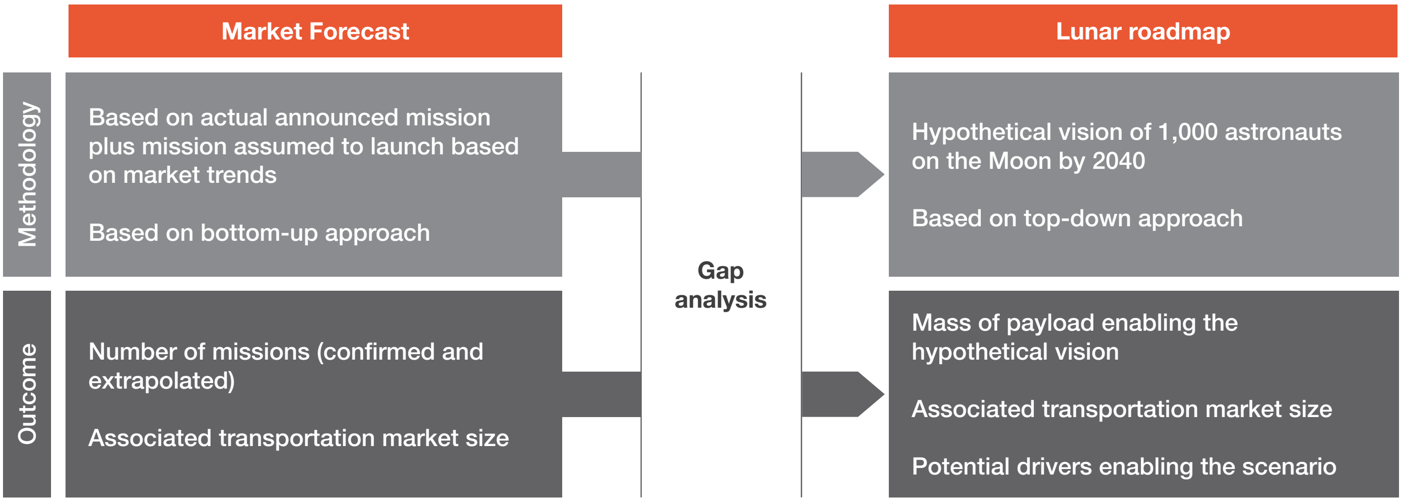


Figure 7 - Gap analysis between market forecast and hypothetical lunar roadmap

Before detailing the sizing of the gap, several potential drivers are identified, which could contribute to the development of a more ambitious scenario than the current market forecasts.

Potential drivers to evolve towards the 1,000 people lunar roadmap

- Successful early robotic missions (2020-2024 timeframe) could provide a boost to the political and social will to explore and exploit lunar resources globally, thus expanding the demand for lunar transportation services.
- High degree of involvement form space powers such as the USA, China, Russia etc. would play a vital role in generating demand (robotic and human presence) which could facilitate the progression of the hypothetical vision.
- Emerging space nations such as the UAE, Australia etc. could also fuel the demand for a lunar base by partnering with traditional space fairing nations and thus facilitate the demand for both SRU and lunar transportation services.
- Terrestrial mining industries in Australia, Europe and South America commenced studies for lunar mining. Additionally, Japanese automotive industry is already involved in the development of lunar rovers. These non-space sector, terrestrial industries could generate demand for both SRU and lunar transportation services.

2.2.3.2 Hypothesis enabling the vision for 2040

Defining the goal of 1,000 astronauts on the Moon surface by 2040 relies on the following assumptions:

- Exponential ramp-up of human presence on the lunar soil starting with 40 people by 2030, 200 by 2035 and 1000 by 2040;
- Availability of high cost-effectiveness rockets capable of sending astronauts on the Moon surface would be achieved by 2030;
- Given the quickly growing number human presence on the Moon, it is anticipated that during the initial years a vast majority of the resources, equipment's, and necessities to sustain life on the Moon will be sent from Earth.
- The percentage of mass of resources and equipment sent from Earth decreases over time, as it is expected that the exploitation of local resources will be decisive to develop these activities.

The projection of associated to the number of astronauts on the moon between 2020 and 2040 is depicted in the figure below.

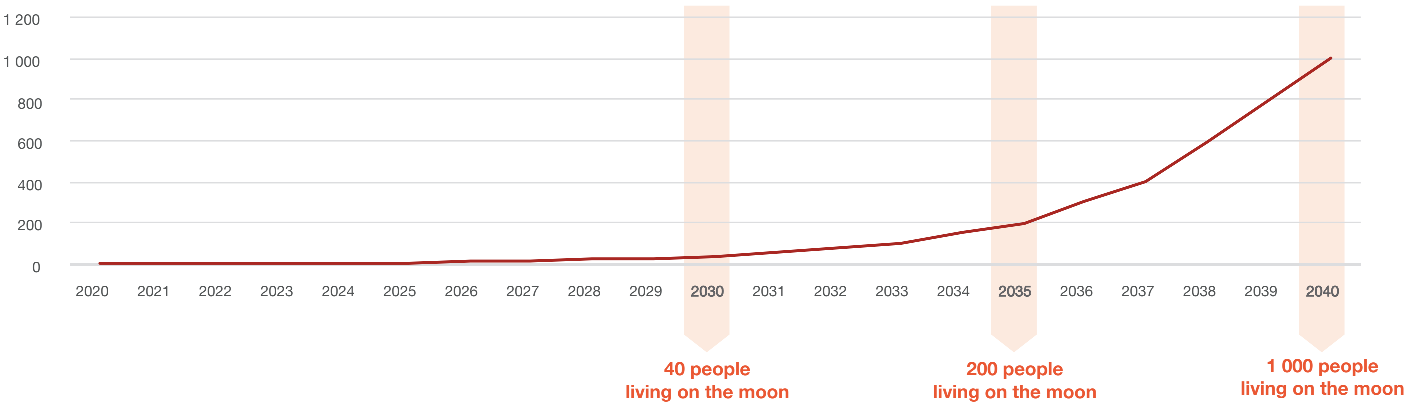


Figure 8 - no. of astronauts envisioned between 2020 and 2040

In order to sustain such large-scale human presence on the Moon, a number of support activities and missions would need to be developed, across the following sectors:

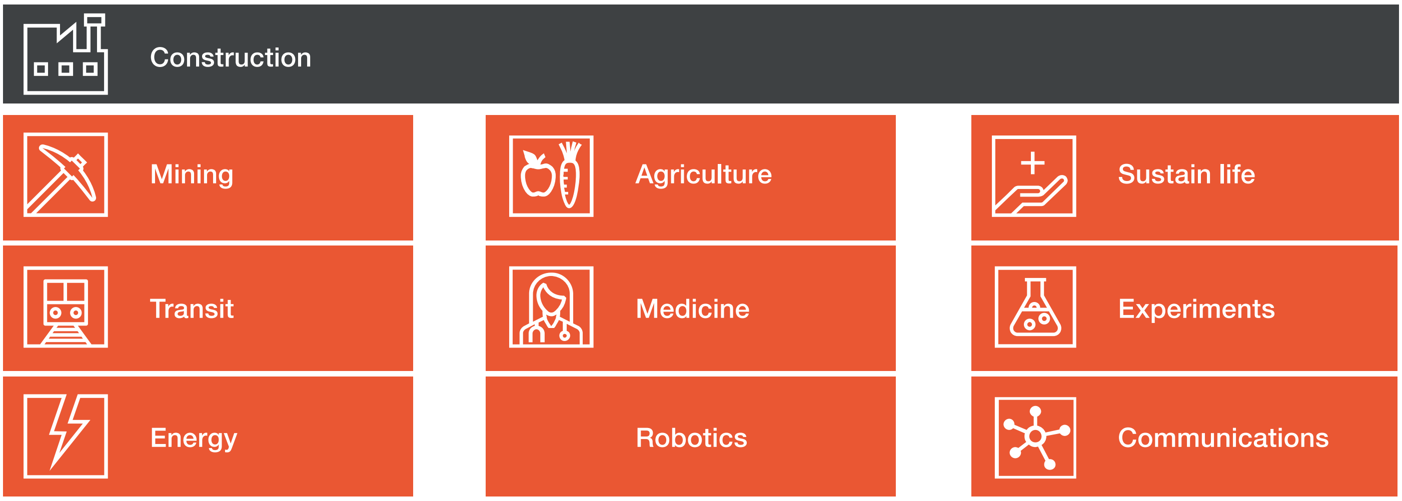


Figure 9 - Activities to be performed on the Moon to sustain long-term human pressence

- **Construction:** encompasses the need for building infrastructure and facilities to support agriculture, energy production, experiments, transit (on surface) medicine, etc, and support other segments.
- **Mining:** encompasses the extraction of resources that are key to support all the segments mentioned. The most important resource to extract being water.
- **Agriculture:** agriculture on the surface of the Moon is key to produce food and sustain life. Growing crops on the Moon can be done using “biosphere” cylinders and greenhouses.
- **Sustain Life:** sustaining life includes all elements enabling humans to survive on the Moon surface: habitats to live, water for drinking and breathing, N2 and 02 for breathing, as well as food for eating.
- **Transit:** transiting includes all activities enabling mobility on the surface of the Moon using lunar vehicles.
- **Medicine:** ensure astronauts’ health condition, medicine on the surface of the Moon can be considered, with two aspects: health services (pills prescription, clinics, health checks, etc.), and training centres (e.g. treadmills, etc.).
- **Experiments:** humans on the Moon are expected to dedicate 1/3 of their time to experiments. To do so, they will need laboratories, which will need to be transported from Earth during the early years while, eventually constructing them on the Moon in the later years.
- **Energy:** production of equipment or facilities that support energy generation activities.
- **Robotics:** support humans in their daily activities, including mining, construction, experiments or other tasks.
- **Communication:** on-Moon communications to connect all humans and objects on the Moon together using communications systems in situ and in orbit.

It is anticipated that roughly 45 tons of mass will be needed per person, per year, to support the above-mentioned applications and enable a sustainable presence on the moon. It is further expected that applications such as construction, mining, agriculture, will account for 68-70% of the total mass needed in per person, per year.

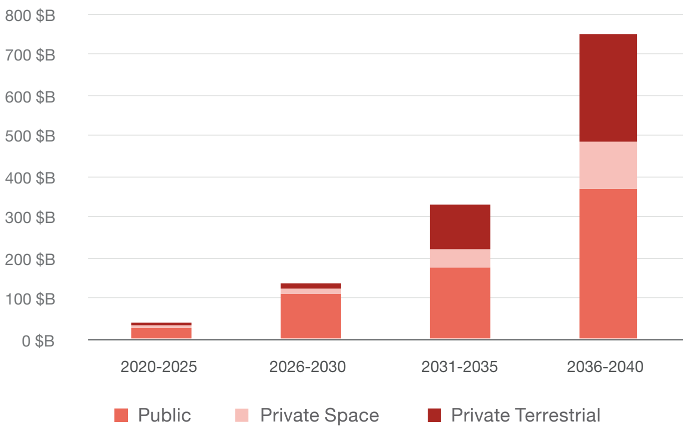
2.2.3.3 Roadmap assessment results

The lunar transportation roadmap assessment indicates a total value of $ 1,250B, following an exponential increase from $ 33B on 2020-2025 to $ 135B in 2026-2030, $ 382B on 2031-2035 and $ 751B on 2036-2040.

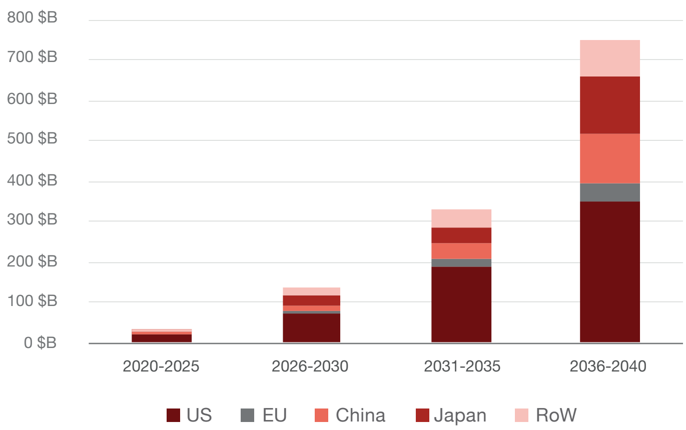
The demand from categories A and B (0-100kg and 100-500kg payloads) would drive launch contracts worth $8 billion per annum between 2020-2030 growing to $37 billion per annum by 2031-2040, cumulatively accounting for $441 billion (2020-2040) in transportation services to meet this hypothetical vision. In addition, the demand from categories C and D (500-1000kg and 1000+ kg) would drive launch contracts worth $811 billion (2020-2040) in transportation services to meet this hypothetical vision, with $9 billion in per annum spending between 2020-2030 then growing to $72 billion by 2031-2040.

Private entities would cumulatively procure launch services worth $569 billion for the timeframe between 2020 and 2040 to enable this hypothetical vision. Among them, the terrestrial (non-space) private sector industry would procure launch services worth $389 billion, whilst the private space sector would procure launch services worth $180 billion to facilitate this hypothetical vision. In addition to this, the private non-space sector launch procurement is expected to rise from 2% of the total launch value in the 2020-2025 period to 31% of the total launch value in the 2035-2040 period. Nonetheless, it is anticipated that the public sector entities would still have to play a dominant role in realizing this hypothetical scenario. For instance, the assessments suggest that, on average, the public sector entities would have to procure 68% of the launch services between 2020 and 2040 to attain the vision of 1000 astronauts, with $29 billion in procurement between 2020-2025,followed by $29 billion in procurement between 2020-2025, followed by $109 billion between 2026-2030, $176 billion between 2031-2035, and $368 billion between 2036-2040.

Lunar transportation roadmap - per entity type



Lunar transportation roadmap - per region



Lunar transportation roadmap - per payload mass

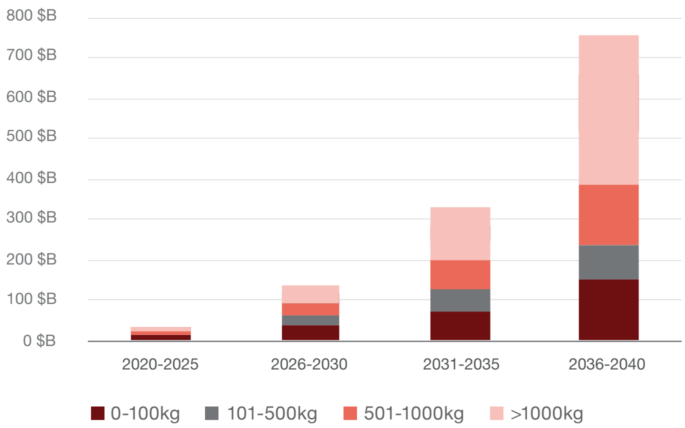


Figure 10 – Theoretical size of the transportation market in order to sustain the roadmap

From a regional perspective it is anticipated that the USA would lead this hypothetical vision by purchasing launch contracts totalling $634billion, accounting for 51% of the total share between 2020-2040 timeframe. Asian countries such as China and Japan would undertake a further 31% of the global share, cumulatively accounting for procurement purchases worth $387 billion. The EU along with the rest of the world (UAE, Canada, Russia, India etc.) would facilitate launch contracts worth $231 billion, accounting for a 18% share. It should be noted that a similar reasoning for the market forecasts explained above leads to a comparable profile of geographical distribution, in particular regarding the weight of China vs. other actors such as the US, and the substantial weight of Japan on the global scene. In terms of payloads mass, heavy payloads (more than a ton) would constitute a bit less than half of the market, with a remaining substantial share for the lighter payloads including the 0-100kg category. Like the transportation market, this is linked to the higher price per kg for smaller payloads.

3 Lunar Data

3.1 State of play

3.1.1 Introduction to the lunar data market

Access to the Moon enables valuable data about the lunar environment to be gathered. This data can take various forms, including surface temperature, radiation levels, terrain topography, surface dust levels, water presence, the concentration of volatiles and the geological composition of the regolith, amongst others. While some data is already available on the Moon characteristics from past missions, there is a constant value in expanding the information available, through the coverage of new areas, refinement of spatial resolution, depth of analysis, time frequency of the measurements etc.

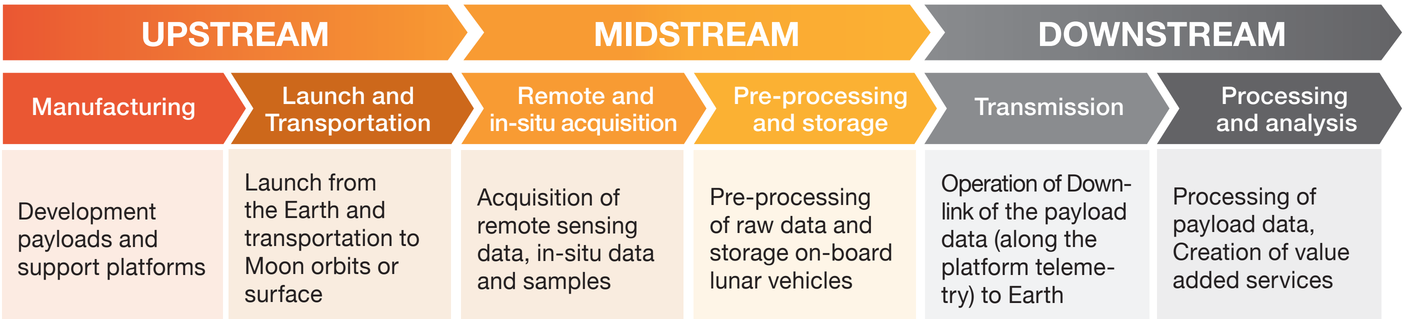


Figure 11 - Value chain for lunar data

In the following sections, we provide a high-level description of current lunar data types as well as their associated applications and the buying habits related to them. This will serve to understand the lunar data market prior to evaluating its evolution over the next 20 years.

3.1.2 Lunar data characterisation

The lunar data market can be classified into three distinct categories, including environment data, telemetry data and entertainment data. Each lunar data category has different applications and a varied customer base.

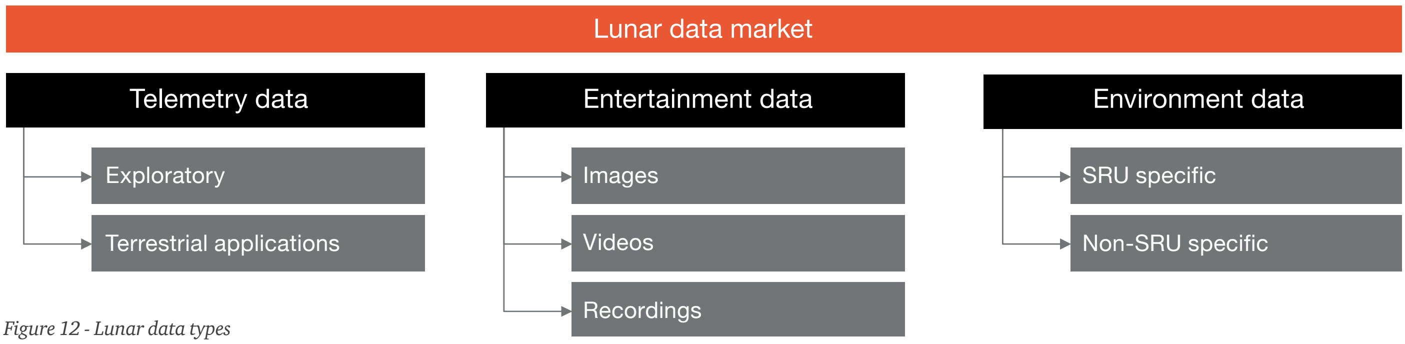


Figure 12 - Lunar data types

3.1.2.1 3.1.2.1 Lunar telemetry data types and their use cases

This type of data is anticipated to be derived from lunar instruments and vehicles which provide information on instrument/payload performance and health. This data type can be segmented into two forms, exploratory data and data with terrestrial applications or 'spin-off' data. Monitoring propellant pressure, thruster temperature, pressure/strain on landing pads, amongst other variables, are examples of raw data that can be utilised for exploratory purposes. Likewise, examples of value-added exploratory data products include rover battery temperature measurements, stress measurements on rover wheels, or data which provides insights into the impact of lunar night temperature drops on sensitive components or systems on landers and their payloads. On the other hand, data derived from systems used on the Moon which could in turn enhance systems on earth is classified as terrestrial data. The application of automation technologies or lessons learned from Lunar prospection drills could, for instance, be transferred onto terrestrial prospection drills to gain better performance or higher efficiencies.

From a use case standpoint, public entities (space agencies, governmental institutions, governmental research centres and others) could potentially use this data in lunar exploration technology development. Likewise, the commercial sector could use this data in lunar exploration technology development or use this data in developing terrestrial technologies in non-space industries.

3.1.2.2 Lunar entertainment data and use cases

Currently the data pertaining to the entertainment market is largely generated and disseminated by public sector missions. This data is widely used by the non-space industries for entertainment. It is anticipated that in the coming years, both private and public missions will supply this data type. Additionally, it is expected that entertainment data will take three forms, video, imagery and other recordings. For instance, video footage, images or audio recording of astronauts or lunar equipment (rovers, landers), or video footage and images of the Moon itself.

From a private sector perspective, the use cases of this data are related to the use given to it by the entertainment industry for movies, TV shows, documentaries, documentary films and video games.

3.1.2.3 Lunar environment data

This type of data is currently collected from scientific payloads and includes images, information about the lunar surface or its environment. However, with the commercialisation of the lunar market this data type is expected to come from both the public and private missions, thus being segmented into two classes, the non-SRU specific data and the SRU specific data. The non-SRU specific data entails the measurement of temperature/ pressure/ radiation (in surface or in orbit), topography/terrain on surface, geology/sub-surface structure, soil mechanics, surface dust characterization, sunlight, etc. The needs for this data are driven by the needs for higher resolution remote sensing data i.e. less than 100-200m/pixels, to detect small pieces on the lunar surface. Additionally, there is a need for ground truth validation in relation to various measurements such as typology (roughness), morphology/ geology (sub-surface, surface, slopes, altitude), temperature, pressure, radiation (surface and in orbit), geological composition as well as data that enables resource identification (water ice, oxygen, lunar volatiles, regolith) and characterization (size, form, distribution), hazard detection (chunks – how deep they are).

From a use case standpoint, public entities could potentially use this data for lunar exploration mission planning or to establish ground truth. Additionally, from a commercial sector standpoint it is anticipated that this data could be utilised for lunar exploration missions planned by industries involved in exploration or be utilised for ground truth validation by both space and non-space private sector industries.

Amongst the three data markets mentioned above the environment data market is expected to grow substantially and represent the largest fraction of the demand with respect to the telemetry and entertainment markets. There is currently a mismatch between the data needed for further scientific, technological or programmatic development and the data available, leading to important knowledge gaps.

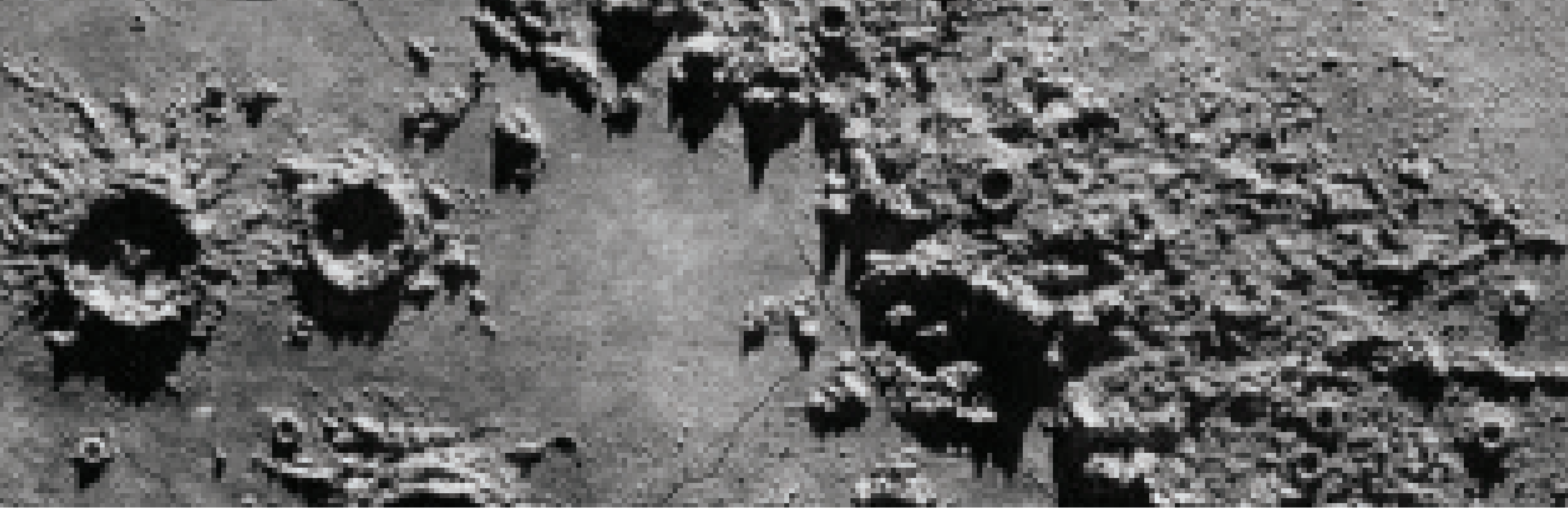
SRU–specific data

- Because of the lack of ground truth data, no sound and thorough relation can be established yet between most of the locations on the Moon surface and the actual geological characteristics, rendering more challenging the kick-start of SRU missions;
- ISRU Strategic Knowledge Gaps (SKG) were identified by NASA (e.g. quality, quantity, distribution, form of volatiles and organics in polar regions, geotechnical characteristics of cold traps, biological effects of lunar dust, radiation effects at the lunar surface, etc.).

Non-SRU Specific data

- Scientists preparing future lunar missions lack information related to gravity or volatiles;
- Fundamental researchers seek for more data to better understand the Moon composition and structure.

Figure 13 - Needs and data gaps for lunar environmental data



3.2 Future evolution and market for lunar data

3.2.1 Market drivers and challenges

3.2.1.1 Telemetry data market

Main drivers for the telemetry data market

- As space agencies and large private sector companies begin to develop a sustainable lunar presence, the demand for developing rovers, and other utility-based products shall significantly rise, thus creating market drivers for telemetry data.
- The automotive sector shall also become a demand driver for Value Added Telemetry Products (VATP) to improve and further develop Lunar surface rovers.

Main challenges for telemetry data market

- Telemetry data from the bus/sub-system is generally not disclosed or sold, as it can be used by competitors to reverse engineer the spacecraft (rover, lander or orbiter). Therefore, protecting IP rights is anticipated to be a challenge faced by this market.
- Telemetry data with regards to 3rd party parts, components, systems and sub-systems cannot be shared unless the supplier is willing to make their data public. Therefore, maintaining supply of this data, and increasing the willingness of third-party suppliers to provision this data is anticipated to be a challenge.

3.2.1.2 Entertainment data market

Main drivers for the entertainment market

- The gaming industry is booming, especially with the advent of VR technology. As a consequence, improved simulation and better graphics for gamers stimulate the demand for associated content such as images and videos, which in turn increases the demand for lunar data.
- Over The Top (OTT) content providers such as Amazon prime and Netflix are gaining momentum, and in many parts of the developed world have become the primary form of consumer entertainment, leaving traditional TV behind. The growth of OTT providers, their spending capacity, and the ongoing trend to provide realistic and original content for movies, TV shows, and documentaries shall act as major drivers in the entertainment data market.

Main challenges for entertainment market

- Based on use cases, it is noted that documentaries do not usually pay for the data / footage of exploration missions (it is offered free of charge with open access), however, it is expected that with the increased crewed missions in the future, footage will be sold rather than offered freely.
- The pricing of footage (same area) varies significantly depending on the its use, it is seen that the pricing is high for movies, whilst it gets lower for use in documentaries or even video games.
- Space-related movies do not usually use real life footage; however, it is anticipated that they will begin to do so once quality, real-life footage is available becomes more readily available
- The technology to turn real life footage into video game graphics is recent. estimates on the use of footage are assumed to be similar to that of movies due to lack of data.

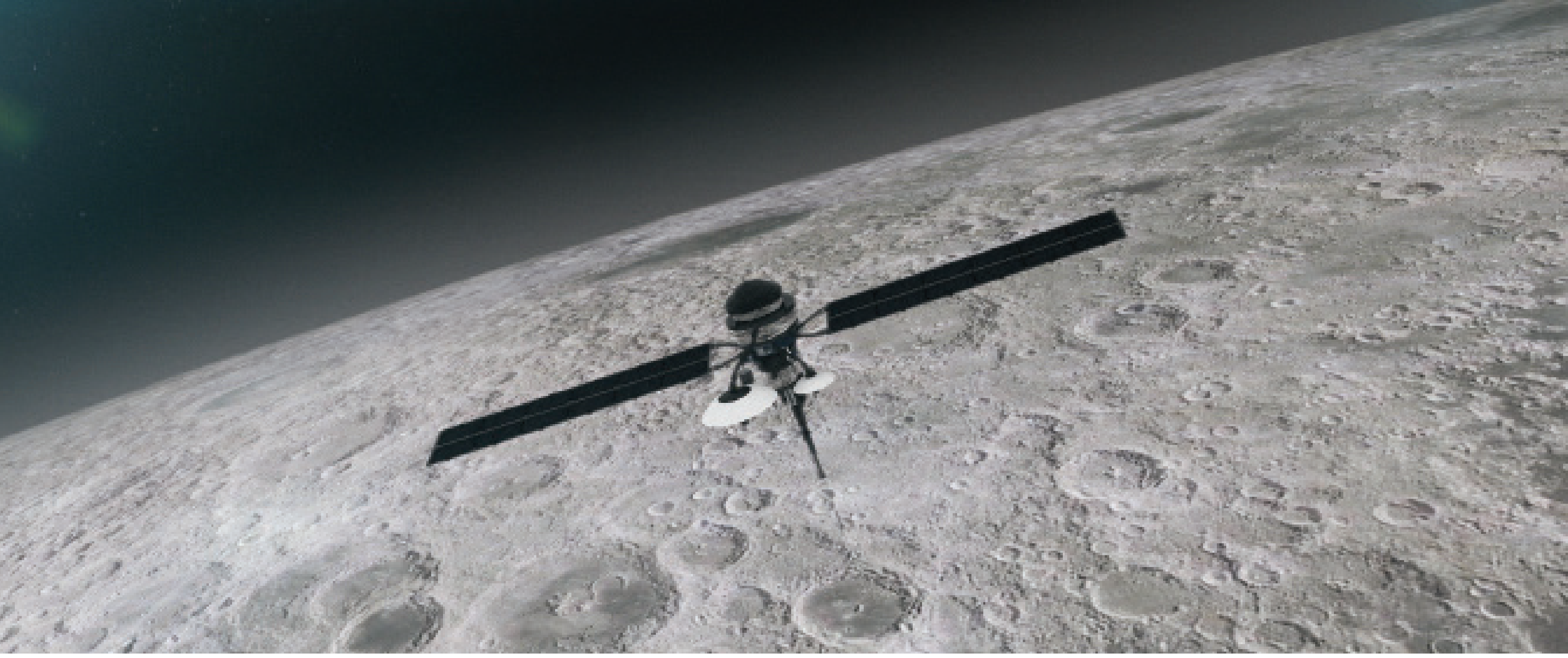
3.2.1.3 Environment data market

Main drivers for the environment data market

- It is anticipated that there will be a willingness to pay by interested entities (space and non-space companies) for this data or value-added products derived from the data provided that it meets key data gaps and provides information of interest to their work.
- The current global push towards developing a sustainable presence on the Moon via SRU activities is likely to increase the demand for data that could enable/activate certain segments within the SRU value chain.
- The lack of ground truth data hinders the detailed and sub-surface characterisation of the geology and resources availability. Many areas of the Moon have only been analysed through remote sensing with low spatial resolution, and with very superficial data. Future missions and other customers will therefore find a great added value in higher resolution and deeper characterisation of the lunar environment.

Main challenges for environment data market

- Lunar environment data is currently free with open access to all and any users interested (typically 6 months after it is acquired). The scientific community is expected to push for such data to remain free and openly accessible.
- The data for environmental market is expected to be fragmented, whereby lunar regions may be prominently covered by one type of data (example- characteristics of regolith), and may have less abundance of other data types within the same region, thus reducing the actionability of the data, especially for SRU purposes. Developing data pools that can co-relate different types of data together on a specific area of interest on the Moon could be a critical challenge.



3.2.2 Market Forecast

3.2.2.1 Overall lunar data market

While the overall lunar data market is an order of magnitude smaller than the transportation market, it is seen to possess the potential to provide valuable business spin-offs and additional areas of revenue for organizations that plan to develop a sustainable lunar economy. Based on the drivers and constraints mentioned in the section above, the cumulated revenues over 2020-2040 across different segments are forecasted at around $8.5 B in the nominal scenario and $11.9 B in the optimistic scenario.

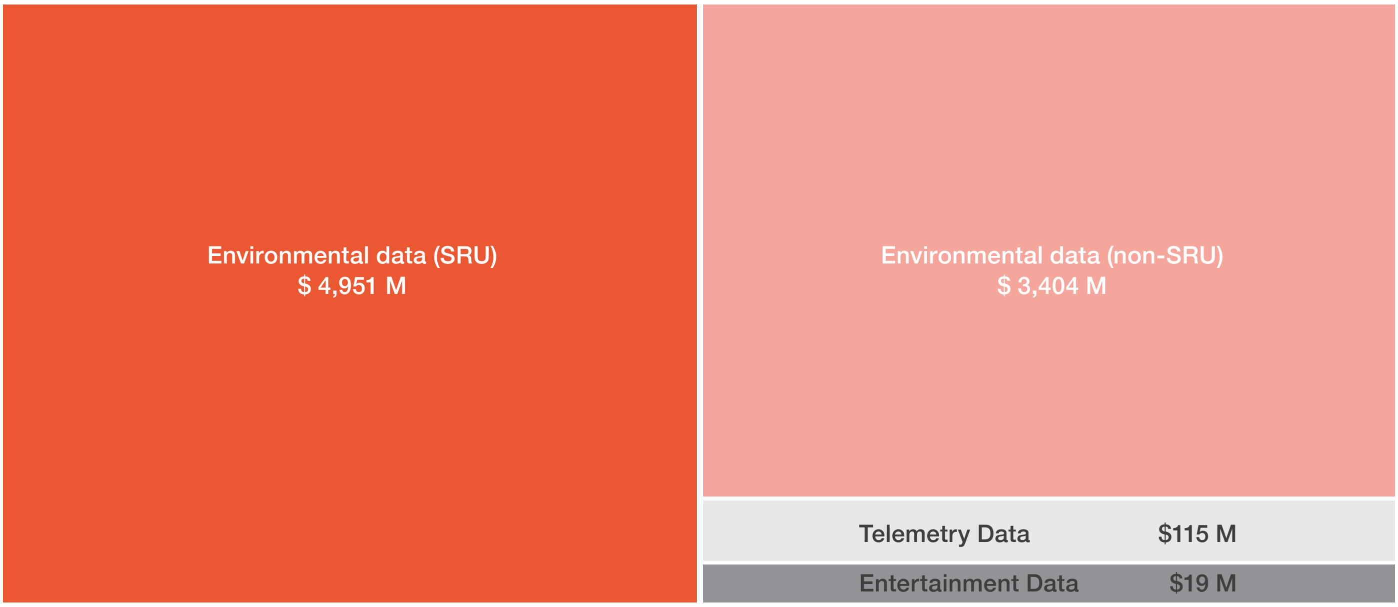


Figure 14 - Cumulative data market forecast on 2021-2040 (nominal scenario)

3.2.2.2 Lunar environmental data market forecast

The vast majority of the market for lunar data is expected to come from the sales of data for the planning and execution of space missions, but also for space and non-space industries interested in validating lunar regions for lunar resources ground truthing. It is anticipated that the environmental market shall account for $8.3B between 2020 and 2040, with 59% of this being generated by the SRU data and the remaining 41% coming from the non-SRU market.

Under the nominal scenario the environmental data market is expected to grow approximately 3.7 times, from $1.8B (45% SRU data, 55% non-SRU data) in the 2021-2030 timeframe to $6.5B (63% SRU data, 37% non-SRU data) in the 2031-2040 timeframe. The optimistic scenario shows a cumulated market up to $12B over 2020-2040 stimulated by a slightly higher demand from the space segment, but to a greater extent by an increased demand from non-space market segments such as the mining industry for ground truth.

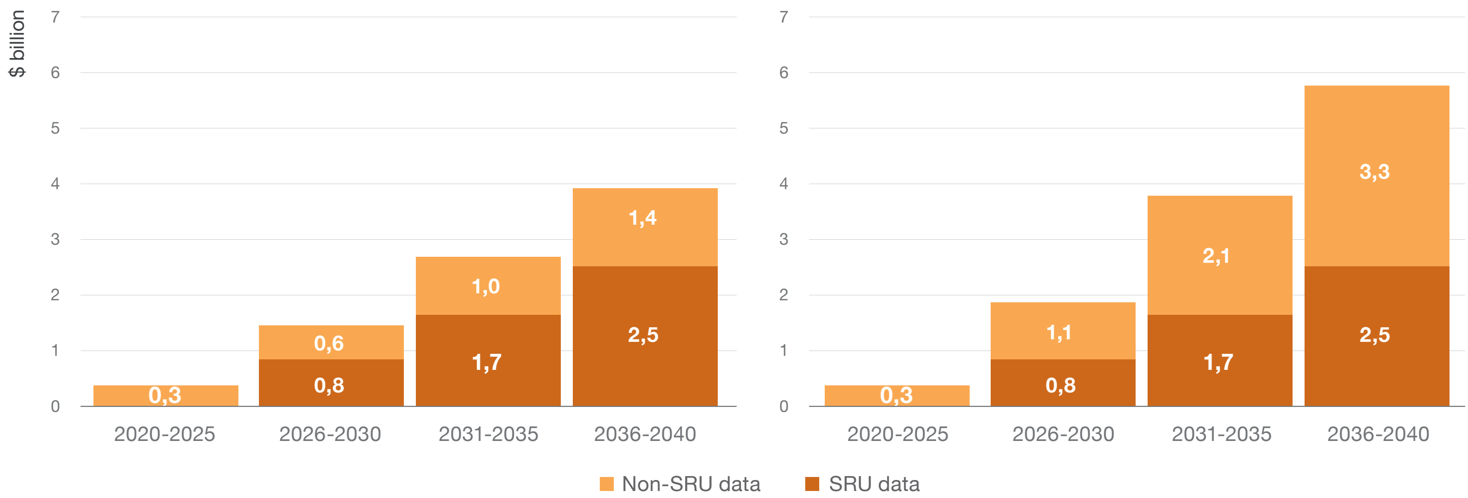


Figure 15 - Cumulated revenues for the lunar environmental data market on 2020-2040 (nominal scenario on left, optimistic scenario on right)

Key market enabling factors and highlights

 As the push for developing a sustainable lunar presence gains momentum, it is anticipated that some commercial entities (space sector, mining sector, construction sector etc.) would change their buying habits. While traditionally commercial entities would generally have waited for the data to become public (up to 6 months to 1 year later in general), there is an increasing interest in paying for the data in order to obtain it immediately and gain a competitive advantage.

 As the number of missions to the Moon increases, the resolution of available data, the timeframe over which it is taken and the variety of locations over which it is recorded shall improve too, thus widening the options to address customer's needs both public and private.

 Echoing the trend observed in the transportation market, non-space companies such as those found in the mining or automotive industries are expected to play a leading role in the data procurement market as they develop their space presence with the objective to first understand the lunar environment (for technology development) and then develop lunar operations (mines, rovers, etc.) that are safe and in line with the international laws pertaining to safe operations in space.

 Future lunar operations are now strongly focused on better understanding the local environment, requiring increased prospection activity. The scientific and space communities (public and private) are anticipated to be significantly interested in using data to understand how dust and gravity impact equipment and crews, but also how metals could be used to enable a sustainable presence (e.g. regolith for shielding) on the Moon which would, in turn, facilitating growth in the market.

 The Artemis programme and the CLPS missions shall potentially assist in filling the data gaps that are currently present in the market. This should, however, only clear the way for further investigations and additional prospection to refine our knowledge, stimulating the market to grow substantially in the 2031-2040 timeframe.

3.2.2.3 Lunar telemetry data market forecast

The telemetry data market is expected to be an order of magnitude smaller than the lunar environment data market. This is largely due to issues pertaining to the supply of this data type. For instance, manufactures of lunar equipment (orbiter, lander, rover etc.), systems, sub-systems and components may not be willing to sell telemetry data related to their products, especially driven by the fear of duplication by potential competitors. Nevertheless, it is anticipated that the demand for this data shall grow with time. Therefore, suppliers may develop inter-organisation agreements with regards to the sales of such data and facilitate the demand. It is anticipated that between 2020 and 2040 the telemetry data market would cumulatively generate $115M in revenues.

The telemetry data market for the 2020-2030 period shall account for $43M, of which revenues associated to public sector exploration shall account for $35M (80.3%), followed by roughly $4M (9%) from private space sector exploration, just above $3.5M (8.7%) from private non-space sector exploration, and just under $1M from private non-space sector terrestrial activities. The Artemis missions and CLPS missions constitute a significant driver of this market under the timeframe considered.

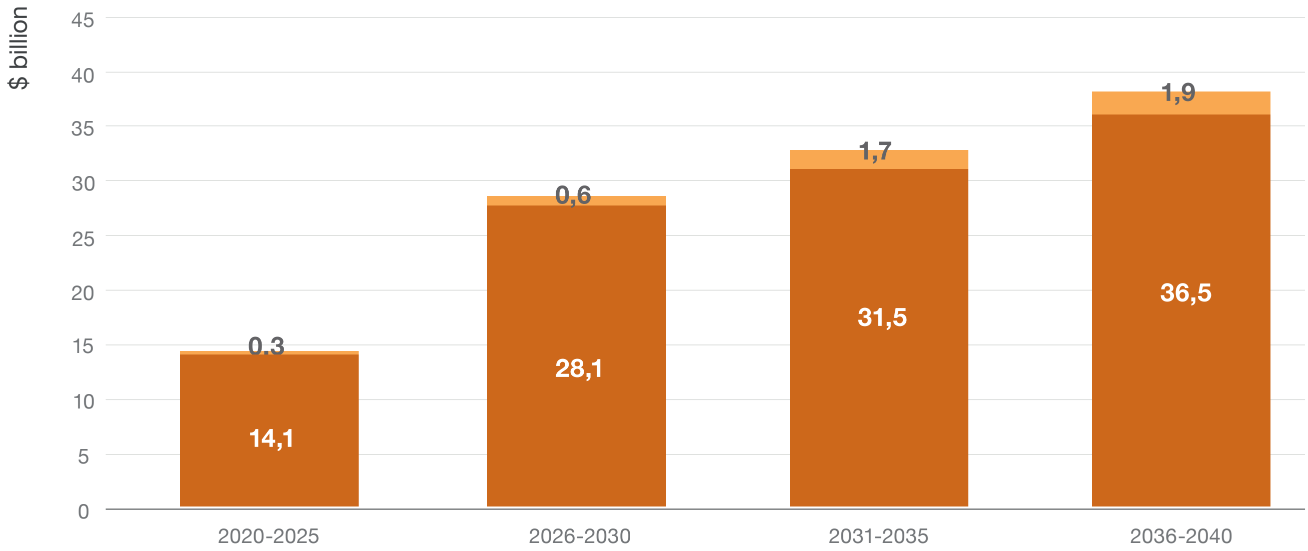


Figure 16 - Cumulated revenues for the lunar telemetry data market on 2020-2040 (nominal scenario)

However, the 2031 to 2040 time-frame is expected to witness a major shift with private sector revenues accounting for nearly $40M (private space sector exploration around $18M, private non-space sector exploration around $16M, and private non-space sector terrestrial activities around $4M). While the revenues of these markets increase, it is anticipated that there may be a slight reduction in the public sector exploratory data revenues reaching $34M thus accounting for slightly less than half of the market share between 2031 and 2040.

Key market enabling factors and highlights

- Privately-led initiatives by space companies are expected to be one of the prime sources of demand for telemetry data, firstly to enhance the capabilities of their systems, and secondly to gain competitive advantage.
- The U.S.A have a leading position in this market, accounting for around 40% of the total market ($57M) over the 2020-2040 period. Their needs are largely driven by the Artemis missions and the objective to maintain a sustainable presence on the Moon.
- Significant private sector involvement is expected from the automotive industry in the transfer of terrestrial applications and technologies for use on the Moon. This is a trend emerging strongly in Asia where several actors such as Toyota, Mitsubishi, to name a few, are actively contributing to lunar exploration plans. The telemetry data of current and short-term missions, in particular involving rovers, will have a great value for these actors, including (among others) what concerns energy provision and fuel cells performances.
- Mining equipment providers are also expected to take special interest in purchasing telemetry data to enhance their terrestrial technologies. Their interests lie in the understanding of behaviour of autonomous vehicles and remotely controlled robotics in lunar environment, which will be a crucial aspect for future operations of mining equipment on the Moon. U.S. actors should have a leading role in this segment.

3.2.2.4 Lunar entertainment data market forecast

The entertainment data market is expected to account for 0.2% of the total cumulative data market. The lower penetration of lunar data in this market is largely associated to the lack of willingness to pay for costly original imagery when alternatives such as green screens and software-based video/image augmentation platforms (Adobe After Effects, Autodesk Maya, Nuke, Mocha etc.) are a viable alternative. However, it is anticipated that as the number of lunar missions increases, both the quality and quantity of data available for utilization shall increase too, enabling production companies to utilize more realistic video footage, audio recordings and images for movies, documentaries, TV shows, video games and other applications in the entertainment industry.

The market for the utilization of lunar data in the entertainment industry is expected to be dominated by the production of documentaries, followed by the production of movies. Both these verticals are expected to grow 4-fold from $3.5M in cumulative revenues between 2020-2030 to $14M in revenues between 2031-2040. Whilst, utilization of lunar data in the video gaming industry is expected to be the smallest market accounting for $0.6M between 2020-2040 timeframe, with more than three quarters of the revenues arriving in 2031 to 2040 timeframe.

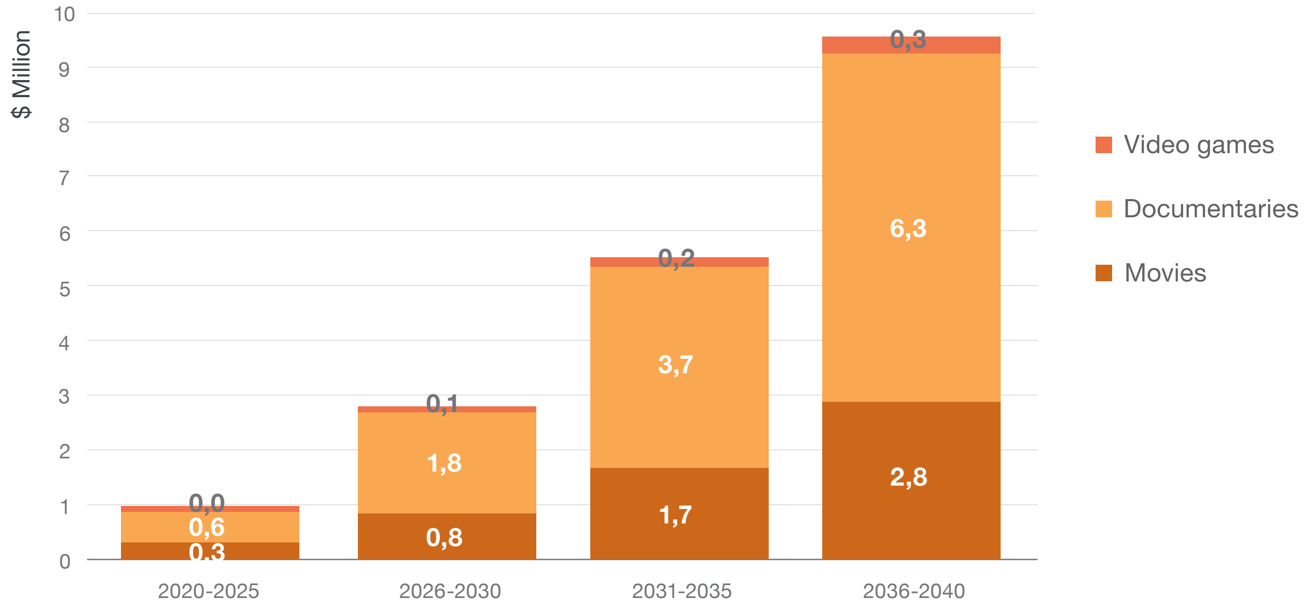


Figure 17 - - Cumulated revenues for the lunar telemetry data market on 2020-2040 (nominal scenario)

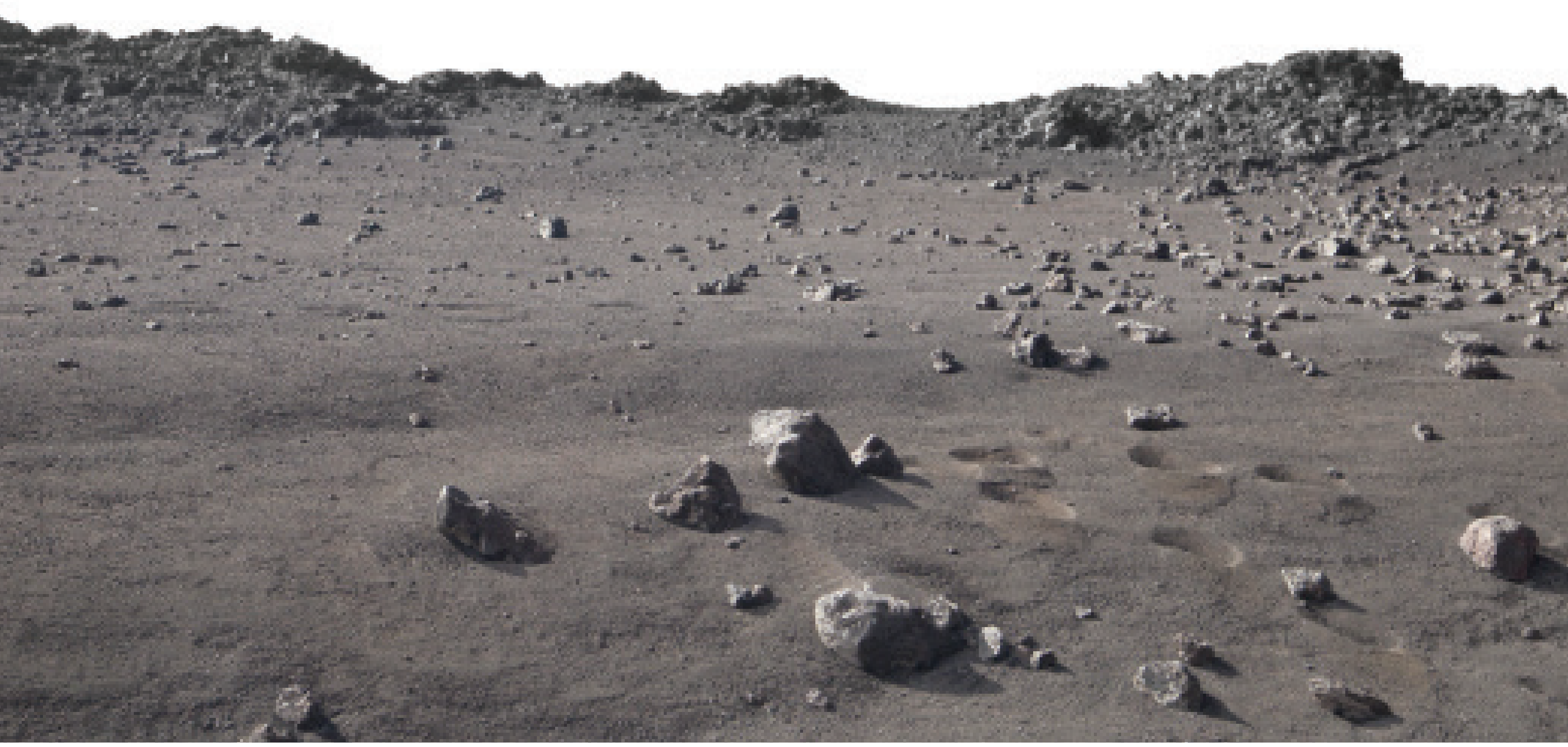
Key market enabling factors and highlights

 The entertainment market is driven by documentaries which both directly require original content and utilise large amounts of real-time footage.

 High price points for purchasing footage that can be utilised in movies (and their marketing) also substantially contributes to the market size. The U.S.A is expected to be the largest market for data utilization in the entertainment industry, since they have the largest cinematography industry in the world.

 The utilization of lunar data in the video gaming industry is expected to be the smallest market due to the low prices associated to data utilized in this industry. The demand for content pertaining to video games shall be dominated by the Asia Pacific region.

 The progressive democratisation of the lunar transportation market, as costs barriers are lowered, should reduce the cost of lunar data and facilitate its acquisition by the entertainment industry.



4 Space Resources Utilisation

4.1 State of play

4.1.1 SRU and its value chain

Beyond lunar transportation and lunar data collection activities, sustained human and robotic presence on the Moon opens the path for local resources extraction and utilisation which will unlock the potential of future space missions. Many actors have started to develop technologies and concepts to work with and utilise the volatiles, minerals, and energy resources on the Moon particularly as In-Situ Resources Utilisation (ISRU) is foreseen as a vital and integral enabler of future space missions. While fully characterising the market potential and timeline for ISRU roll out remains a challenge, current forecasts suggest it harbours tremendous economic potential.

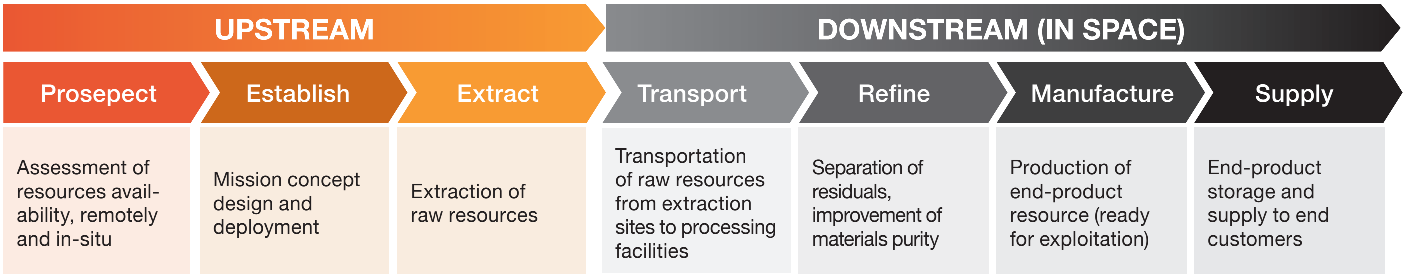


Figure 18 - Value chain for SRU

4.1.2 SRU demand and supply

4.1.2.1 SRU demand

Space Resources Utilisation is foreseen to serve different types of applications, in space as well as on the Earth. It relies on the exploitation of different molecules, including volatiles (oxygen, nitrogen, hydrogen and water for instance) and minerals (present in the regolith of the Moon or the soil of asteroids). Once extracted and processed, these resources serve the production of life support gases and water, the production of propellant for rockets, and the manufacturing of infrastructure for space equipment and for facilities to support space exploration and human presence in space.

The demand for SRU will be driven by a mix of publicly and privately oriented applications. Crewed missions, requiring both life support and propellant, are mostly driven by space agencies programmes as, to date, these are the only type of organisations to have successfully landed on the Moon and Mars. Some private actors have expressed their ambition to develop endeavours such as commercial space stations visited by private astronauts (such as envisioned by Axiom Space) or ambitious interplanetary missions with a high frequency rate as announced by SpaceX. The in-space manufacturing of orbital equipment or ground infrastructure would serve both the institutional organisations leading the exploration activities and the ecosystem of private actors developing alongside the space agencies.

Volatiles and refractory

Life Support

- O_2 and N_2 for breathing
- Water for drinking
- Food production

Propellant production

- O_2 and H_2
- For rocket propellant and for cis-lunar transportation vehicles

Industrial metals

Manufacturing equipment

- Satellites and SS components, spare parts, maintenance tools, radiation shielding etc.
- Tools and machines for extraction, resource processing etc.

Building ground infrastructure

- Human facilities, roads, landing pads, power plants, extraction plants, and radiation shielding of infrastructures

Figure 19 - Resources and applications considered for SRU

4.1.2.2 Supply

As an emerging market, the supply of SRU products and services is in its early stages, focusing on technology maturation and technology demonstration missions. The efforts of the SRU community are currently working on the prospection stage of the value chain which is essential to establishing the abundance of space resource availability. The growth of these activities will depend largely on upcoming technology developments and business case viability. While remote sensing has been available for decades, in-situ measurements and characterisation is indispensable to reach sufficient accuracy and to analyse the sub-surface composition of the Moon. Other developments and missions undertaken by public and private actors show an increase in activity along other stages of the value chain. Notable examples of said activity include the PROSPECT demonstrator mission by ESA, the various landers developed by Astrobotics (Peregrin, Griffin), Blue Origin (Blue Moon) and Lockheed Martin (McCandless), rovers developed by ispace (Hakuto-R), NASA (VIPER), CSA (Chang'e 4) or ISRO (Chandrayaan-3), the Roscosmos Luna27 mission, Perseverence NASA mission as well as the development of the FFC method by Metalysis, amongst others.

Today, several companies have engaged in the development of SRU technologies globally, highlighting the dynamism of the sector. The complementarity of public and private sectors in the development of the SRU ecosystem reflects the general dynamic observed across other space domains where public programmes play a role in stimulating the market and the establishment of primary customers for private companies to emerge and mature their technology.

Figure 20 - Ilustrative examples of companies involved in the SRU supply chain

The respective maturation of the demand and supply will dictate the pace of evolution of the overall SRU ecosystem with a short-term focus on water and volatiles resources, followed by a medium term (>10 years) development of regolith and metals exploitation. PGMs, on the other hand, are expected to reach maturation on a much longer timescale, considering the heighted challenges that their extraction and repatriation pose.

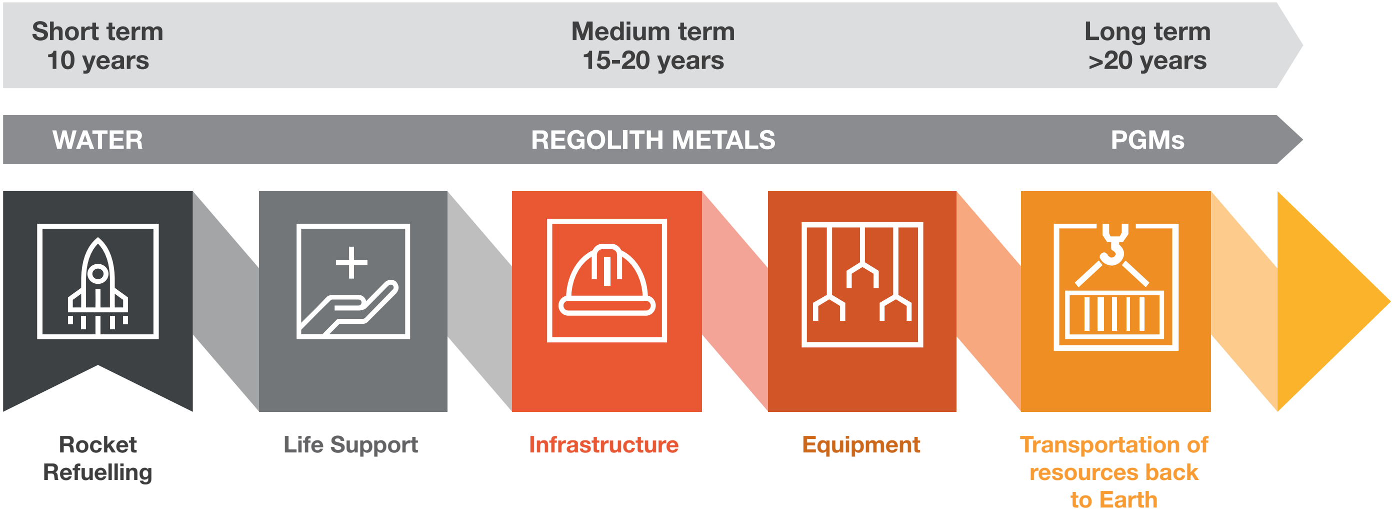


Figure 21 - High level roadmap for SRU maturation in the coming decades

4.1.3 Global Political and Regulatory landscape assessment

4.1.3.1 National initiatives around SRU

Due to the inherent novelty and uncertainty surrounding this field, the growth of SRU activities is closely linked to the level of support granted by governmental agencies towards this field. This can take various forms but primarily includes the provision of regulatory and political conditions that enable industry providing a safe operating context for business. To this end, many states and agencies have taken steps to establish a regulatory framework or policy with respect to the exploitation space resources.

In the U.S., the intent on returning to the Moon and establishing a sustainable presence there as expressed by the two most recent Administrations highlights increasing importance of SRU on the global space exploration agenda. In 2020, the U.S. government issued an Executive Order encouraging international support in favour of space resources utilisation, affirming the desire minimize policy barrier restrictions related to SRU whilst seeking to further global buy-in on this approach. In Europe, Luxembourg has created an attractive environment for SRU companies and foreign businesses, offering a concentration of specific expertise, maximizing the creation of business cooperation and partnerships. The country is also actively developing solutions to the financial, technological and operational challenges related to SRU.

Other entities and states have initiated SRU frameworks following dedicated roadmaps which outline their long-term commitment to SRU. The European Space Agency has developed its Space Resources strategy, in coherence with its European Exploration Envelope Programme (E3P), which includes the PROSPECT mission and other opportunity missions to perform technology demonstration (focusing first on water) and which involves the commercial sector alongside the public actors. In the U.S., NASA's Tipping point Awards play an integral role in supporting the growth of SRU technologies with several SRU companies developing their technology through Public-Private Partnerships. Australia's National Research Agency has also included SRU in its roadmap, including habitat and life support, in-situ SRU, autonomous robotics, power and propulsion. In doing so, the country is able to leverage its strong heritage in mining technologies. In addition, the UAE is now the first middle eastern country to have developed a comprehensive legal framework for space activities, including SRU as part of the national space strategy. Furthermore, an international co-operation agreement was signed between the UAE space agency and the Duchy of Luxembourg, and the UAE's vision of a Mars Village by 2117 has started to materialize through international cooperation, illustrated by the Hope mission to Mars.

4.1.3.2 Development of an International Framework on Space Resource Activities

Besides various local and regional initiatives, ongoing discussions are taking place on an international level to define a common legal framework for SRU activities. Such initiatives include the discussions within the legal subcommittee of the UN COPUOS, as well as the work carried out by The Hague International Space Resources Governance working group. In 2019, a wide consultation was performed by this international working group leading to the development of 20 building blocks for the development of an international framework on space resources activities. These building blocks were designed to form the basis of legislations, which when implemented at national level, should facilitate the obtention of preliminary agreements. This international process has the advantage to have been conducted hand in hand with the industry, maximising its relevance from a commercial perspective, and ensuring that companies will be able to develop, invest and conduct operations without the risk of harming other countries.

4.2 Future evolution and market for lunar data

4.2.1 Market drivers and challenges

The evolution of the SRU market is driven by current and future missions to the Moon and Mars which stimulate rocket propellant demand and involve a sustainable human presence in the extended lunar environment.

4.2.1.1 Market drivers

The materialisation of the SRU market is uncertain due to the market drivers it is contingent upon.

A renewed interest for the Moon from space agencies

Recently, many space agencies worldwide have made the Moon a key part of their exploration strategy, extending their interest in going beyond the ISS with crewed flights. This kind of strategy foresees various types of mission from those that characterise the lunar environment, to those that carry out resource prospection, others that develop ground equipment and the orbital infrastructure for a Lunar gateway. In the U.S., the ambition of the Artemis programme reflects this mindset with the announced objective to send humans back to the Moon as soon as 2024. Other regions such as Europe, Japan and Russia also defined their roadmap and established cooperation agreements going in this direction. These agencies contribute to the maturation of SRU technology and increasing buy-in from commercial sector through their different missions (JAXA resource prospector; Luna missions, Polar sample return, ISRU demonstrator). Although more isolated, China also has an ambitious lunar roadmap and demonstrated its ability to land on and return samples from the Moon through its Chang'e programme. Other nations such as Canada, India, Australia, Korea or the UAE are also involved in exploration and SRU activities, showing signs of an emerging and dynamic ecosystem to roll out in years to come.

The development of exploration and SRU programmes by space agencies also creates opportunities for commercial actors. Private actors are involved in the development of the institutional programmes such as the Commercial Lunar Payload Services of NASA, or as contractors for the development of the modules of the Lunar gateway. Beyond the development of said programmes, commercial actors are also expected to play a role in the future lunar ecosystem as service providers of transportation services (landers, rovers), communication services and along the overall SRU value chain. For example, in 2020, NASA challenged members of the private sector to submit designs for a key component of a lunar-digging robot (the RASSOR) as part of a greater regolith excavation challenge, which could ultimately help support a human presence on the Moon.

A promising future for Mars exploration as a consequence of the growth of lunar resource utilisation

Beyond the Lunar programme, regular missions to Mars also constitute a driver for SRU on the Moon. Mars missions could greatly benefit from in-orbit refuelling in cislunar space, in order to boost the payload capacity to the red planet compared to single-leg missions where a majority of the fuel is burnt just to exit the Earth's gravity well and reach Mars transfer orbit.

While the timeframe for future Mars missions is somewhat uncertain, the recent success in 2021 of the UAE, Chinese and U.S. space agencies is encouraging. In the private sector, SpaceX's intention of carrying out Starship missions on a regular cadence before the end of the decade could catalyse the need for in-situ resources utilisation both to enable propellant production (for return trips) and life support.

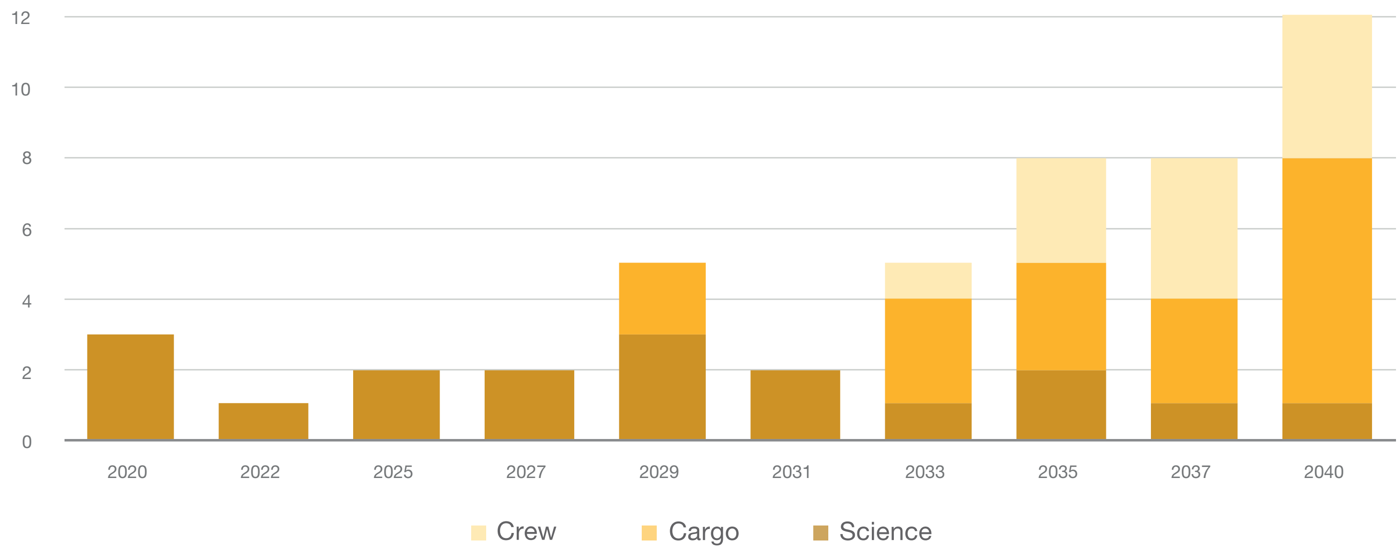


Figure 22 – Assumed Mars missions for up to 2040

The projected number of missions to Mars is expected to grow significantly within the next twenty years. Scientific missions are expected to drive initial growth but as space becomes more accessible in the long term, cargo-related ferrying should be required and increase significantly. This expected growth is primarily driven by the increased innovation and development of vehicles capable of deep space exploration such as the Starship (SpaceX), SLS (NASA/Boeing) and Long March-9 (China) rockets.

4.2.1.2 Market challenges

Remaining knowledge gap on resources characterisation before envisaging exploitation

The first step to be overcome is the demonstration of the resource availability and its characterisation (prospection phase). Moving from the identification of surface molecules to the geological analysis of the regolith and underground soil in extended areas of the Moon is necessary in order to develop the appropriate extraction and processing technologies and confirm the economic viability of SRU for commercial actors.

Remaining unknowns on technologies demonstration

Another challenge for SRU development is the materialisation of demand. This is tied to specific technology developments and programme maturity. Among the main challenges, technologies maturation and demonstration remain a key unknown today. Many concepts are being studied which feasibility is still to be proven, from water extraction to energy production or regolith processing for instance.

The technology developments required include for instance technologies and interfaces for in-orbit refuelling of launch vehicles tanks, and the even more challenging issue of long duration storage of cryogenic propellant in orbit.

Absence of consensual regulatory framework for resources exploitation

Another potential barrier is the regulatory context for the rights and acceptance of the commercialisation of space resource on an international level. National initiatives led to the formulation of regulations, mostly in the U.S. and Luxembourg, but with little international recognition and some opposition on such interpretations of the Lisbon Treaty and Outer Space Treaty, notably from Russia. A commonly shared regulation within the international space community remains to be proposed in order to ensure that private and institutional players will be able to exploit and commercialise these resources. However, it is also worth noting that there is a growing number of initiatives that indicate a favorable policy environment in the near future for commercial ventures.

4.2.2 Market Forecast

Input parameters and assumptions

In the context of market drivers and barriers discussed above, an estimate of the overall SRU market was performed. It is emphasized that this market is an estimated as the revenues are generated from the sales of space resources only, hence does not include the underlying markets of upstream equipment manufacturing or launch services. Below we outline our vision for what would be a nominal scenario with its associated assumptions, before highlighting the main caveats to consider when interpreting the values.

The quantification of the market for SRU-based propellant is built upon a set of assumptions, including:

 The total number of missions to the Moon and to Mars in the coming decades;

 The share of these of mission using SRU-based propellant, evolving with time, and depending on the type of propellant used by the vehicles (LOx/LH2 and LOx/LCH4)

 The needs of propellant for transportation vehicles from the extraction sites to orbital delivery locations, which can be substantial when considering refuelling operations in LEO for instance. The architecture proposed in the NASA study , relying on “honey bees” and “worker bees” was used to obtain the additional propellant consumed for support operations.

 The progressively increasing share of propellant needs that are procured from SRU vs. from the Earth

 The market is always provided at the year of demand. In practice, the actual market revenues might be flatter over time, as payments could start before and extend beyond mission durations.

Overall, the total projected value of the aggregate SRU market is expected to be worth a little above $63 billion by 2040. However, the life support and construction markets represent only a minor share of the overall SRU market (around 1% of the total value). The propellant market represents the other 99% of the overall SRU market and is the main driver of growth.

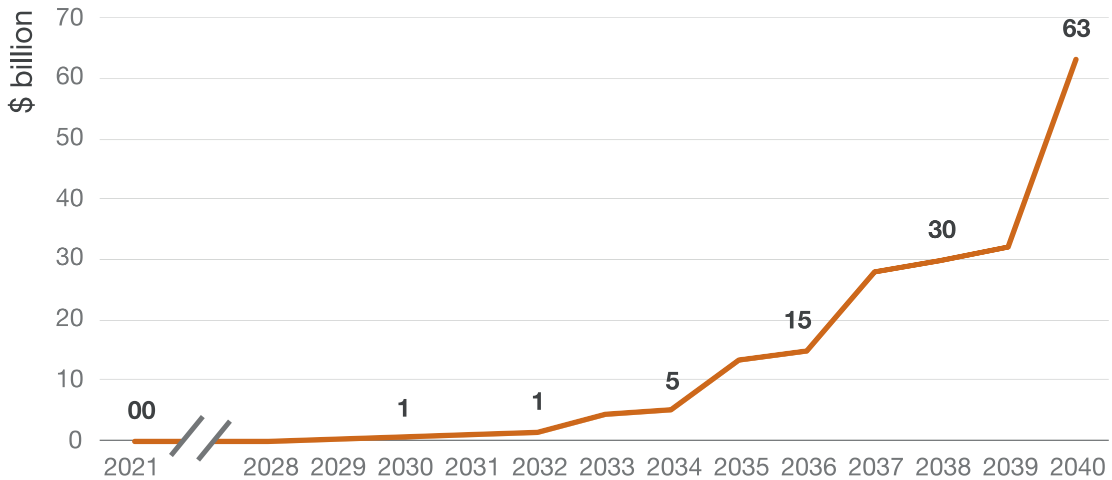


Figure 23 - Evolution of the cumulative SRU market size

There is negligible growth in the overall SRU market between 2020-2030, followed by a drastic change in growth post-2030. This significant difference is primarily driven by the change in projected demand for propellant during this period. The increase in the demand for propellant is driven by two factors. First, an increase in the mass of payloads for these missions, which will also require more propellant. Second, an exponential increase in the frequency of missions – both to the Moon and Mars – starting in 2030, which will require increased amounts of propellant. This increase in the number of missions is partly stimulated by a shift from institutional missions to private missions, which will drive the commercial ventures into space and increase the number of players entering the market. In this increasing demand, inter-planetary missions to Mars should play a predominant role considering the payload and propellant needs for these missions, hence affecting the overall SRU market.

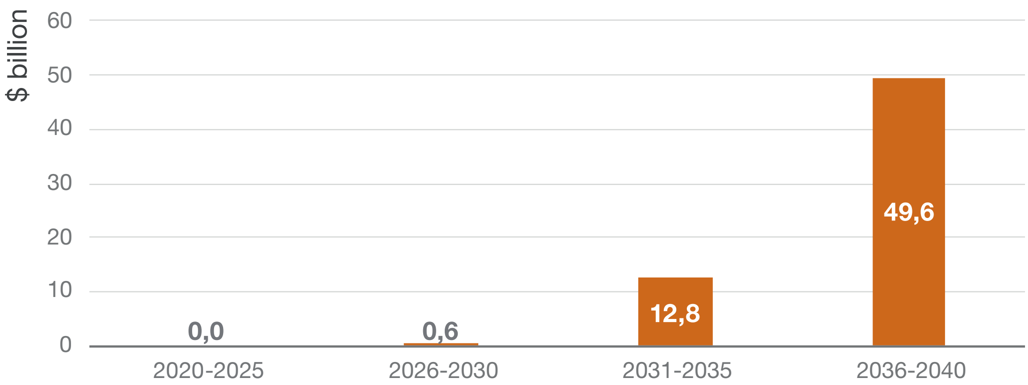


Figure 24 - SRU projections for launcher propellant market

The monetisation of the market is tied to the price per kg of propellant. While said value remains highly hypothetical at this stage, some raw orders of magnitude are used based on the costs of bringing such propellant to LEO ($3,000/kg, as mentioned in ULA's Cislunar vision) or on the lunar surface directly ($ 500/kg, as supported by the REACH study on Commercial Lunar Propellant Architecture). The projected cumulative value for the launcher propellant market is expected to be worth around $63 billion by 2040.

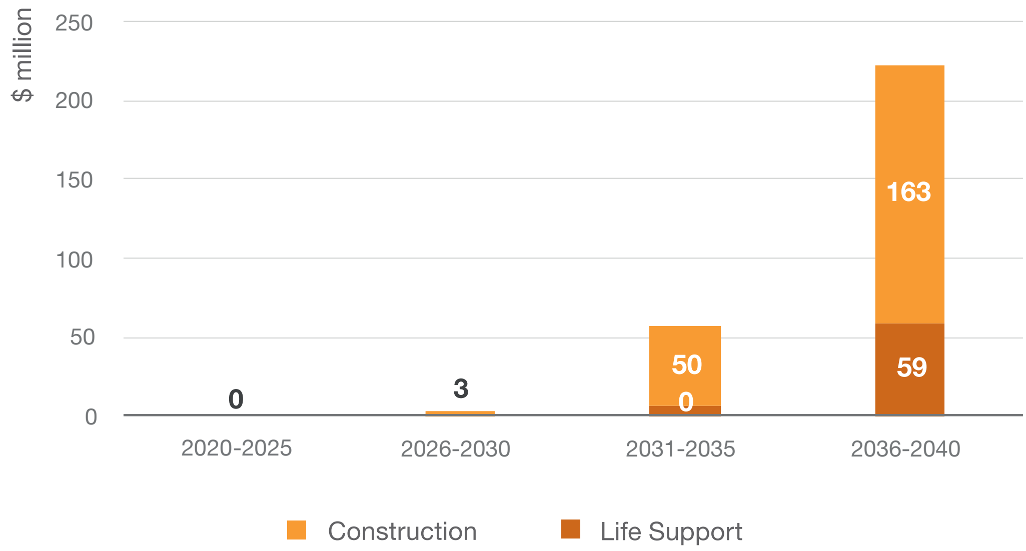


Figure 25 - SRU projections for life support and construction markets

In parallel, the demand for life support resources is estimated based on a set of various assumptions affecting the mass of SRU-based resources consumed, such as the expected number of astronauts travelling to the Moon and to Mars, the length of their stay on the Moon (or in the orbital station) or on the Martian surface and the share of resources embarked from Earth vs. those procured through SRU. Similarly for the propellant market, the main driver for the life support market is the frequency of missions and a shift towards human presence on both the Moon and Mars post-2035. The projected cumulative value for the life support market is expected to be worth around $66 million by 2040.

Similarly, the demand for construction resources is also estimated based on the required support for Moon and Mars missions, taking into account the number of astronauts with sustainable presence on the surface of the Moon (with proportionate needs for support facilities) and the amount of orbital and Moon surface infrastructures to be maintained and to which SRU can provide processed regolith and metals. This application is constrained by the expected maturity of in-situ metals processing within 2040 timeframe. As with the propellant and life support markets, the construction market will be driven by the increased human presence in space, which will call for increased demand in infrastructure and manufacturing capabilities. The projected cumulative value for the construction market is expected to be worth around $216 million by 2040.

Caveats and critical analysis

The demand and supply for SRU markets is affected by many external forces. While the trends associated with the results presented in the current analysis are considered robust, there might be gaps with the actual values, especially considering the 20-year timeframe considered. The projections presented in the SRU section of this report, which estimate the projected growth of the different SRU market segments (Propellant, Life Support, Construction) are based on limited available data and educated estimates. Research behind this report helped establish a tentative cadence for missions over the next twenty years which was used as a baseline to further calculate projections for the value of the market. These calculations used formulas which assigned different weights (levels of importance) to various factors.

For example, the demand for propellant is based on a pre-determined projected number of missions – and the projected market value in this report is heavily dependent on the successful undertaking of these missions. Any change in the number of missions (cancellations or additions) in the next twenty years would directly affect the demand for propellant, subsequently affecting the overall market for SRU.

Conversely, certain factors such as the number of astronauts per mission is not expected to have significant effects on the future projections of the SRU market. Adding one astronaut per mission would be relatively inconsequential and would likely result in only a slight change in the amount of life support needed but would not affect the amount of propellant required to transport the total payload to the Moon for that mission. Thus, the projections for the SRU market would remain largely unchanged.

Other important considerations that could skew the findings in this report include the price of materials and resources which vary depending on the location of supply (for instance, on the surface of the Moon vs. in LEO) and for which there is no existing data point, not to mention any commercial value. While this does not affect the volume of resources consumption and the rations between the market sizes, it could directly affect the monetary value of the markets presented in this paper.

Finally, the projections performed in this report are also subject to potential disruptive technological innovations and shifts in national priorities. It is, therefore, important to state that the numbers and figures presented in the report can change and evolve over time.

5 Conclusion

A promising cumulated $170 billion market with exponential growth beyond the current timeframe

As space rapidly becomes more accessible and activities begin to ramp up, two clear goals have clearly emerged– establishing a permanent presence on the Moon and developing a self-sustaining lunar economy. With this in mind, the next twenty years are key in terms of lunar activities, and the markets for lunar goods and services are expected to rapidly expand in an effort to match the demand, growing to a cumulated $170 billion over up to 2040.

Revenues in this timeframe will be primarily driven by the market for lunar transportation, expected to be cumulatively worth roughly $100 billion by 2040, and the SRU market, expected to be cumulatively worth about $63 billion by 2040, driven primarily by the demand for propellant. The appealing perspectives of these two markets are supported by the expected growth in the frequency and number of missions to the Moon, as well as the increasing scale of the missions, targeting larger payloads with the aim of enabling a sustainable human presence. It is worth noting that the exponential growth of the SRU market is expected to take off as technology demonstrations that will enable the lunar economy take place in the coming years. The SRU activities are therefore likely to play a predominant role beyond 2040, primarily driven by Mars exploration missions and increased support activities on the Moon to support a human presence. SRU-related numbers remain linked to external factors such as the compatibility of launchers and the maturation timeline of associated technologies.

An order of magnitude smaller than the transportation and SRU markets, the lunar data market follows a similar growth dynamic, benefiting from the traction from space missions development and associated terrestrial research activities. The demand and use of space data should be continuously stimulated by the pressing need and immense value of ground-truth data. SRU technologies and concepts rely heavily on an in depth understanding and characterisation of the lunar environment which cannot be obtained through traditional remote sensing data.

A market extending beyond space actors and increasingly involving terrestrial industries

Growing involvement from non-space actors is expected in the lunar ecosystem despite it being associated with a select group of space agencies or space companies. Terrestrial industries such as the automotive, mining or construction industries have identified close synergies in terms of their core expertise and the challenges met in the lunar exploration when working in remote locations and hostile environments. Both technology spin-offs and spin-ins are targeted by these actors, many of which are already concretely engaged in research activities and cooperation with Moon exploration actors, be it space agencies or commercial actors. As a consequence, such actors are expected to have an increasing role in particular after 2030, constituting a sizeable share of the lunar transportation market as payloads increase in mass and number.

A pace of development subject to technology and political factors

There are multiple milestones to be met in the next few years which would help confirm the trajectory of current roadmaps via missions and international cooperation. The success of the upcoming lunar missions will serve as steppingstones for the blooming of a wider ecosystem, both institutional and commercial.

The first success factor will be technology maturation. Short term lunar missions will pursue resource prospection activities and should enable technology demonstrations of super heavy launch, new lunar landers and rovers, resource extraction, processing, in-situ manufacturing and more. Each success will be a step forward to the stimulation of the market and materialization of revenues.

The second success factor will be the international cooperation – including treaties and inter-agency cooperation – which will promote a common effort towards achieving these objectives. Lunar exploration is very capital intensive, and as a consequence is the subject of a widely international cooperation. Cooperation between space agencies, as initiated for instance under the Artemis accords or through bilateral agreements, is a mean for countries to bring together their scientific expertise and financial means. In the meantime, current tensions regarding space resources ownership and commercial property are a reminder of the high political stakes involved in this matter. Such issues could reduce the pace of development of lunar exploration activities, and the proper management of political friction will therefore play a decisive role on the timeline of materialisation.

Acronyms

ASA	Australian Space Agency
CAGR	Compound annual growth rate
CLPS	Commercial lunar payload services
E3P	European Exploration Envelope Programme
EC	European Comission
EIB	European Investment Bank
ESA	European Space Agency
EU	European Union
GES	Goonhilly Earth Station
H2020	Horizon 2020
ISECG	International Space Exploration Coordination Group
ISEF*	International Space Exploration Forum
ISRO	Indian Space Research Organization
ISRU	In-situ resource utilisation
ISS	International Space Station
ISS ECLSS	International Space Station Environmental Control and Life Support System
JAXA	Japanese Aerospace Exploration Agency
JUICE	Jupiter Icy Moons Explorer
JWST	James Webb Space Telescope
LEO	Low-Earth orbit
MBRSC	Mohammed bin Rashid Space Center
MPCV	Multi-Purpose Crew Vehicle
NASA	National Aeronautics and Space Administration
O&G	Oil & gas
OTT	Over-the-top
PGM	Platinum group metals
PPP	Public-private partnership
PROSPECT	Package for Resource Observation and in-Situ Prospecting for Exploration, Commercial exploitation and Transportation
RASSOR	Regolith Advanced Surface Systems Operations Robot
SKG	Strategic knowledge gap
SLS	Space Launch Systems
SME	Small and medium-sized enterprises
SRU	Space resources utilisation
UAE	United Arab Emirates
ULA	United Launch Alliance
UN COPUOS	United Nations Committee on the Peaceful Uses of Outer Space
US/USA	United States of America
VATP	Value Added Telemetry Products
VC	Venture capital
MPCV	Multi-Purpose Crew Vehicle

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