The Lunar Commerce Portfolio

First Edition, 2022

Lunar Commerce and Economics Working Group

Preface

Humankind is returning to the Moon, this time to stay, and a number of matters (international governance, regulatory, policy), in addition to the perhaps more direct national technological and funding issues, need to be resolved before that can happen. The Moon Village Association (MVA) was established in 2017 to address these matters of international governance, and in furtherance of these aims has achieved Permanent Observer status at the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS).

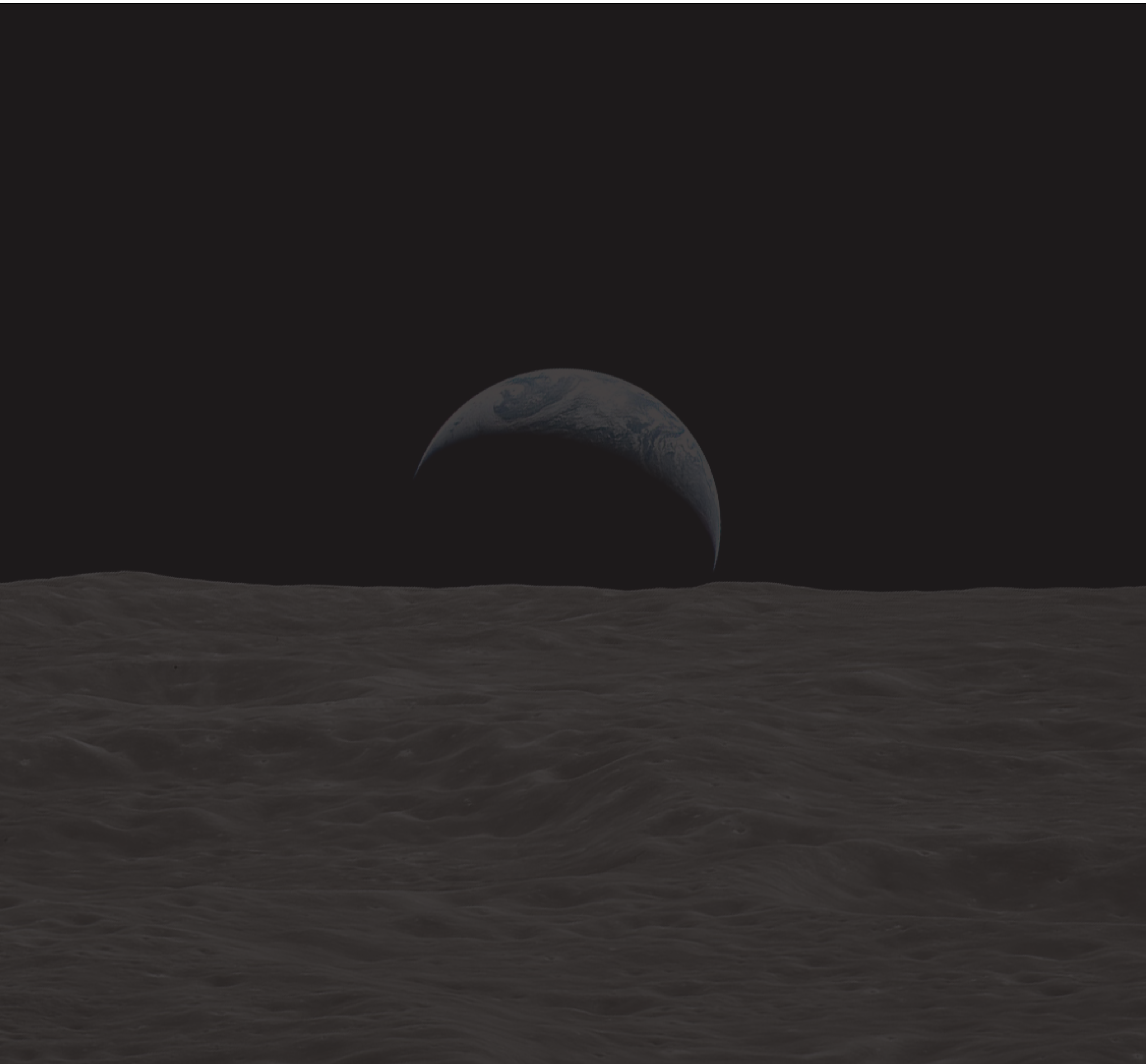
The Moon Village Association is a volunteer organization and contains a number of multi-national, multidisciplinary Working Groups. One of them is the Working Group on Lunar Commerce and Economics (LCE). In this second phase of humanity's venture to the Moon, sustainability has become a key aspect, and it is expected that it will require commercial motivations in support of governmental initiatives to achieve this end. The LCE Working Group of the MVA has therefore set out to determine whether there can indeed be viable commercial markets on the Moon, and if so, to try to assess their timing and scale. The Working Group initially established that no reliable and unbiassed source material for this already existed in the public domain, and so set out to create a reliable document, called the Lunar Commerce Portfolio (LCP), to capture the best, and most rigorously calculated, estimates of potential regarding Lunar commerce opportunities. This first version of the Lunar Commerce Portfolio is the result of nearly two years of work of its international volunteer members, operating in an era during the covid pandemic when face-to-face meetings have been impossible. It is offered free to all users as a contribution from the Moon Village Association to assist in the furtherance of the development of the Lunar economy.

The methodologies and assumptions adopted by the MVA Lunar Commerce and Economics Working Group in deriving this Lunar Commerce Portfolio have been explicitly and transparently stated in the report, including the implicit current wide ranges of uncertainty. Therefore, it will become possible, in subsequent versions, to update the estimates and reduce the uncertainties as better data becomes available.

I hope you will find it a helpful resource in your endeavors related to developing the Moon. There is material here, quite apart from the quantified analysis, which will help all potential contributors to the development of the Moon to understand the interrelationships, value chains, and opportunities for their involvement.

November 2022
Giuseppe Reibaldi,
President, Moon Village Association,
Vienna, Austria.

Executive Summary



In a very real sense, it is not possible to provide an effective Executive Summary for the Lunar Commerce Portfolio (LCP) because the whole point about the LCP is its completeness. In this one 250-page document, the members of the Moon Village Association's Working Group on Lunar Commerce and Economics have compiled, to a standard format, the full range of potential lunar businesses, and their interactions, that are anticipated not only in the near term, but in the long term; not only on the Moon, but in lunar orbit. In this same document, moreover, are collected the best assessments of prices for commercial products and services on the Moon, and the resulting revenue projections. And all of this information is tied together through a transparent set of modeling calculations that make possible a series of alternative scenarios to be investigated. This process makes it possible for future versions of the Lunar Commerce Portfolio to be provided which successively improve on assumptions and thereby progressively reduce the range of uncertainties, and, therefore, the potential risk to investors of prospective lunar businesses. This is provided freely by the Moon Village Association to a range of groups interested in possible commercial lunar developments, from entrepreneurial companies, investors and insurers to national space agencies and international space policy and governance organizations.

The work represented by this document is the result of two years of analysis by a team of volunteers from all over the world, operating largely via Zoom during an era of covid travel restrictions. This is not a document fueled by hype regarding the potential of lunar business, but is a realistic assessment of the range of possible outcomes which might emerge depending on a set of clearly established external variables, many of which are beyond the control of individual potential lunar businesses. The document lists a series of these external parameters – many of them remaining in the realm of international space law and governance – and shows the consequences that would emerge from changing these essential assumptions.

The work can be considered to consist of two distinctive parts – a very detailed qualitative arrangement of market materials, and a quantitative projection of the range of revenue outcomes resulting from changing assumptions of the key external variables. And, given the range of unknowns about the future of lunar business from where we sit in November 2022, the range of potential revenue outcomes is very wide. This is to be expected. For instance, one possible driver of future commercial demand on the Moon could be lunar space tourism, and clearly that market in itself is highly uncertain right now. Because of the inherent uncertainties, the projections did not attempt to come up with annual estimates from 2022 onwards. Instead, the approach was chosen to produce just two representative time zones; the first is described as the Early Phase – representing the era between now and 2030, largely determined by governmental expenditures, and another period described as the Mature Phase, probably not happening before at least 2040, when life on the Moon will be self-sustainable from local resources. For each of these two time periods, an average annual commercial operation is envisaged.

So, the great merit of the Lunar Commerce Portfolio lies not in its projections of future revenues, which we have just pointed out come surrounded by an implicit aura of uncertainty, but in the constituent market descriptions, their value chains and potential interested commercial supplier company data, their interactions, and their dependency on future national and international lunar governance decisions. The LCP provides a tool for the nascent industry to use to explore the implications of changing assumptions, and the tool has been deliberately stripped of any untoward certainties or hype. As the industry develops, the database and assumptions in the model will improve, and uncertainties will be able to be reduced. New potential companies willing to consider the prospects of seeking a share of the potential era of lunar commerce, will be able to explore where best they may fit within the indicated value chains laid out in the Portfolio. There will be opportunities even for companies (and countries) with no prior experience of space-related work.

The Lunar Commerce Portfolio is indeed intended to be a portfolio of possibility.

Having set forth the caveats above, it is nevertheless possible to come up with some basic overarching findings from the work contained in the full Lunar Commerce Portfolio document:

The Lunar Economy: An Overview

The work of the LCP describes a future era of lunar commerce which is segmented into nine basic sectors, and all of which interact with each other. And within each sector an attempt has been made to try to differentiate whether the customers for the business are truly commercial or whether they are all dependent in part on government funding. The precise definitions of the market sectors have been chosen to avoid overlapping/double-counting of revenues, and to provide as complete a picture as possible of the potential future needs, whether living on the Moon will eventually turn out to be like living on Antarctica on Earth today, or whether it will be a more-inclusive commercial framework.

In brief, the market sectors chosen to depict the range of possible lunar commercial futures in the LCP were:

- Transportation to/from the Moon
- Transportation on the Moon
- Communications and Navigation on the Moon
- Energy and Power on the Moon
- Supplies and Services on the Moon
- Construction and Manufacture on the Moon
- Mining and Resource Extraction on the Moon
- Habitation and Storage on the Moon
- Agriculture and Food on the Moon.

The full Lunar Commerce Portfolio contains the intricate descriptions of these sectors which ensure no double-counting, and the precise interrelationships between them. Furthermore, there is considerable further sub-division of markets within these sectors – particularly in sector 5, which has been designed to make sure it encompasses everything else which is not included in the other sectors. So, by definition, this 9-sector description ensures that we have a complete description of lunar commercial possibilities. As an example, lunar space tourism is handled by its impact on all of these listed individual markets.

For each of these market sectors, the LCP contains an identical breakdown, for both the Early Phase and Mature Phase, of market descriptors, potential customers (whether governmental or commercial), potential suppliers (currently known to have expressed an interest), value chains, and the market drivers and constraints which lead to the revenue calculations.

Analysis and Key Findings

As pointed out earlier, the qualitative information of the Lunar Commerce Portfolio cannot be usefully summarized. It consists of the very detailed descriptions of the market sectors with mutual interdependencies, a listing of potential customers and suppliers and associated value chains. We find, however, that at least for the Early Phase – from now until 2030, most of the customers for the markets are governmental under one form or another.

We identified a series of nineteen external variables which individually or in combination would significantly affect the projected revenue outcomes for lunar businesses, and in this initial version of the Lunar Commerce Portfolio arranged them into four named scenarios to observe the impacts. The detailed descriptions of the constituent assumptions of the scenario are included in the LCP, but the resulting named scenarios chosen for the analysis were:

- "Sorties"
- "Research Stations"
- "Sustainable Community"; and
- "Resources for Earth"

Clearly, the major finding is that there is an enormous range of uncertainties in revenue estimates for lunar commerce, dependent on a range of factors, many of which are national or international governance related. Other aspects which lead to uncertainties are the consequence of the technological unknowns about lunar resources in November 2022. We do not know how much water there is on the Moon, for instance, and how easily it will turn out to be capable of mining and processing. Although there is abundant Oxygen in the regolith and lunar rocks, we do not know today how easily it can be transformed into breathable or rocket fuel variants.

However, the Lunar Commerce Portfolio, and its constituent models, have been designed for easy updating as newer data emerges which will narrow the range of uncertainties in any given input assumption.

Implications

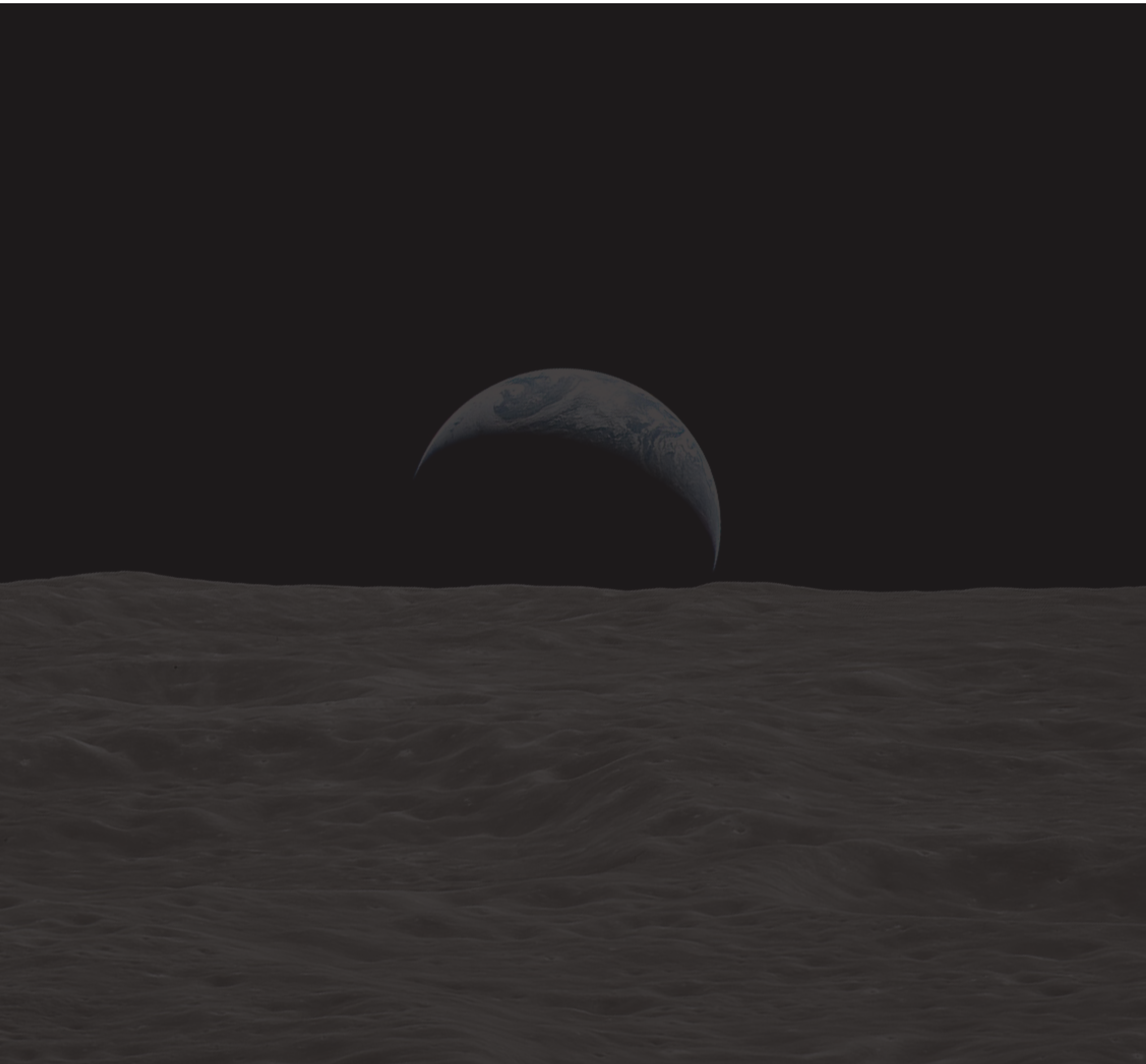
We have demonstrated that it is possible to assemble all the assumptions about a future era of lunar commerce in a single document and model. We have learned that currently the range of uncertainties is so large that it will make it difficult for commercial entities to raise the necessary investment funding to proceed with their proposed offerings. Therefore, it is a clear requirement to work jointly with stakeholders to create the conditions to reduce the uncertainties. Some of the steps needed will be in international governmental fora working on lunar governance areas. Other aspects of uncertainty can be addressed by conducting experiments on lunar precursor spacecraft, and finding the key information points that improve the forecasting regime in particular market segments. Other ways of reducing uncertainty in given market segments will include conducting appropriate market research.

It is proposed, therefore, that a Lunar Commercial User Group be set up to explore mutual steps to help guide the evolution of the future realm of lunar commerce. And that User Group will be able to take advantage of the Lunar Commerce Portfolio and its models to evaluate the implications of different steps as progress is made.

Therefore, it is anticipated that there will be a series of future versions of the Lunar Commerce Portfolio produced in the months and years to come, each succeeding version reducing the range of uncertainties, thus making it more likely that potential suppliers will emerge to make the necessary investments to be a player in the future realm of lunar commerce.

The Moon Village Association has made this material free for the user communities, and made the thinking fully transparent, so that the user community will provide feedback to the creators of the Lunar Commerce Portfolio to make it progressively more useful.

Contributors & Acknowledgements



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The above is intended to be a complete list of all members who contributed to some degree over the last two years, and who signed the Volunteer Agreement. Any omissions are regretted, and thanks are hereby offered to anyone in this category.

Report Assets

Cover Photo: Publicdomainpictures.net, Виталий Смолыгин, Earth And Moon

Section Photo: NASA

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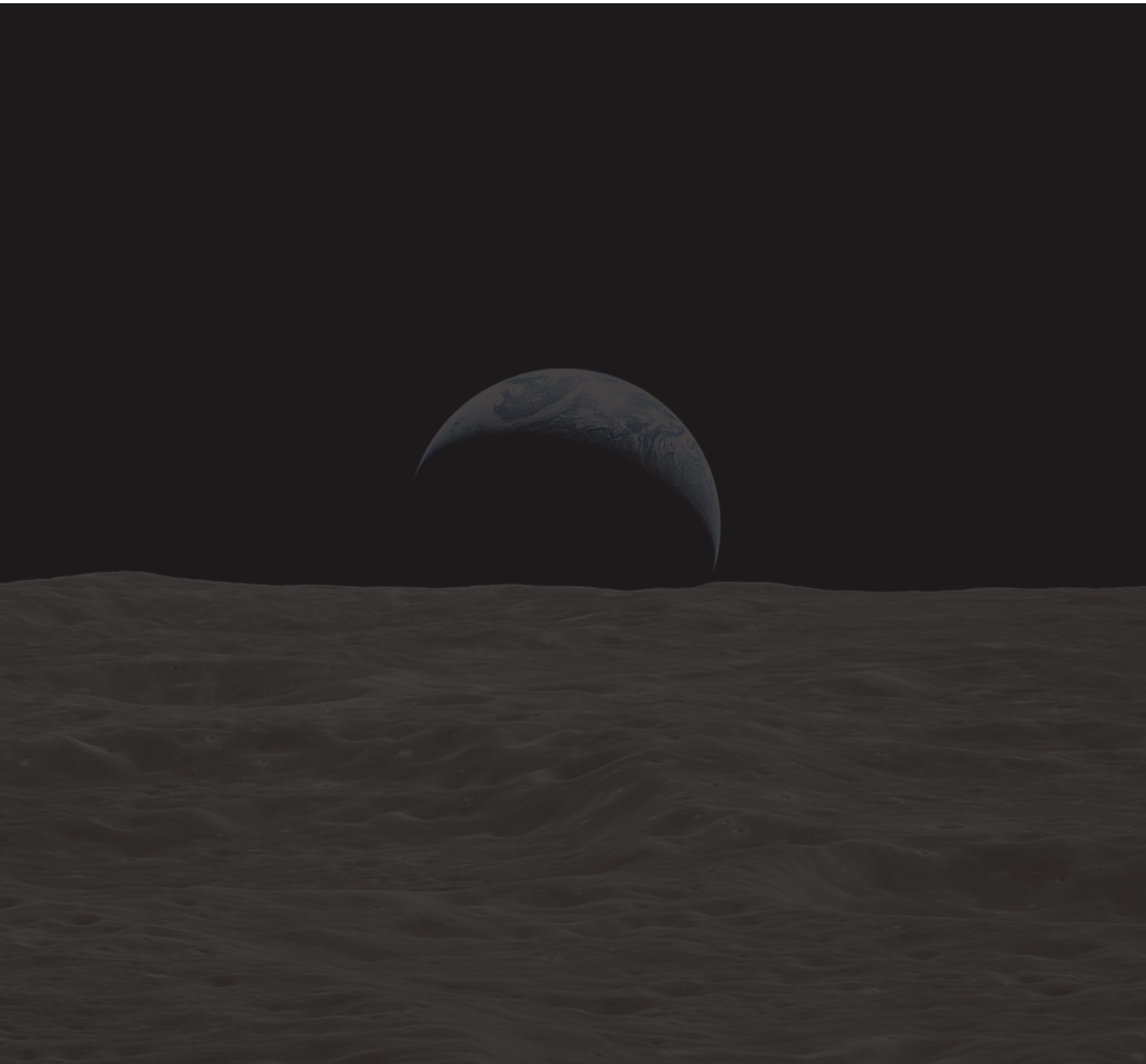
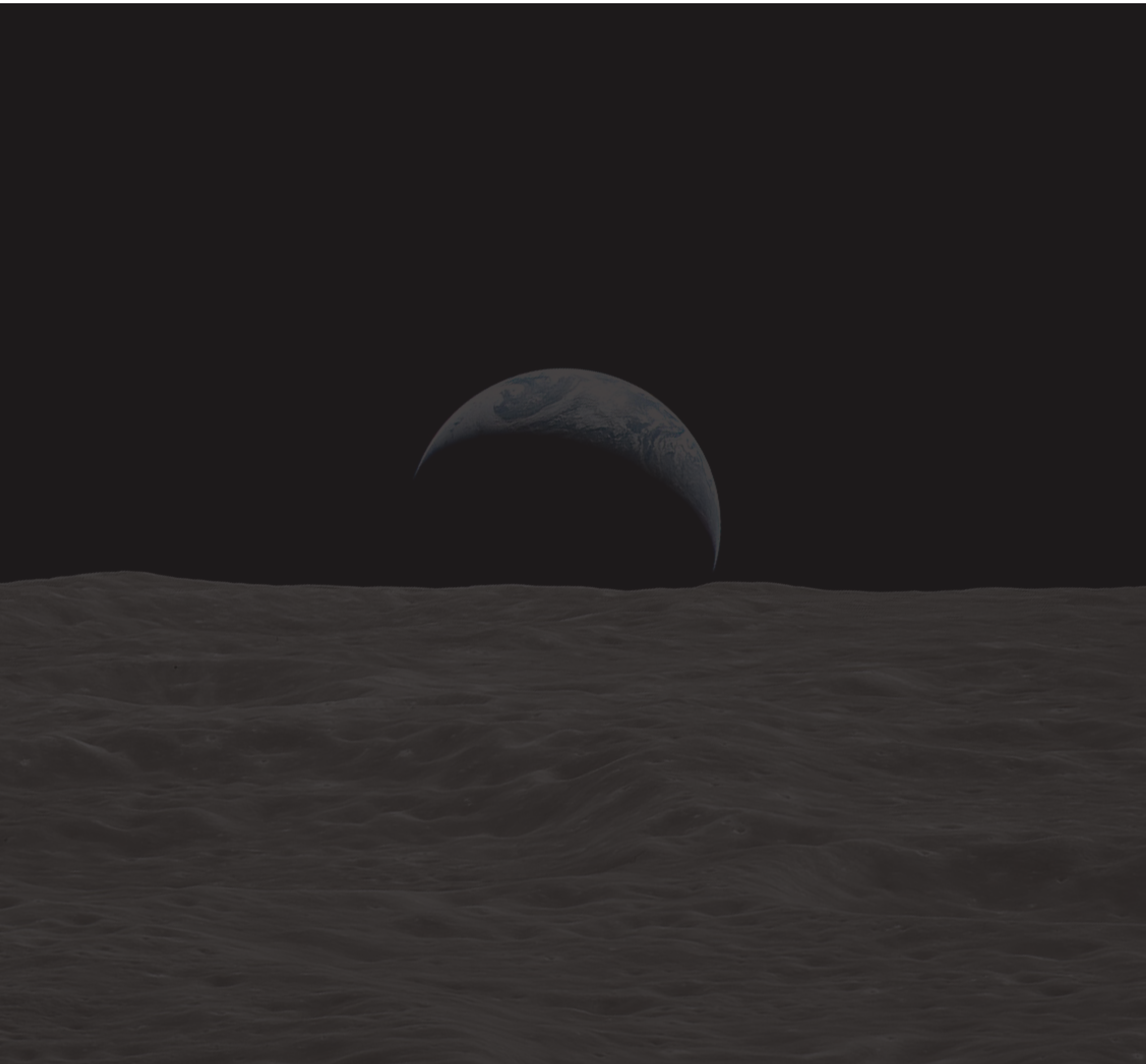


Acronyms and Abbreviations

Acronym/Abbreviation	Definition
Ax-1	Axiom 1st mission to ISS, the 1st all-private crew to visit the ISS, aboard a Crew Dragon Spacecraft.
ASIC	Application-Specific Integrated Circuit
ASSP	Application-Specific Standard Product
BLSS	Bio-regenerative life support system
CAB	Chargeable Atomic Batteries
CNSA	China National Space Administration
CSA	Canadian Space Agency
ECLSS	Environmental Control and Life Support System
ESA	European Space Agency
GNC	Guidance, Navigation and Control
HEU	High Enrichment Uranium
HLH	Habitation Lunar Habitat
HSH	Habitation Space Habitat
HUT	Hard Upper Torso
IMF	International Monetary Fund
IP	Intellectual Property
ISRU	In-Situ Resources Utilisation
ISS	International Space Station
KREEP	Potassium (K), Rare Earth Elements (REE), and Phosphorous (P)
LCE	Lunar Commerce and Economics
LCP	Lunar Commerce Portfolio
LEU	Low Enrichment Uranium
MCP	Mechanical Counter-Pressure
MRD	Market Requirement Description
MVA	Moon Village Association
Mx	Market x (1, 2, 3, …)
NASA	National Aeronautical and Space Administration
NRHO	Near Rectilinear Halo Orbit
PGM	Platinum Group Element

PNT	Positioning, Navigation and Timing
PUE	Payload Unit Equivalent
RDI	Recommended Daily (Food) Intake
RTG	Radioisotope Thermoelectric Generator
SBSP	Space-Based Solar Power
SMR	Small Modular Reactor
TRL	Technology Readiness Level
WG	Working Group
WTO	World Trade Organization

1. Introduction



The Moon Village Association (MVA) has determined the need for a framework to understand the potential for commercial development of the Moon. This framework should be robust, transparent, data-based, comprehensible, fully referenced, and should utilize an unbiased methodology. In response, the MVA Working Group on Lunar Commerce and Economics (LCEWG) has produced this Lunar Commerce Portfolio (LCP). The LCP is a fully-referenced database and resource that feeds into a model of lunar commercial developments.

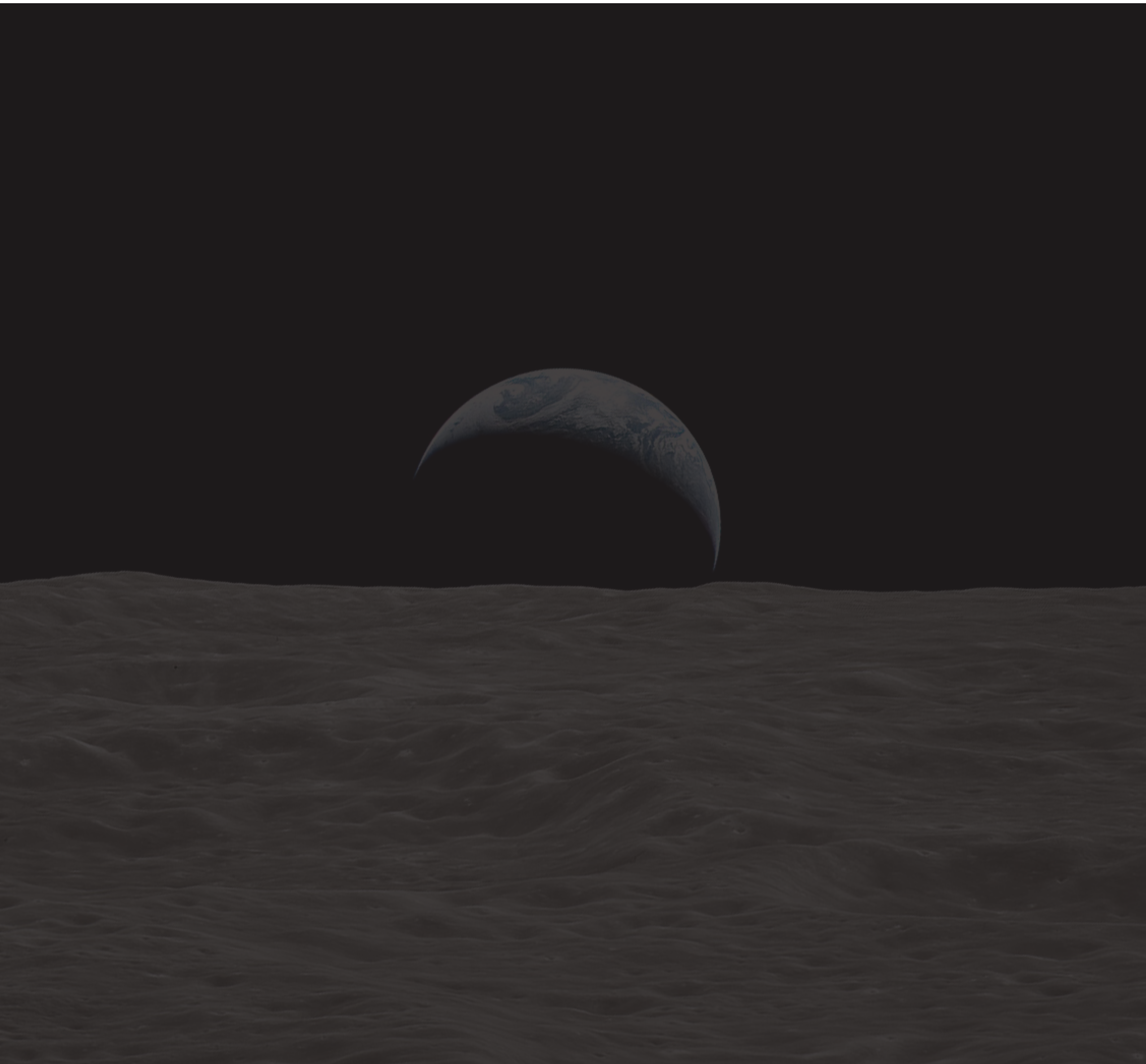
There are at least three very different target groups for this work. The first grouping consists of potential businesses, investors and insurers seeking to understand how they can contribute to, and profit from, a commercial lunar economy. The LCP seeks to aid this group in identifying their position in the value chains, and feed into the determination of revenue potential, timing, and risk. The second grouping comprises national and international bodies concerned with the regulation of future lunar developments. For this group, the LCP is intended to feed into matters such as infrastructure development and the management of scarce resources that are subject to international conventions such as the Outer Space Treaty. Finally, the third grouping contains national space agencies. Here, the LCP aims to aide in the formulation of assumptions regarding the augmentation of national governmental budgets through commercial contributions.

The work began in January 2021, when over 200 applicants responded to a request issued by the MVA. Applicants represented 53 nationalities from a wide range of disciplines. The study progressed in two phases. The first stage established, through systematic analysis and documentation, a firm understanding of the qualitative aspects of the potential lunar market segments. During this phase, all the reference sources were fully documented. For our purposes, a "commercial market" was defined in the following way: "For any given lunar product or service, either the provider or customer (or both) must be non-governmental." In the second stage, the paper moves on to the quantification phase described later in this paper. Both aspects of this work are considered of equal importance in the Lunar Commerce Portfolio. Indeed, the quantitative results alone would have little merit if they were not a consequence of the careful qualitative documented assessments in each market sector.

The data and the models established during this work have made it possible to establish the consequences of changes in assumptions, and to therefore establish the ranges of uncertainty and their impacts. One object of the Lunar Commerce Portfolio is to see if there are indeed any truly commercial opportunities. In order to do so, it has been necessary to firstly be very precise about the content of supply chains and secondly to understand when government funding appears superficially as lunar commercial business. A Drafting Group was set up to establish the layout of this document, which, after the methodology section, proceeds to describe the market characteristics for each of the identified nine market segments, and their interactions, and provides helpful appendices which contain information on potential customers and suppliers for Lunar business. This Version 1 of the Lunar Commerce Portfolio is available in both digital and hard copy, and is provided free by the Moon Village Association. Opportunities will emerge for further iterations of the economic model as new data emerges in subsequent months and years.

A cut-off date of 30th June 2022 was assumed for the data used and assembled in this version of the Lunar Commerce Portfolio. Any changes in the assumptions or real-world circumstances which will have occurred since that date are therefore not taken into account, and must await a subsequent update of the Lunar Commerce Portfolio.

2. Methodology



2.1. Research Approach and Methodology

For the Portfolio, it was decided up-front that transparency and clarity of thinking would be key attributes. We therefore made some explicit and key simplifying working assumptions. For example, it was determined that for the Lunar Commerce Portfolio, any forecasts would be demand-based, not supply-based. It is very easy to produce supply-based forecasts by merely adding up the published aspirations of potential suppliers; but that method does not properly take into account what the customers really need. So, by adopting this demand-based approach, we ensure that we are not merely transmitting the marketing hype of potential businesses trying to obtain funding. If there is no reliable demand information, then we record that fact, thereby highlighting the areas of weakest data, which will require more research to reduce the uncertainties. In our methodology, we also keep track of the potential suppliers' and customers' commercial operations, and are therefore able to monitor, and apply in future updates, the knowledge gains from early robotic ISRU tests. The material assembled in the LCP has been created by consensus by multi-national and multi-disciplinary analysts from public domain sources, using transparent methodology, modeling, and assumptions. For the Lunar Commerce Portfolio, it has been considered very important that potential future users can replicate the findings, because of the explicit links between the data, assumptions and calculations. The aim is that, after the Version 1 of the LCP has been published, then there can be ongoing future development of the model, and updating of the assumptions, as more data becomes available, reflecting ongoing changes in national space programs, international regulatory developments, and the subsequent issuing of consequential LCP revenue forecast version updates. One further point needs stating. Particularly at this very early stage of assessments of Lunar commercial developments, it was decided to provide only revenue assessments; therefore, no attempt has been made to produce profit projections (which would depend, inter alia, on such matters as numbers and pricing of competitors, etc.). It will therefore be up to individual potential Lunar product and service providers to assess whether the revenue projections derived in this analysis will allow the possible generation of profits within their internal cost structures.

2.2 Assumptions

On approaching the data collection and forecasting processes of the Lunar Commerce Portfolio, we faced a critical decision related to time frames. It was recognized at the outset that it would not make sense to attempt to derive yearly forecasts, because of the implicit uncertainties in assumptions. To do so would merely provide a false sense of precision and validity. So, instead we established two distinct phases – the so-called Early and Mature phases – and set about developing our best assessment of the demand picture in each of these two time periods.

The Early Phase represents a time interval between now and 2030 during which it was assumed that most of the activities on the Moon are going to be government-driven, and about which there is relatively good data in the public domain. We exercised extreme care to not include potential revenues in this phase that would only be possible when later infrastructures have been established.

The Mature Phase is not expected to happen before at least 2040, and is not in fact defined by dates at all. It is defined precisely as "That period when there is a permanent human presence on the Moon self-sustainable with the necessities of life, and not dependent for them on a logistical supply chain of deliveries from Earth". Clearly, the data for this timeframe is inherently less robust than that employed in the Early Phase. We recognize and acknowledge that there will therefore consequently be a gap (of unknown duration) between these two phases, during which there will be a mixture of both Early and Mature phase attributes.

The analysis covers both lunar surface and lunar orbit governmental and commercial operations. Key common assumptions are identified, agreed by consensus, and described which cover the whole commercial Lunar domain, and in addition there are market sector - specific assumptions, all documented in the subsequent relevant sections of the report. Lunar space tourism is expected to be an early source of commercial revenues, and is therefore an important factor in the calculations, yet is amongst the least-researched in terms of available market research data. So, a method was developed, and is documented in the addendum, referring to available terrestrial space tourism public domain demand and price elasticity information, and making related demand forecasts for lunar space tourism taking into account the assumed likely very high prices, and the available data on high-net-worth individuals who would be able to afford the experience, if they wanted to do it.

Another key assumption which was adopted a priori, and which may be reversed for a later version of the Lunar Commerce Portfolio, was to not include in this first version any assessment of lunar commerce markets which would depend upon subsequent Mars-exploration driven activities. This decision was made because it was considered difficult enough to pin down the likely needs of those trying to create sustainable activities on the Moon. Thus, the present exercise may be viewed as a baseline estimate of commercial Lunar demand associated with achieving a steady-state sustainable habitation on the Moon. Any future plans for including Mars exploration and/or settlement would therefore have a basis of activities on the Moon upon which to build.

Furthermore, for this first version of the Lunar Commerce Portfolio, we have focused on the prime markets, and not the probable spinoffs, since at this stage it would have been too difficult to assess – although we know from the experience of early space developments in the Earth-centric domain, that such spinoffs can be of enormous consequence in terms of the creation of businesses (consider, for example, the electronics and GPS-based industries). This will have to be material for consideration beyond the confines of this initial Portfolio.

2.3 Quantification Approach

An overview of the interactions which take place within the data and modeling of the Lunar Commerce Portfolio is shown in Figure 2.1. The process for developing the revenue forecasts is market segment driven. A set of nine distinctive markets was agreed by consensus to allow and encompass all potential commercial Lunar market opportunities. The nine markets were designed, and the market descriptions carefully negotiated and crafted, to avoid overlaps and therefore double-counting of business potential. Within each of these markets, there were sometimes market sub-sectors. And one of the nine categories was specifically designed in its definition to allow for developing opportunities that were not obvious at the outset of the work. Therefore, the attempt has been made to include all potential markets and take care of all overlaps. However, it was recognized that there would be interactions between the separate markets (sometimes one market could become a customer, or supplier, to another market, for instance) and these interactions were documented and allowed for in the calculations.

The elements of the nine market segments are described in detail in the following Market Characterization section, but in summary, the segments used were:

1. Market 1 (M1) Transport to/from the Moon, or Lunar Orbit
2. Market 2 (M2) Transportation on the Moon
3. Market 3 (M3) Communications and Navigation on the Moon
4. Market 4 (M4) Energy and Power on the Moon
5. Market 5 (M5) Supplies and Services on the Moon
6. Market 6 (M6) Infrastructure, Construction and Manufacturing on the Moon
7. Market 7 (M7) Mining and Resource Extraction on the Moon
8. Market 8 (M8) Habitation and Storage on the Moon
9. Market 9 (M9) Lunar Agriculture and Food Production

Note that, to avoid double-counting, lunar space tourism, for example, does not appear as a separate category, but its elements are nevertheless captured, carefully allocated so as to avoid double counting, amongst many of the Market Teams. Also, for future reference, Market Team 5 was designated as the category which handled any new concepts which might emerge. The precise and full definition of the content of each of these 9 market segments is contained in the following Market Characterization section, where it is made clear how the carefully crafted language prevents overlaps between segments, and the associated double counting of demand. The relative shares of the total lunar commerce opportunities will be expected to vary through time amongst these nine major categories. For instance, M1 will always be significant, but M9 will only emerge as a revenue generator much later.

Each of the nine market teams had a Team Lead who became, over the course of more than a year of research, the LCP expert in that particular lunar commercial market. The process was managed via a series of monthly Team Lead meetings, and intervening meetings within each of the respective market teams. It was recognized that sometimes the customer or supplier would be governmental, and these instances were separately identified. It was recognized that one potential useful output from the LCP work would indeed be an understanding of the proportion of governmental versus true commercial players in the outcome.

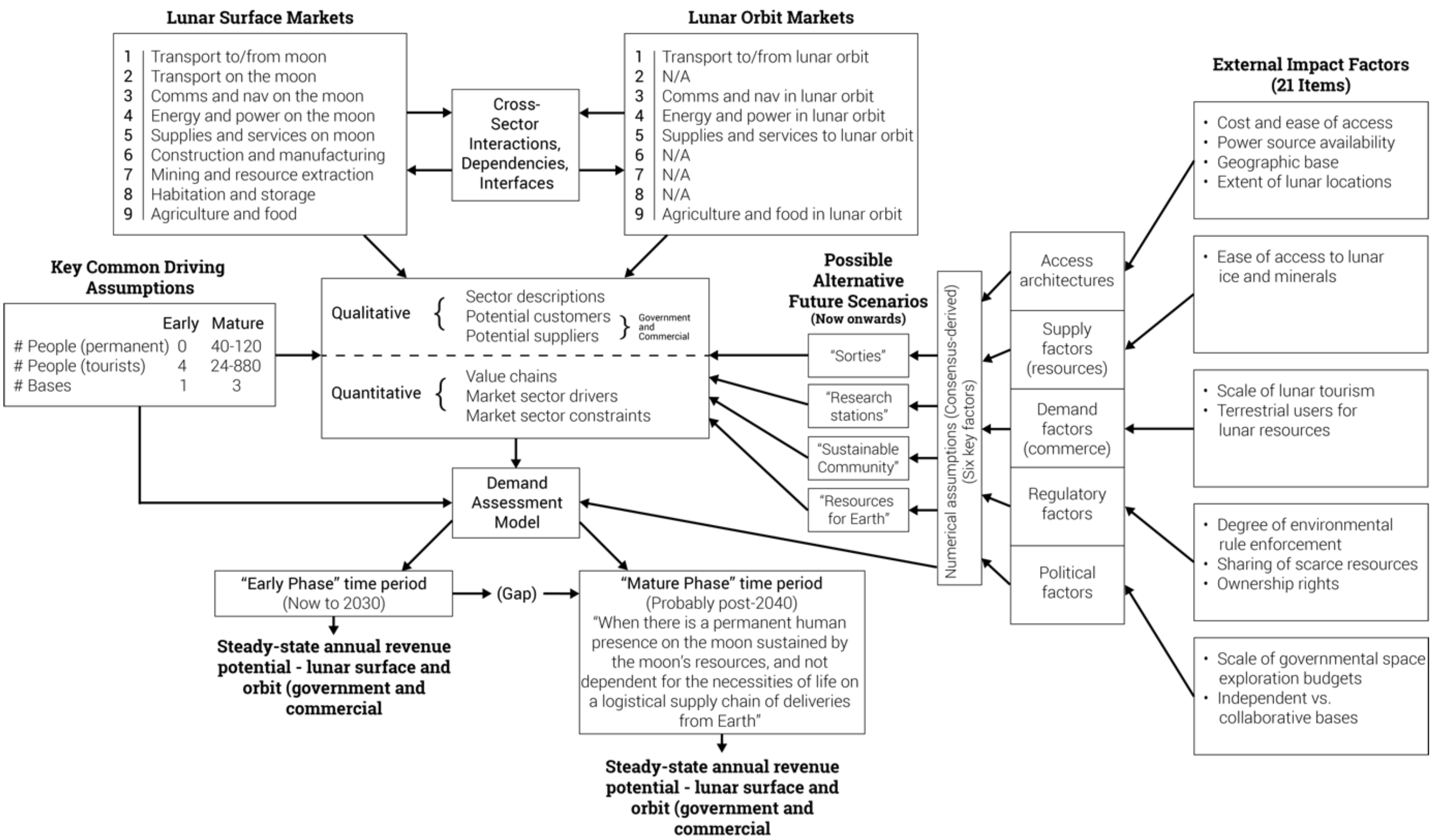
A standard approach, and an associated agreed common data format or template, was adopted for each market segment, and material was assembled in the initial qualitative stage for each of the nine market segments covering six steps (labeled A to F), and indeed this material in itself is expected to be a major source of value to the community who will be referring to the LCP in future. Data with reference to an associated, trusted, reference source was prioritised. The six steps that took place before quantification began were:

1. STEP A - a careful detailed description of the market (avoiding potential overlaps with other market sectors),
2. STEP B - research into potential customers for the product or service,
3. STEP C - the same thing for potential suppliers, then
4. STEP D - the very important consideration of value chains (which in future will be helpful to potential new entrants seeking a place in the lunar commerce domain)
5. STEP E - an assessment of the market driver trees, and finally
6. STEP F - the likely constraints on demand.

In each case, the market team leads, in discussion with the other team leads, carefully mapped out the mutual interlinks between all market segments. All of this work was carried out for both the Early Phase and the Mature Phase as discussed above. Finally, all of the quantitative assumptions were organized and were fed into an overall, transparent, model of revenue generation.

In order to quantify revenue by market, each market was broken down into a revenue driver tree. The production of each market's revenue driver tree takes as inputs: Qualitative research on market interdependencies, barriers, value chains, and customer groups. In most cases, these have directly informed the structure of the market driver tree. For example, in most markets, the first layer of the market driver tree is composed of the revenue from primary customer groups that have already been identified. Similarly, where in the value chain revenue is measured has been informed by prior qualitative analysis of each market's value chain.

Figure 2.1. The Lunar Commerce Portfolio, methodological chart



The market drivers were encoded in Excel from the most granular level upwards (individual sub-elements driving price and quantity). Excel was used as it was deemed the most suitable tool for an international and entirely virtual volunteer organization, whose members compose a variety of backgrounds. Secondly, given the inherent uncertainties surrounding some of the lunar markets under consideration, transparency in assumptions, and the flexibility for individual users of the LCP to change them upon publication to suit their own needs, was considered paramount.

Throughout each stage of qualitative analysis conducted, market interdependencies have been documented. This has been critical for the quantification stage, as demand in multiple markets is considerably, and in some cases, wholly, dependent on activities in other lunar markets. Examples include M1, where, beyond human spaceflight, the total upmass from Earth is largely dependent on the level of activity in other markets, and M3, as demand for lunar communications and navigation will also be driven almost entirely by the level of activity across other markets. Interdependencies were resolved dynamically through teams communicating their required inputs among each other to ensure these were readily produced in the required format by the other team in question (e.g., M7 requiring estimates of the tonnage of resources demanded by M6 for lunar manufacturing and construction). As individually encoded market driver trees were integrated into a single demand model, market interdependencies were dynamically linked in order to be consistent.

Unit prices have been estimated through a variety of methods. In some cases, suppliers provide pricing intentions for future product lines e.g., novel extravehicular mobility units, and these are used as inputs. In other cases, historical pricing values have been used and adjusted, where analogous markets have existed in Earth orbit, on Earth, or during the Apollo missions. The LCEWG spoke to industry experts, for example project managers of planned systems, where possible to determine intended pricing. Finally, in select cases, price has been determined through examining certain costs and determining the pricing level required for the business case to close. However, generally unit costs were not independently modelled. This was considered out of scope of this study, and viewed as prohibitively difficult, given the low TRL of many technologies on the supply side, and the resulting uncertainties around cost. While care has therefore been taken wherever possible to use pricing estimates that are feasible given input costs, businesses using the LCP must examine their own cost structures and adapt the portfolio's inputs accordingly, which the accessible nature of the LCEWG's published work seeks to facilitate. Similarly, this version of the LCP does not dynamically vary price according to supply-demand interactions, though some variation in price is incorporated by scenario. All of these elements may be incorporated in future iterations of the Lunar Commerce Portfolio.

To the greatest degree possible, quantities driving revenue have been derived from the core assumptions of the WG and from assumptions inherent to each of the four scenarios described above. In some cases, revenue drivers are largely independent of the core factors considered under the four scenarios of the LCP. An example of this is potential demand for components and fuel manufactured in the lunar environment for use by systems in Earth orbit. Orbital fuel depots may use fuel derived from lunar water, or a space-based solar power plant may use some components (likely structural) manufactured on the Moon. In these cases, further independent assumptions were implemented specific to the market in question.

2.4 Scenarios

No-one can predict the future, and all the relevant external forces which would make a lunar economy possible. But we can look at groupings of related events that might sway the results from a least probable to most probable likelihood of commercial development of the Moon. A Scenarios Task Force was set up to agree by consensus the main options to be considered for Version 1 of the LCP. The idea was to attempt to contain within the options the most likely range of future alternatives possible.

Twenty-one separate key assumptions were identified in this process, combined in clearly stated groupings of the key variables, which in themselves addressed potential changes in A - Access Architectures, B - Supply Factors, C- Demand Factors, D - Regulatory and E- Political Factors. For each of the key driving factors, the range of uncertainty was captured between conservative and ambitious extremes. By grouping these various factors in different combinations, appropriate to the either conservative or ambitious premise for society, the resulting four scenarios adopted for this Version 1 of the Lunar Commerce Portfolio were, as named and described:

1. "Sorties": A continuous campaign of single missions to various locations around the Moon. Some states and corporations land professional astronauts. Some tourists fly there but remain in lunar orbit. All personnel, consumables and equipment are assumed to be included in the transportation systems that get them there.
2. "Research Stations": One or more facilities similar to McMurdo Station in Antarctica are assumed. Some base infrastructure is established. Miscellaneous research and development activities take place both in lunar orbit and on the surface, aimed at gaining knowledge for future potential use elsewhere in the solar system. Cargo delivery missions are assumed to complement the personnel transportation.
3. "Sustainable Community": When there is at least one permanent human presence on the Moon self-sustainable with the necessities of life, and not dependent for them on a logistical supply chain of deliveries from Earth. It is assumed there would be a cislunar propellant depot network, one autonomous base, and propellant and life support value chains. Cargo delivery missions are assumed to complement personnel transportation; and
4. "Resources for Earth": The Moon is fully open for business. Financial returns are assumed to be provided by export from the Moon of PGM's, KREEP, He3, etc., to Earth. Several government and private autonomous bases are assumed, with sustainable Earth-Moon resource utilization industrial value chains. Cargo delivery missions complement personnel transportation.

For the purposes of quantification, it was assumed that the Early Phase would manifest as the "Sorties" scenario. The Mature Phase was then considered to manifest as one of the four possible scenarios. While not explicitly examined, one must also recognize that a possible outcome in the Mature Phase is that lunar development plans are abandoned, and that lunar economic activity falls again close to zero.

The scenarios are not recommendations or plans, they are not inevitable, merely plausible ranges of futures. They are, however, based upon the considerable research and analysis performed during this LCP project, and represent a consensus view. They derive from the most important and unpredictable driving forces that will impact the potential for lunar commerce, they are designed to push the envelope and bracket the range of possibilities, they are not designed to encourage or discourage potential future actions, or to hype any possible outcomes, they in a sense reflect alternative value assessments of potential future stakeholders in lunar commerce, including states, corporations, academia and individuals. It is anticipated that future versions of the Lunar Commerce Portfolio will entertain some different scenarios, all of them however reflecting on combinations of the 21 key assumptions described above. For completeness, the following is a list of these assumed key external factors which would have significant impacts on the revenue projections:

1. A1 Cost and Ease of Access: Assumed delivery service to the lunar surface and lunar orbit
2. A2 Adequacy of Power Sources: Energy assumptions particularly during lunar night
3. A3 Private Sector Financing: Whether limited or widely deployed
4. A4 Lunar Location Options: Only South pole or wider deployments assumed
5. A5 Human Health Factors: Is long-term human residence possible in lunar conditions
6. A6 Connectivity and Data: Whether private or government infrastructure assumed
7. B1 Exploitability of Lunar Ice: Conservative vs ambitious
8. B2 ISRU Difficulties: Ease of access to lunar minerals and propellants, including cryo-storage factors
9. C1 Scale of Lunar Space Tourism: Conservative vs ambitious
10. C2 Degree of Lunar Orbit Activities: Assumptions on permanent and visiting populations
11. C3 Lunar Mining for Terrestrial Needs: Platinum Group Metals and Rare Earths availability, economics
12. C4 Terrestrial Markets for Lunar Manufacturing: Assumptions on high value components, luxury items
13. D1 Degree of International and National Regulatory controls: Assumptions on degree of “full access” allowed
14. D2 Inclusion of Peaceful Security Activities: No vs Yes (with implications on level of staffing, etc.)
15. D3 Some Equivalency of Land Ownership: Assumptions on rights ownership and licensing system
16. D4 “Government Only” Option: It is assumed that this will not be the approach – else no commerce
17. D5 Environmental Rules: Assumptions on restrictive vs moderate on recycling, landing pads, mining etc.
18. D6 Sharing of Scarce Resources: Assumptions on rules involving developing countries, etc.
19. E1 Emergence of Multiple National Lunar Bases: Impact on investors of collaborative vs adversarial plan
20. E2 Number of Moon Village Bases: Assumption on no real base, or one, or several independent
21. E3 Government Space Exploration Budgets: Assumption on continuing as now, or more ambitious basis

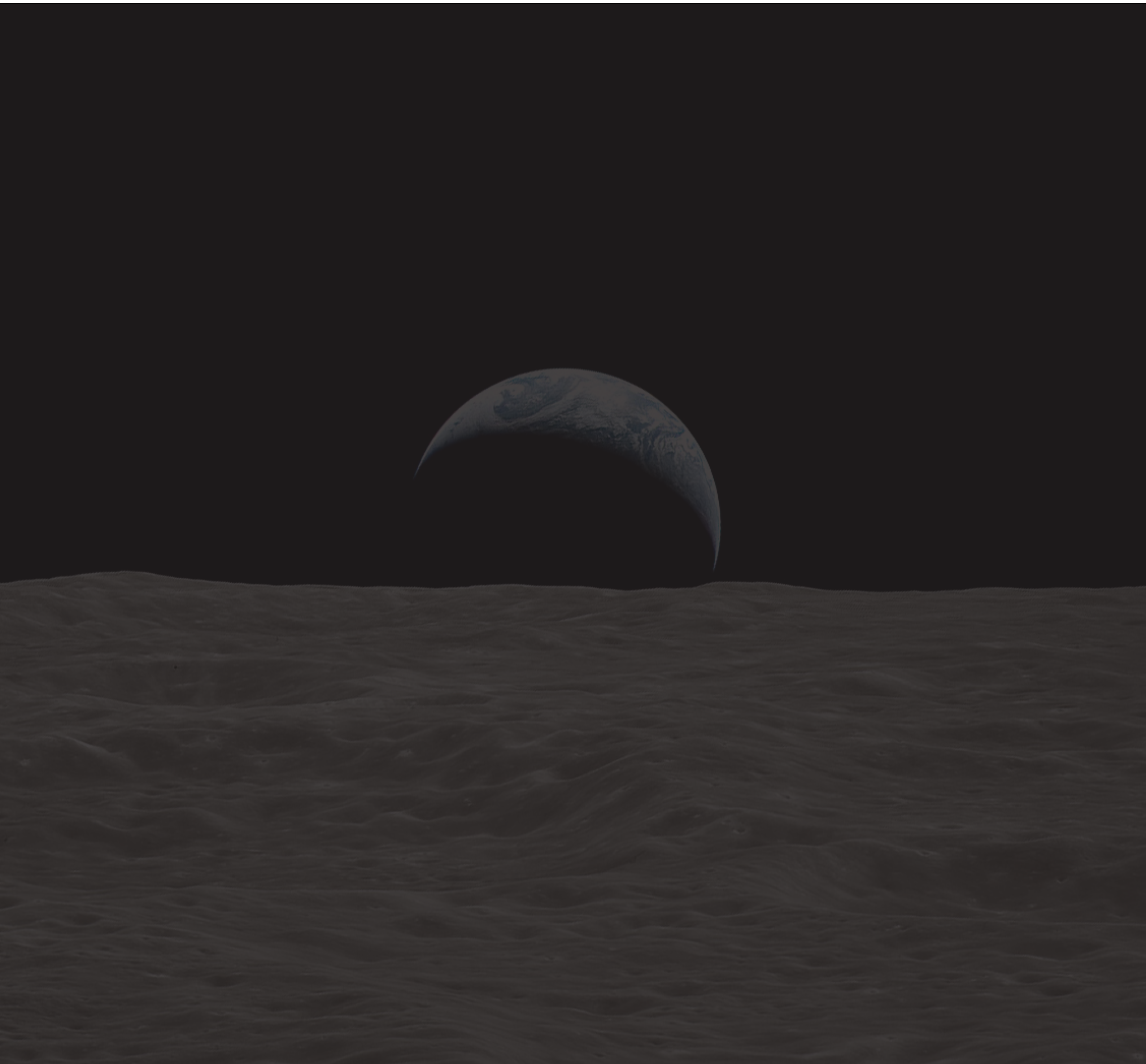
2.5 Scope

We have described the process and our assumptions, and in particular the methodology adopted for this first Version of the Lunar Commerce Portfolio. We have pointed out that there is room for future development, and that it is the intention within the Moon Village Association to progress the research and modeling which will lead to future versions of the Portfolio. We believe this version is the best available source right now for this material. Nevertheless, it has been produced entirely by volunteers, and because of the global COVID-19 pandemic, the essential work has been conducted entirely by remote interactions via Zoom and similar social interactive systems, such as Slack. All contributors signed an agreement to refrain from relating any of the findings before this first Version of the LCP has been released. However, from this point onwards, it is likely that the results will be quoted in various forums, both in their entirety or in subsections. The volunteer workforce of analysts has "day jobs", and consequently there has already been, and there is expected to be in future, a great deal of turnover. Therefore, this document, in its entirety, must stand as the only complete integrated reference to the findings, assumptions and methodology – since its various creators will generally have moved on after having made their substantial contributions.

Needless to say, the Moon Village Association cannot be held responsible for the consequences of any financial decisions that will have been made by making reference to the findings of the Lunar Commerce Portfolio. The manner in which this document has been published, with the underlying model fully available, makes implicitly clear where our assumptions are based on uncertain data (although it was the best we could find), and therefore it would be a good outcome of the release of this Version1 of the Lunar Commerce Portfolio if commercial or government entities with available funds could undertake the necessary market research and experiments needed to reduce the uncertainties in the outcomes for future iterations. We have created an engine capable of refinement through future iterations, and provided a great deal of material reflecting the current engagement of commercial entities.

Hopefully, the outcome of this work, and in particularly its value chain data and documentation, will encourage further engagement from companies, and even developing countries, who have not yet considered taking part in lunar activities. As we have seen, there is potentially an entire ecosystem of interrelated companies who can provide products and services on the Moon and/or in lunar orbit, and very many of them do not require any particular former experience in space activities. Creating a sustainable presence on the Moon is new for everyone. No-one knows how to do it. We have shown how all the various parts of the process interact with each other, and identified the revenue-generating elements. But at this stage, the uncertainties remain perhaps overwhelmingly large. But we believe by looking at, and comparing, our two identified time periods (of the Early Phase and the Mature Phase) it should be possible to assess where best a new firm, or perhaps a nation new to the concept of space commerce, can be expected to contribute.

3. Market Descriptions



3.1 Transportation To and From the Moon

3.1.1. Definition

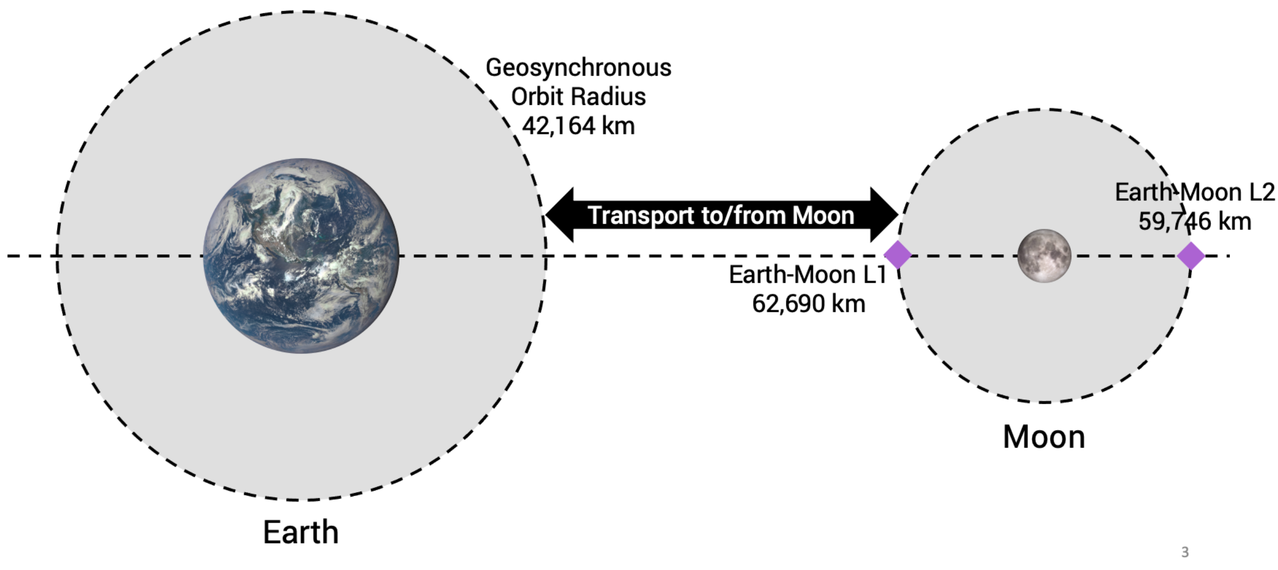
The definition for Market Team 1, Transportation to/from the Moon and Lunar Vicinity, is, "The movement of materiel (people, goods, consumables, etc.) between the Earth and the Moon and lunar vicinity." This definition applies to the Early and Mature Phases of lunar development.

Activities beyond the Earth-Moon economic sphere are not included by the LCEWG ground rule. The Transportation to/from the Moon and Lunar Vicinity market is driven by demand rather than being constrained or driven by supply. By our definitions, Earth encompasses its surface and orbits out to geosynchronous altitude. The Moon and Lunar Vicinity extends from the Moon's surface to the volume inside Earth-Moon Lagrange Points 1 and 2 (Figure 3.1.).

3.1.2. Early Phase Products and Services

Transportation to/from the Moon and lunar vicinity products and services during the Early Phase include cargo transportation to the lunar surface, human transportation between low Earth orbit (LEO) or Gateway Near Rectilinear Halo Orbit (GNRHO) and the lunar surface and propellant sales in the GNRHO. Cargo transportation can be provided by NASA Commercial Lunar Payload Services (CLPS) contractors, NASA Human Landing System (HLS) contractors or other commercial providers. Personnel transport can be provided by NASA HLS contractors or commercial providers. Propellant for NASA HLS contractors may be self-provided or available from a commercial propellant depot.

Figure 3.1. Transportation to/from the Moon and Lunar Vicinity can begin or end anywhere between the Earth's surface and geosynchronous orbit and end or begin anywhere between the Moon's surface and lunar orbits out to EML1/EML2, including the NASA Gateway Near Rectilinear Halo Orbit (GNRHO)



3.1.3. Mature Phase Products and Services

Transportation products and services during the Mature Phase are the same as in the Early Phase with some key differences. Demand quantity and frequency for cargo, propellant and personnel are higher in the Mature Phase than in the Early Phase, propellant and water are available on the Moon from ISRU developers, and there will be demand for cargo and propellant transport from the Moon to the lunar vicinity and, perhaps, to Earth orbit and the Earth's surface.

3.1.4. Market Interdependencies

Market Team 1, Transportation to/from the Moon and Lunar Vicinity, has interdependencies with every other Market Team, as described in Table 3.1. More detail is provided in chapter 4.

Table 3.1. Interdependencies between Market 1 and Markets 2 through 9.

#	Market Team	Product or Service Needed or Provided	Market Team 1 Impact
2	Transportation on the Moon	Equipment transport needed	Increased cargo flights
3	Communication and Navigation	Equipment transport needed	Minimal additional cargo flights
4	Energy and Power	Equipment transport needed	Increased cargo flights
5	Products and Services	Specialty item transport needed	Minimal additional cargo flights
6	Infrastructure, Construction and Manufacturing	Equipment transport needed	Increased cargo flights
7	Mining and Resource Extraction	Equipment transport needed Propellant and water provided	Increased cargo flights Reduced propellant from Earth; reduced transport prices
8	Habitation and Storage	Equipment transport needed	Increased cargo flights
9	Lunar Agriculture	Seeds and specialty supplies transport needed	Minimal additional cargo flights

3.2 Transportation On the Lunar Surface

3.2.1. Definition

This sector consists of three distinct categories:

1. Robotic rovers/hoppers: provided or leased by commercial robotics firms conducting ongoing surveying/resource mapping
2. Crewed rovers/hoppers: provided or leased by commercial taxi firms, including providing site visits for lunar tourists
3. EVA systems: provision or lease of a range of hardware (including spacesuits) to service the need to leave the fixed habitats.

The Transport on the Lunar Surface would encompass multiple conventional verticals (both robotic and crewed) that would draw comparison to on Earth. This market includes all segments that directly create novel methods of transporting goods and humans across, below, or above the lunar surface. This market also includes segments that supply components, and services that facilitate and result from transportation.

3.2.2. Early Phase Products and Services

During the Early Phase, transport on the Moon will support activities such as lunar surface survey, scientific experimentation (i.e., field-work, geology/mining, physical sciences, and biological sciences), and infrastructure construction/maintenance (i.e., systems for agriculture, water). The Early Phase will be primarily governmental and/or contracted commercial workers seeking to create the infrastructure for habitation on the Moon and conduct scientific experiments. Lastly, the goal in the Early Phase for this market is to conduct initial surveying/resource mapping for possible commercial customer usage. It is assumed that for the Early Phase there will be no lunar surface tourism activities.

3.2.3. Mature Phases Products and Services

During the Mature Phase, there will be an increase in the scale and further developments of the activities conducted in the Early Phase. There will also be new activities added in this phase that serve different purposes (i.e., Creativity, entertainment, and leisure). Activities, such as tourism and hospitality, will become more common. The Mature Phase will expand from the primary Early Phase's population and support additional lunar surface residents whose role in the lunar society will serve other purposes. Lastly, the goal in the Mature Phase for this market is to have an established economy that supports commercial customer usage (i.e., leasing of vehicles and tourism business models).

3.2.4. Revenue Generation

This market assumes that revenues will be generated through lease of transportation systems or of their payload space, rather than the sale of individuals systems. This is based on what is known about NASA's current intentions to lease spacesuits and, most likely, Lunar Terrain Vehicles (LTVs), as well as NASA's ongoing efforts to procure lunar transportation (both to and on the Moon) as a service from CLPS providers. Additionally, it is considered likely that a lease/rental model is more favorable for suppliers.

3.2.5. Market Interdependencies

An overview of market interdependencies between M2 and the other eight markets is provided in the table below.

Table 3.2. Interdependencies between Market 2 and other markets

#	Market Team	Product or Service Needed or Provided
1	Transportation To/From the Moon	Required to transport vehicles/EMUs to lunar surface
3	Communication and Navigation	Provider of mobile communications services to M2 assets
4	Energy and Power	May be required to recharge certain vehicles should these not carry their own power source
5	Products and Services	M5 may operate lunar roadways utilized by M2, making M2 a customer of M5
6	Infrastructure, Construction and Manufacturing	Required to provide transportation infrastructure
7	Mining and Resource Extraction	May provide hydrogen for vehicles utilizing hydrogen fuel cells
8	Habitation and Storage	-
9	Lunar Agriculture	M2 may sell food transport services to M9

3.3 Communications and Navigation

3.3.1. Definition

This segment evaluates both the communications system needs, including IT and Internet, and the navigation system capability to maneuver on the lunar surface. The purpose of Market 3: Communications and Navigation on the Moon is to build and maintain mission support infrastructure which provides commercial space communication services that support overall future lunar missions, Moon Village operations on the lunar surface, in cislunar space, and on lunar orbital stations, as well as for future lunar research stations, with the overall aim being to develop a sustainable Earth-Moon ecosystem for all partners.

A review of existing literature has been conducted in order to investigate the current products and services demanded, as well as to act as a method to gauge market maturity. Although there is a current demand for many different products and services, the dominant method of providing communication and navigation services to spacecraft has been through Earth-based tracking stations such as ESA's Estrack and NASA's Deep Space Network. These must be understood, prior to considering any further developments relating to lunar communications and navigation.

3.3.1.1. Introduction to ESA's Current Communication Capabilities

ESA's Estrack is a global system of ground stations that connect the satellites in orbit with the European Space Operations Centre (ESOC), in Germany.

The system is comprised of seven core ground stations; four of which are used for tracking near-Earth satellites and launches using 13-,13.5-, or 15- meter dish antennas in Kourou (French Guiana), Redu (Belgium), Santa Maria (Portugal) and Kiruna (Sweden), and three of which are deep space antennas for tracking deep-space probes for lunar and interplanetary satellites using 35-meter dish antennas in New Norcia (Australia), Cebreros (Spain), and Malargüe (Argentina). All seven stations are centrally operated from the Networks Operation Centre at ESOC 365 days a year.

All core stations have the capability to use X-band communication (7145-8500 MHz), with the four smaller stations supplementing this with S-band communication (2025-2300 MHz). These stations provide uplink and downlink communication with a typical range of 256 Kbit/s through to 8Mbit/s, with the exact data rate varying depending on the mission profile.

The core ESA network is augmented by a series of commercially owned and operated stations, with agreements in place with organizations such as the Swedish Space Corporation, the Spanish National Institute of Aerospace Technology, and Kongsberg Satellite Services. These are collectively referred to as the augmented network.

In addition to this, ESA also has a series of international cooperation agreements with other national space agencies. These cooperation agreements are with both European and international agencies, providing ESA with access to networks and stations operated by ASI (Italy's space agency), CNES (France's space agency), DLR (Germany's space agency), JAXA (Japan's space agency) and both NASA's Deep Space Network (DSN) and it's Goddard Space Flight Center. An overview of the aforementioned networks is seen in Figure 3.2.[1]

The cooperation is not limited to the partners mentioned above and instead is with almost every spacefaring nation. An exam-

Figure 3.2. ESA's ground station network

ple of this was seen in late 2020 when ESA's Kourou station tracked Chang'e-5, a Chinese lunar mission to collect the first lunar samples in 44 years. ESA's support included the tracking of the spacecraft in the Early Phase, establishing a communication link and verifying its health, as well as providing an on-call backup for China's ground stations.[2]

The ground stations are capable of communicating with any mission in the solar system, using their large antenna to control spacecraft, sending and receiving data in a wide variety of orbits and are set to be used for the lunar missions that are seen in the Early Phase. However, it is at this point at which a limitation of this method of communication is seen, namely that as the number of lunar missions increase, the ground stations operated around the world would need significant improvements in order to meet these demands.

In order to examine the limitations of the current systems, it is important to note that the majority of the Earth to Lunar orbit communication using ground stations involve one antenna on the ground and one spacecraft in orbit. There do exist two techniques which are able to improve the capability of existing assets in some way; Multiple Spacecraft per Aperture (MSPA), and Multiple Uplink per Aperture (MUPA). The first technique, MSPA, is where a station receives data from up to four spacecraft simultaneously and is possible as each station has four separate receivers. The second technique, MUPA, is where a station provides data to up to two spacecraft simultaneously, using the X-band to communicate to the first satellite and the S-band to communicate to the second. These techniques were successfully tested in January 2020, when the New Norcia ground station deployed both to control both the Mars Express and the ExoMars TGO spacecraft.[3]

3.3.1.2. An Introduction to NASA's Current Communication Capabilities

The next set of networks and communication capacity featured in this section is NASA's Deep Space Network, one of the world's largest and most sensitive scientific communication systems. This network is similar to ESA's with an international collection of radio antennas that provide support to spacecraft missions and it is operated by NASA's Jet Propulsion Laboratory (JPL) with facilities in Goldstone (United States), Madrid (Spain), and Canberra (Australia).[4]

Similar to ESTRACK, the three Deep Space Network sites have a minimum of four antenna stations with large parabolic dish antennas that detect radio signals from space. These sites differ from ESA's in terms of the antennas that are found on site, with each site having one large 70-meter antenna, at least two 34-meter antennas including a high-efficiency antenna and a beam waveguide antenna, and one 26-meter diameter antenna.[5]

The DSN has historically been used since the 1960s and has been continuously expanded upon and improved to support NASA's programs, with improvements covering both the construction of improved facilities and with additional communication frequencies. Despite this, there are still a number of network limitations and challenges that are similar to the challenges faced by ESA. These include the same limitations on the number of uplinks and downlinks, as well as additional challenges with supporting legacy missions, being used in radio experiments, and equipment approaching end-of-life.

NASA has already worked to solve some of the problems faced by these networks, with a primary example being seen with the MARS Relay Network. The network is an array of five spacecraft in orbit around Mars that are used to communicate with spacecraft landing there. Whilst it is possible for direct communication to occur between the Martian surface and the DSN through the use of radio relays and other devices, it is impractical due to both the high volume of data that is collected as part of the missions on the planet and the fact that as spacecraft pass beyond the planet's horizon from Earth's perspective, they lose the ability to communicate using the X-band frequency.[6]

NASA is aware of these limitations, with Brad Arnold, the manager of the DSN, saying that even with the upgrades to the sites they are unable to keep up with the demand that is expected. This increase in demand has some short-term fixes not yet discussed, including reducing the capacity allocated to each mission by reducing the 20% buffer that they request and then finally by prioritizing specific spacecraft and missions. Of a particular interest to this report is the demand needed for the upcoming Artemis missions to the Moon which will impact the ability of the DSN to service other missions. Other solutions include reducing congestion on the X-band by encouraging use of the Ka-band.[7]

3.3.2. The Maturity of the Market and its Products and Services

Example of the current products and services provided within the area of lunar communications are:

- Lunar Relay Systems (LRS),
- Lunar Communication Terminals (LCT), and
- Direct to Earth capabilities (CTE)

An example of the current services demanded and enabled in part by the above products include:

- Lunar Space Internet
- Lunar Space Intranet, and
- Lunar Surface Network

Despite the services and product demands as mentioned above, the current state of the market is very immature, with current communications and navigation capability being government provided as described, and other technical roadblocks needing to be solved before there is a significant market demand for these services. These services will be of critical importance for future sustainable lunar human space exploration. However, there are current and previous studies and market development projects that have begun exploring the topics of communication and navigation, usually in a combined system architecture approach.

3.3.3. Early Phase Products and Services

The Early Phase will see the majority of demand come from institutional stakeholders, in particular key players such as NASA, ESA, JAXA, etc., as initial customers with commercial customers beginning operations.

During the initial exploration phase, activities will continue to be controlled and monitored from the Earth. The requirement to support these activities will be for near real-time command and control and payload data recovery, with processing done on the Earth in a non-real-time environment. There will be a growing requirement for communications relay capability to address increased capacity requirements, provide increased coverage, and support missions. To improve the efficiency and cost-effectiveness of exploration activities, it will be necessary to stop considering missions in isolation and start supporting activities across multiple programs. Groups are considering, for example, the use of very small satellites and landers for further exploration, which cannot physically accommodate the equipment needed for direct-to-Earth communication and require the use of a lunar communications relay to provide connectivity to the Earth. Today, groups are struggling to bring their programs to fruition as the cost of implementing a lunar relay in addition to the experimental satellites and landers makes this prohibitive.[8] This issue is being addressed in part by companies in M1 and M2, who provide communications services to surface assets via a mothership lander. Revenue for these communication services, which are included in a broader price for comprehensive service delivery, are not counted within the M3 scope, in order to avoid double counting.

The following subsections go on to describe various existing studies that are relevant for the Early Phase, in particular covering existing architecture definitions and relevant programs from both ESA and NASA.

3.3.3.1. The Interagency Operations Advisory Group

One group that has developed a potential lunar communication architecture is the interagency operations advisory group (IOAG), an international group founded to provide a forum for identifying common needs across multiple agencies related to mission operations, space communications, and navigation interoperability. IOAG's members include ASI, CNES, ESA, JAXA, DLR, CSA ASC, NASA, and the UK Space Agency, with additional agencies being included as observers from countries such as Korea, India, and Australia amongst others.

The IOAG led a Lunar Communications Architecture Working Group that aimed to study a future Lunar Communication Architecture that would facilitate support to lunar missions.[9] The study itself covered:

1. Defining the communication architecture based upon requirements and the concept of operations, taking into account science and exploration orbiters, mobile and stationary lunar vehicles, relay orbiters, ground stations, and lunar ascent and descent modules;
2. Providing communications links for Earth-Moon, lunar proximity, lunar crosslink, Earth orbiting relay links and Earth-Space link extensions;
3. Defining the specific services provided by network communication assets within the architecture to user mission;
4. Considering both RF and optical communication, including specific frequency/bands; and
5. Considering robotic and human exploration missions from 2018 to 2030.

IOAG analyzed all planned missions from 2018 to 2028. Amongst its findings was that a minimum of four (non-commercial) lunar relay orbiters are to be deployed to provide communication services to lunar surface missions in this period. Related to this, it was found that there is a demand for systems enabling far-side communications, as the lunar far-side is shielded from Earth-based radio transmissions.

Of missions surveyed, the IOAG found that there exists a wide divergence in frequencies used, but with a trend towards X-band and even Ka-band and optical links for high-rate communication. It was found that the upcoming missions in the Early Phase do not tend to use bandwidth efficient modulation, for example GMSK, even for the bands which are looking to be congested. It was suggested that this is because they do not require a high spectral efficiency. They go on to find that only the Lunar Communications Pathfinder and the Lunar Gateway are explicitly planned to offer interagency support, and that a lunar network is likely to be online in the Early Phase.

This analysis leads one to find that one of the key pain points seen is that there are too many standards to choose from, an issue that would both drive up costs and limit the potential interoperability of missions. IOAG then goes onto define the following types of connections:

- **Earth-to-Moon:** The uplink from the Earth to cislunar, lunar orbit and lunar surface,
- **Moon-to-Earth:** The downlink from the cislunar, lunar orbit and lunar surface to the Earth,
- **Cross Link:** The link between two relay spacecraft,
- **Proximity Link:** The link between a relay satellite and its relay service user. Relay service users can be orbital spacecraft, descent/ascent vehicles, lander, rovers, and, potentially, astronauts equipped with portable communication device, communication stations/towers on surface, and human habitats,
- **Lunar Surface to Lunar Surface:** The communications between a landed asset and a landed asset.

Each of the above links were then explored in terms of frequency, modulation, coding, protocol, security, and ranging, and the IOAG then suggested standards for each of the links.

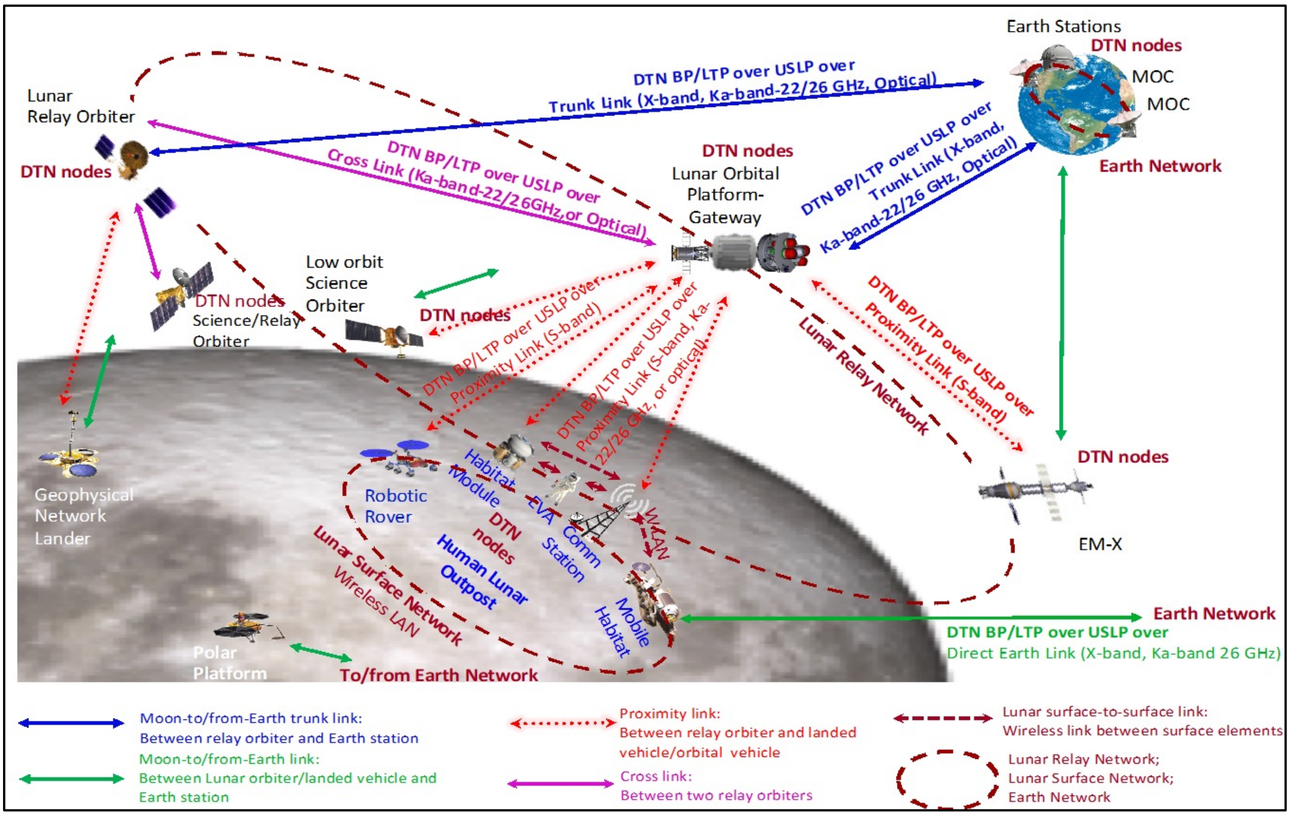
This IOAG determined that any architecture would need to be highly interoperable, flexible, scalable and expandable, secure, and backwards compatible. After the analysis the IOAG proposed the architecture that is seen in Figure 3.3. which has the following key characteristics:

- A lunar space internet that is similar to what is seen on Earth, consisting of a lunar relay network, a lunar surface network, and the Earth network,
- A lunar relay network that consists of lunar relays in orbit that can provide communication capabilities to space vehicles on the lunar surface and in orbit,
- A lunar surface network that consists of a link between the human habitats, rovers, and landers that facilitate wireless communication between them,
- All components to serve as data transfer nodes to improve reliability and robustness,
- A high-speed trunk link that connects to the Earth network.

After defining the architecture, the IOAG then went on to provide protocols and use cases for a lunar space internet, a lunar space intranet, a lunar space network, security architecture for lunar communications, and cross support services at a space data link layer. These are not being expanded upon in this section of the report but have been considered throughout.

Another example of an architecture can be seen in the 2008 SpaceOps Conference Paper 'NASA's Lunar Communication and Navigation Architecture'[10], which presents an overview of the results of a year-long study called the Lunar Architecture Team (LAT) which investigated the concept of operations, spectrum utilization, traffic models, and much more. These projects are merely intended to be illustrative, with a wide variety of other projects being related to or competing with these being run by both industry and institutional stakeholders.

Figure 3.3. Future Lunar Communications Architecture - A Conceptual View



3.3.3.2. The Lunar Pathfinder

An example of the products and services seen in the Early Phase can be identified from the aforementioned lunar missions led by institutional stakeholders. Of particular interest is the development of the Lunar Pathfinder, a spacecraft that is designed to provide affordable communication services to lunar missions via S-band and UHF links to lunar assets on the surface and via a X-band link to the earth. The Lunar Pathfinder is expected to be a more cost-effective alternative to current Direct-to-Earth solutions and it will enable both polar and far-side missions on the Moon which are currently only possible if they first launch a communications relay satellite. In addition to the aforementioned benefits, the strongest benefit in the context of this report is that Pathfinder is set to increase the number of assets that can be simultaneously tracked and communicated with, something that is vital to meet increased demand that from 2028.[11]

3.3.3.3. ESA's Project Moonlight

Another example of an Early Phase project is the ESA-funded 'Project Moonlight'. This is a project which has had a business case developed for many years, and is related to the Lunar Pathfinder mentioned above. Moonlight is a project that crosses three ESA directorates, and is intended to solve the pain points surrounding the reliance on ground stations, namely that there are only a limited number of possible ground stations, that developing new ones is very costly, and that even if new ground stations are built, the current method requires a large and expensive receiver to be on every single craft, taking up valuable mass and financial budget.[12]

The first stage of Moonlight is to utilize GNSS positioning to ensure that spacecraft have reliable position, navigation, and timing information from the signals that currently pass the Moon. This stage involves the aforementioned Lunar Pathfinder, which will be testing GNSS signals on the Moon and will be combined with a laser to provide additional data. Further steps include having a constellation of satellites that would allow for positional accuracy of 100 to 30 meters, a requirement from NASA's landers. The value proposition of this is that it would allow the landers and other craft to eliminate a 40kg navigation subsystem and instead rely on smaller, cheaper technology.

In order to maximize the success of the project, ESA is running two parallel consortiums to work towards this goal in the Moonlight Phase A/B1 study that will define the service infrastructure and lay out a development path for a future lunar communication and navigation system. Moonlight is looking at a segmented system consisting of Lunar Space Segment, the Moon Surface Segment, the Lunar User Segment and the Earth Ground Segment. This is a feasibility study, but there is to be an initial deployment of three to four satellites that will be used to provide data that will enable a full landscape of possibility that is not yet foreseen, with these satellites being able to provide both near and far-side capabilities.[13]

One of the consortia is led by SSTL Lunar, and also includes: SES Techcom, Airbus, GMV-NSL, Kongsberg Satellite Services, and Goonhilly Earth Station. The second consortium is led by Telespazio and includes: Inmarsat, Hispasat, Thales Alenia Space, OHB Systems, MDA, ALTEC, SMEs (Nanoracks Europe and Argotec) and research centers (SEE Lab SDA Bocconi and Politecnico di Milano).[14]

3.3.3.4.NASA's LunarNet

Although the majority of the discussion around the Early Phase is centered upon items such as the Lunar Pathfinder, it is important to note that there are communication demands that are set to be met by various programs. An example of this is seen in LunaNet, an architecture proposed by NASA's Space Communication and Navigation program that aims to facilitate communication on the Moon itself.

As described earlier, Moon-to-Earth communication currently uses pre-scheduled links through space or ground-based relays that are reliant on ground stations. LunaNet aims to solve this problem through the creation of a network approach that is similar to the internet on Earth, one where the users maintain a connection to a larger network. LunaNet is set to offer independent data processing that provides an on-Moon capability to calculate the position of spacecraft, ensure their guidance, and provide some initial autonomy on the Moon. LunaNet navigation services aim to form the basis of a lunar search and rescue service, and provide additional scientific research capacity.[15]

3.3.3.5. The Lunar Data Market

In addition to the core demands outlined in the previous subsections, there is also the lunar data market to consider. In the Early Phase of market evolution, communications services will have to be able to have the capabilities to transfer telemetry, environmental and entertainment data through the lunar communication infrastructure. The data of interest can take various forms, including surface temperature, radiation levels, and much more.

The communication and navigation architecture has to be able to support missions and services through the entire value chain, from providing support to spacecraft themselves, to assisting in data acquisition, storage, processing, and operation of downlink to Earth. A report by PwC outlines three distinct categories of data for this; environmental, telemetry, and entertainment. Each of these comes with its own set of requirements, demands, products, and services to support them.

The report by PwC covering key enabling factors, including:

- The changing buying factors for commercial entities, in particular the interest in paying for data as it is collected in order to gain a competitive advantage;
- The resolution and timeframe of data is set to increase, which will widen the opportunity to address customer needs; and
- An increase in interest and participation of non-space entities.

The market demand for the data as estimated by PwC will be around 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 study's optimistic scenario.[16]

3.3.4. Mature Phase Products and Services

Now that the expected activities, products, and services in the Early Phase has been considered, it is important to next consider the Mature Phase of the market. This involves a variety of differences to the Early Phase, with an additional focus on technology that will revolutionize the reliability of communication and navigation systems on the lunar surface, along with their size, power, and cost effectiveness. This phase involves industrial, academic, and institutional customers, with progress being driven by an increase in competition between the commercial communication and navigation service providers.

The Mature Phase has a greater and more specific demands, products, and services, including but not limited to:

- Providing communications and navigation service deliverables for maintaining a sustained lunar presence and Earth-Moon ecosystem
- Developing various orbital platforms and Lunar Surface Ground Station and Core & Access Network Infrastructure to allow for data exchange across communication and navigation networks
- Communication coverage, availability, and performance assessment (i.e. bandwidth availability, download/upload rate)
- Ensure development of navigation and communication protocols and support systems

It is possible to expand on the above products and services, but there is not yet sufficient information to accurately predict what will be the dominant services in the Mature Phase. Due to the speculative nature of the predictions, the above description has been limited to the broad trends and this section is not as detailed as the Early Phase, instead there is to be a greater focus on a brief overview of other aspects not yet covered in this section.

3.3.5. Revenue Generation

The communication and navigation markets both provide companies with a wide variety of revenue generation models depending on the end user and the market phase. This section of the report intends to provide a brief process-oriented view of the potential revenue models in both the Early and Mature Phase.

In the Early Phase, it is imagined that due to the critical nature of navigation and communication to the ongoing success of all lunar surface activities that a selection of the potential services and products would be funded by government and international organizations through mechanisms similar to the Horizon Europe funding for science and innovation. A brief overview of potential revenue models, including ones that are free at the point of use, for the Early Phase are as follows:

- Grant funding by governments with specific funding directed towards providers in order to increase their share of the global market. The aim of this would be to foster innovation in the respective country / geographical region and to benefit from the downstream market impacts that having market leaders in this domain would provide
- Government funded, usually by the military due to security reasons. As seen in similar domains on Earth, with the most striking communication example being the development and funding of one of the prototypes to the modern internet, ARPAnet, by the U.S. Department of Defense, and the provision of location data required for navigation through the U.S. Department of Defense
- A transactional revenue model, where the users of the communication and navigation system would directly pay for the services that they use. This is likely to be the case if private entities enter the lunar market without backing from their respective governments, and could lead

to a situation where there are multiple competing organizations offering products and services with similar capabilities
- A venture capital / private equity funded approach, with the intention of taking advantage of the first mover advantage in order to lock organizations into an ecosystem in an effort to create a fully captured customer base that would result in future revenue once the ecosystem has matured. This approach should be seen as a precursor to later revenue-driven models

A trade approach, where access for services is given in exchange for another organization's expertise in a specific area. Hypothetical examples of this include exchanging the use of earth to Moon data transfers with launch companies in exchange for priority access to their launch vehicles to launch additional satellites to improve the services.

The above list is not comprehensive, but it showcases the different methods by which an Early Phase organization could cover their costs or generate revenue. It is expected that during this phase a broad mixture of the above models would be used for different services depending on the specific needs of the end customers.

Following this, it is expected that as the market matures, the revenue models listed above could be supplemented by the following methods:

- A freemium model where basic services are covered by the government-provided or subsidized version, with a cost for some form of advantage in the form of temporary or permanent boosts to the service
- A subscription model where the user pays a recurring fee for access to a particular service or product
- A free at the point of use model where the provider would then be able to utilize this data to generate revenue in other ways

3.3.6. Market Interdependencies

In order to fully comprehend the importance of communication and navigation on the Moon, it must be considered in the wider context of enabling the other markets as discussed throughout the report. A brief introduction to the overall links with the other markets can be seen below. As becomes immediately evident, every market in the economy is dependent on M3's services for their operations.

Table 3.4. Interdependencies between Market Team 3 and other markets

#	Market	Product or Service Needed or Provided
1	Transportation to/from the Moon	This market contains several potential customers, with the logic being that both robotic and crewed taxi services would benefit from communication with ground stations on the Earth and Moon, the provision of positioning data on the Moon and in lunar space, and the provision of timing information related to this in order to facilitate both crewed and uncrewed landings.
2	Transportation on the Moon	This market is another customer segment that is easily exploited. Crewed and uncrewed rovers, any fixed infrastructure, and even individual transportation through EVA's are vital customers for the services outlined above due to their entire purpose being navigating around the Moon.
4	Energy and Power	This market would likely be a minor customer segment compared to MT 1 and 2, however, it should not be discounted. On Earth, GNSS is vital to energy and power companies due to the provision of timing and synchronization through the provision of access to Coordinated Universal Time, with receivers at different locations being used to maintain a common reference time. It is also expected that an energy and power architecture would be reliant on a lunar internet and other communication services and products to allow the system itself to function.
5	Products and Services	M5 Products and Service on the Moon - In the Early Phase, a limited demand for communication and navigation services and products is expected. Examples of demand in the Early Phase are limited to the potential operation of the launch and landing pads and for the ongoing construction of Mature Phase systems. In the Mature Phase, there is expected to be both communication and navigation requirements coming from the emergency fire and rescue services, medical health and centrifuge facilities, landing and launch pads, roadways, waste processing and recycling, central banking, admin, and governance, as well as the management of general provisions. Each of these systems would require lunar surface communication services to allow communication with the different subsystems, the provision of timing data for synchronization, and will require navigation services to allow them to move assets on the Moon.
6	Infrastructure, Construction and Manufacturing	During the Early Phase, the main market demands for M6 would be to coordinate materials, assembly, and manufacturing assets. During the Mature Phase, this is could increase as the volume of manufacturing on the Moon increases, as well as additional bases and areas are constructed.
7	Mining and Resource Extraction	This market is affected by the same considerations as M6 Infrastructure, Construction, and Manufacturing on the Moon.
8	Habitation and Storage	During the Early Phase, there are very limited interdependencies between these two groups. The main dependency would be on the provision of the ability to communicate between the different habitable spaces, but this is covered by M2, M5, and M6. During the Early Phase, the main market demands for this would be to coordinate the materials, assembly, and manufacturing assets. During the Mature Phase, this is expected to be increased as the need for archival facilities and other such storage is considered.
9	Lunar Agriculture	Limited expected interdependencies, aside from the provision of database access and storage, the movement of goods, and the facilitation of communication between parties.

3.4 Energy and Power

3.4.1. Introduction

This chapter will provide an overview of Market 4 - its definition, a high-level breakdown of the framework that will be utilized for this research, and will classify potential revenue-generating aspects of the energy demand to break the market down into piecewise, manageable sub-segments. It is also paramount to identify the working assumptions and applicable validation methodologies for the scope of this report for a quality end-product; accordingly, the assumptions have been also documented in this chapter.

Chapters 4 and 5 build on the market segmentation to identify players actively working on, or can potentially play a significant role, in the Energy and Power market. In order to identify the power demand, it is critical to develop the anticipated value chain between the aforementioned players, this shall be discussed in Chapter 6.

3.4.2. Definition

As part of the Early phase, all lunar missions will require individual energy sources in the form of Solar panels, Radioisotope Thermoelectric Generators (RTGs), Hydrogen fuel cells, or other equivalent energy equipment. The rationale for this is that during the Early phase, the energy requirements shall be sporadic and spread across the Moon for different missions. Furthermore, building a complete centralized energy support system would not be possible without intensive manual involvement (Moonbase 2030). Gradually, either a unified council (including several countries as council members) or specific brokerages will pave the way for power generation, power transmission, power distribution, and power storage applications, for use by all other activities/Markets on the Moon. Similar to how the Lunar Gateway is being set up, where the power module is put into operation first, the power infrastructure on the Moon will dictate the complete system architecture and markets for all missions and applications for lunar commercialization.

As part of the Mature phase, there shall be a demand for significant power generation (e.g.: Solar arrays; Chargeable Atomic Batteries (CABs), Small Modular Reactors (SMRs), Hydrogen Fuel Cells, etc.), power transmission, power distribution (e.g.: cabling; transformers; etc.), and power storage solutions. This will also generate a need for supplementary products and services like operational equipment, tooling solutions for the specialized equipment, preventive maintenance and data collection, radiation protection services, etc.

For the overall report, it is important to note that the intent of this report is not to identify and finalize the way the demand is met, but rather, identify the actual demand. The rationale being that several cutting-edge technologies are currently being developed, and it is too early to conclude that one specific technology will dominate the power supply-chain on the Moon; hence, they are just placeholders for now. During the quantification effort, this understanding translates into the creation of different scenarios for the Energy and Power market portfolio.

3.4.3. Early Phase Products and Services

During the Early phase, the power modules should be part of individual mission operations following a traditional Engineer, Procure, and Construct (EPC) approach for sub-functions: generation, distribution, and storage. For example, for the Lunar Gateway program, NASA awarded Maxar technologies the contract to develop the Power and Propulsion Element that provides power generation functionality using the 50 kW solar electric propulsion (SEP) spacecraft (link). Furthermore, Airbus shall be developing the power management and distribution (PMAD) system for the Lunar Gateway and interfacing directly with NASA (link).

There shall also be a market segment during the Early phase that is solely for research and development (R&D) initiatives to prototype and develop strategic technology maturation capabilities that can be used for large-scale lunar commercialization. For example, NASA is actively working on several initiatives in partnership with commercial players and Department of Defense (DOD) to seek synergies and collaboration in the field of space nuclear technologies (here).

3.4.4. Mature Phase Products and Services

In order to simplify the overall market revenue generation, the market is subdivided in the following main and sub-segments.

- Power generation – Entails demand revenue associated with power generation equipment (solar array, reactor, balance of plant equipment, etc.), associated consumables (fuel, PPE, H2, etc.), and operating equipment (maintenance toolsets, inspection systems, etc.).
  - Raw material or Fuel – e.g., TRISO fuel for X-Energy's reactor or equivalent; Hydrogen; Water; etc.
  - Systems, Structures, and Component (SSCs) design – e.g., Reactor design, solar panel design and curation. There may be several, niche, consulting services within this sub-segment as seen from the market on Earth (systems engineering, commissioning, codes & standards development and compliance, software, electrical, mechanical, thermal, etc.), these services shall be touched upon within the quantification effort, later in this report.
  - Design of maintenance and operating toolsets – e.g., robotic system for visual inspection; robotic system for cleaning; monitoring sensors, etc.
  - Supply of consumables apart from fuel – e.g., Gases, Personal Protective Equipment (PPE), etc.
- Power transmission – Entails demand revenue associated with power transmission equipment (cables, circuit breakers, wireless, laser systems, etc.) and operating equipment (maintenance toolset, inspection systems, etc.)
  - SSCs design
  - Design of maintenance and operating toolsets – e.g., periodic inspection of the equipment, etc.
- Power distribution – Entails demand revenue associated with power transmission equipment (cables, circuit breakers, etc.) and operating equipment (maintenance toolset, inspection systems, etc.)
  - SSCs design
  - Design of maintenance and operating toolsets – robotic deployment for periodic inspection, etc.
- Power storage – Entails demand revenue associated with power storage solution (batteries, fuel cells, etc.) and operating equipment

3.4.5. Revenue Generation

As briefly touched upon within the market segmentation, the Early phase contracts shall predominantly be from EPC services being offered to space agencies, military organization, and some private companies that are strengthening their core competencies for long-term strategic development.

During the Mature phase, similar to the power grid on Earth and associated revenue generation model, the utility council should regulate the market and provide revenue to each market segment.

3.4.6. Market Interdependencies

Collaborating with 8 other Market Teams, it is critical for the team to brainstorm and document all potential interdependencies with other Markets to avoid rework related to scope that may fall in more than one Market. These interdependencies will feed into the Value Chains to develop a coherent portfolio calculation methodology and fiscal value.

Accordingly, highlighted below is an initial draft of the interdependencies identified by the team:

Table 3.5. Interdependencies between Market Team 4 and other markets

#	Market	Product or Service Needed or Provided	Market 4 Impact
1	Transport to and from the Moon	Transport of equipment, fuel, and operational and maintainance tooling.	Required, operating power for existing facilities on the Moon.
2	Transport on the Moon	Transport of equipment, fuel, and operational and maintainance tooling on the Moon.	Required, operating power for existing facilities on the Moon.
3	Communication and Navigation	Most of the communication and Nav shall be turnkey provided by the market segment service provider or the utility or both.	Required, operating power for existing facilities on the Moon.
5	Products and Services	Operations and maintainance of the plant including on-power operations, period inspections, preventive maintainance, etc.	Required, operating power for existing facilities on the Moon.
6	Infrastructure, Construction, and Manufacturing	Construction of the facility building; most of the specialized equipment shall be manufactured on Earth due to material and fiscal considerations and transported by M1.	Required, operating power for existing facilities on the Moon.
7	Mining and Resource Extraction	There may be a need to mine lunar regolith to provide construction and temporary and permanent shielding for use in nuclear plants, but the current understanding is that, that shall be covered by M6. There may be a need for ISRU for H2, He, or other elements, but this is currently unknown. This should be accounted for at a later date.	Required, operating power for existing facilities on the Moon.
8	Habitation and Storage	While habitation shall be minimal as plant operations including generation, transmission, and storage shall be limited, there will be a need for specialized, environmentally controlled storage solutions for equipment.	Required, operating power for existing facilities on the Moon.
9	Lunar Agriculture	Minimal as human involvement for plant operations is considered negligible.	Required, operating power for existing facilities on the Moon.

3.5 Supplies and Services

It should be noted that Market 5 should be viewed as a special case. Activities under this market are included to try and capture to the greatest extent possible the potential activities required for a functioning commercial lunar ecosystem. However, there will not be commercial markets for several of the elements described below. And, where commercial markets may exist, the business case is often not entirely clear, or insufficient data is available to enable proper quantification of demand. Therefore, the below activities are provided for completeness' sake, and should be understood as an exercise to understand the full spectrum of lunar activities. However, only operation and maintenance of launchpads and roadways was quantified under this team in the demand estimation exercise of the LCP (resource depot operation and sales for propellant and other uses were modelled under Market 1 and Market 7).

3.5.1. Definition

Market 5 is composed of five segments:

- Segment 5-a: Launchpads Operations and Maintenance
- Segment 5-b: Roadways Operations and Maintenance
- Segment 5-c: Operation of Depot for Supply of Water, Oxygen, Hydrogen, and Nitrogen
- Segment 5-d: Miscellaneous Emergency, Medical, Recycling and Provisions
- Segment 5-e: Data, Fintech, Governance

Segment 5-d: Miscellaneous Emergency, Medical, Recycling and Provisions includes 4 sub-segments:

- Sub-segment 5-d-1: Emergency/Fire/Rescue Services
- Sub-segment 5-d-2: Medical/Health/Hyperbaric/Centrifuge facilities
- Sub-segment 5-d-3: Non-Nuclear Waste Processing/Recycling
- Sub-segment 5-d-4: General Provision Stores, Maintenance, and Repair

Segment 5-e: Data, Fintech, Governance includes 3 sub-segments:

- Sub-segment 5-e-1: Data
- Sub-segment 5-e-2: Fintech
- Sub-segment 5-e-3: Governance

the later 5-e-3 including four further categories:

- Category 5-e-3-i: Central Moon Port administration
- Category 5-e-3-ii: Environmental and Nuclear protection, Nuclear Waste Treatment
- Category 5-e-3-iii: Moon Traffic Management, Registry, Interference Zoning, Damage Assessment, Policing, Mobile Units for Incident Monitoring
- Category 5-e-3-iv: Education and human physio-psychological resilience for short and long duration visitors

These are considered separately in each of the report's chapters

3.5.1.1. Segment 5-a - Launchpads Operations and Maintenance

Once the building and operation of sintered regolith common landing zones with berm protection surrounds and other debris and dust mitigating devices has started to take place, these require operation services, as well as dealing with emergency repairs, in addition to scheduled maintenance.

In the Mature Phase, these landing zones may be built, operated, and maintained as a regulated Moon Port infrastructure, under a Port Authority model (see segment 5-e, Governance).

The level of emergency repair and scheduled maintenance, in a context of international activities on the Moon requiring transportation for and by government and private sector, also depends on a variety of factors, such as damage and deterioration rate, navigation issues, environmental constraints, etc. Decision criteria behind demand drivers and constraints on both and supply and demand, depend on several political, legal, regulatory, commercial, and technical factors.

Of paramount importance are location (either resource-centric or not), landing/take-off capacity, single/multiple use, embedded comms and NPTs, data, power, servicing, and the room allowed for considerations of environmental protection and operational safety.

Launchpads with protective berms may undergo a trial-and-error cycles, evolving through several generations, that reflect the overall evolution of lunar activity and its incremental regulation through the Early Phase and then towards the Mature Phase. However, because these entail costly investments by government and/or private sector, we would expect even Early Stage models, to the extent that such infrastructure exists in this Phase, to still be used and 'amortized' over a period of time, until rendered obsolete, in which case they will still require to be decommissioned, dismantled, and 'recycled'. Below sub-segments may be relevant for qualification and quantification in both the Early and Mature Phase:

- Sub-segment 5-a-1: ad-hoc experimental pads
- Sub-segment 5-a-2: semi-permanent pads
- Sub-segment 5-a-3: fully regulated pads

3.5.1.2. Segment 5-b: Roadways Operations and Maintenance

Once the building and operation of sintered regolith common routes with protective side barriers has started to take place in the Early Phase, these require operations services, as well as dealing with emergency repair, in addition to scheduled maintenance.

In the Mature Phase, these roadways may be built, operated, and maintained as a regulated Moon Surface Transportation infrastructure, under a Moon Traffic Management model (see segment MT5-e, Governance).

The level of emergency repair and scheduled maintenance, in a context of international activities on the Moon requiring transportation for and by government and private sector, also depends on a variety of factors, such as damage and deterioration rate, navigation issues, environmental constraints, etc. Decision criteria behind demand drivers and constraints on both and supply and demand, depend on several political, legal, regulatory, commercial, and technical factors.

Of paramount importance are location with distance and topography trade-offs, back and forth traffic capacity, embedded comms and NPTs, data, power, servicing, and the room allowed for considerations of environmental protection and operational safety.

Roadways with protective barriers may undergo a trial-and-error cycle, evolving through several generations, that reflect the overall evolution of Moon activity and its incremental regulation all through the Early Phase and then toward the Mature Phase. Similar to landing pads, these will likely also need to be decommissioned, dismantled, and 'recycled'. Below sub-segments may be relevant for qualification and quantification in both Early and Mature Phase:

- Sub-segment 5-b-1: ad-hoc experimental roadways
- Sub-segment 5-b-2: semi-permanent roadways
- Sub-segment 5-b-3: fully regulated roadways

3.5.1.3. Segment 5-c: Operation of Depot for Supply of Water, Oxygen, Hydrogen, and Nitrogen

This segment addresses three markets: two obvious ones are propellant and life support. However, a third one, water for industrial manufacturing processes, is also considered.

In the Early Phase, no independent facilities are assumed: Water, Oxygen, Hydrogen, and Nitrogen imported from Earth remain within spaceships on the lunar surface and in orbit. In case minute quantities are produced on the Moon, they may be stored in existing facilities.

In the Mature Phase, a utility model is considered for Water, while Oxygen, Hydrogen, and Nitrogen are managed as commodities for life support and for propellant use. Imports from Earth may dominate the orbital and surface lunar market, until such a time when there are several tipping points, and locally produced $H2O/H2/O2/N2$ becomes competitive compared to imports from Earth, on the lunar surface, in lunar orbit, at EML and in GEO/GTO.

3.5.1.4. Segment 5-d: Miscellaneous Emergency, Medical, Recycling and Provisions

Market segment 5-d is split in 4 sub-segments:

- Sub-segment 5-d-1: Emergency/Fire/Rescue Services
- Sub-segment 5-d-2: Medical/Health/Hyperbaric/Centrifuge facilities
- Sub-segment 5-d-3: Non-Nuclear Waste Processing/Recycling
- Sub-segment 5-d-4: General Provision Stores, Maintenance, and Repair

Sub-segment 5-d-1: Emergency/Fire/Rescue Services

In the Early Phase, it is assumed that no independent facilities exist. As such, accidents may happen either inside a spacecraft (on the lunar surface or in orbit). In the Mature Phase, facilities will appear, that are susceptible to accidents.

Regarding fire risk, should this occur inside a spacecraft, this will already be equipped with internal fire countermeasures.

A fire cannot occur in the open for lack of atmosphere. A fire may happen inside a warehouse only as long as there is enough oxygen to sustain it. Each facility will require its own mix of fire counter measures; water, fire-extinguishing chemicals, and ventilation / depressurization as a last resort. Airlocks inside facilities may be required to isolate the location of the fire area from asphyxiating the rest of the human presence and burn the facility from the inside, causing catastrophic structural damage.

Regarding accidents and loss of consciousness happening both indoor and outdoor, a number of Emergency Rehab outfits may be advisable in order to stabilize casualties prior to sending them to medical unit(s). Meanwhile, injured crew need to be evacuated to a center for triage, to then be dispatched to morgue facilities, emergency and/or intensive care, or benign care that could also be provided inside a habitat.

Sub-segment 5-d-2: Medical/Health/Hyperbaric/Centrifuge facilities

Visitors present on the lunar surface and its orbit for a certain period of time may be classified as tourists and personnel (such as government astronauts and private sector contractors and employees). However, they are all human, and while some may have a top military and astronaut grade health condition, some may have issues and comorbidities, but will be present because they can afford a ticket. While accidents and operations require considerations similar to Earth analogs (self-operating an appendicitis inside a tent in the middle of the Antarctic), some issues are directly related to time. For these we use the standard terminology Short and Long Duration Space Travel (SDST and LDST respectively): generally Long Duration starts after a couple of months once certain health effects manifest.

Issues for immediate consideration in life sciences and demand for space medicine include but are not limited to: food production; bio-regenerative life support system design (BLSS); muscles and bones degradation in reduced gravity; cardiac health; SANS (Spaceflight-Associated Neuro-Ocular Syndrome); and radiation. These issues are of concern for LDST visitors and the top duration segment of SDST.

However, for LDST, the following health issues are noteworthy of consideration: LDST specific medicine; gynecologic and obstetric aspects of LDST; risks and benefits associated with taking the combined oral contraceptive pill during LDST; treatment of LDST-induced antibiotic resistant E. Coli Infections; role of precision medicine in LDST; use of hibernation for humans in LDST; and the ethics of conducting genetic modifications to improve survival in LDST. And, for both SDST and LDST, training for resilience.

This initial version of the report covers markets for Moon usage only. However, in a future version of this report, it may be considered to plan and regulate for the hypothesis that the Moon and cislunar space may also become a hub for human-operated LDST toward the rest of the Solar System.

This version of the report doesn't cover pregnancy and birth, nor does it cover death and funerals. While pregnancy in space isn't legally permitted, it remains to be biologically assessed for mammal reproduction in gravity lower than 1G, especially low-G and G/6. In the event of death of either tourist or personnel, the body is simply shipped back to Earth.

There can be medical benefits to a weightless/variable gravity environment, including hypergravity (greater than 1 g) creating a medical tourism market. However, this area is at an early stage of development and research, and benefits need to be further explored, articulated, vetted and approved before a market can be created.

In Early Phase, there are no independent facilities. These appear only in Mature Phase.

Sub-segment 5-d-3: Non-Nuclear Waste Processing/Recycling

Current experience of waste management methods in space is limited to the ISS: there, waste disposal methods rely on astronauts manually processing waste by placing it into bags then loading it onto a designated vehicle for short term storage, which, depending on the craft, returns waste to Earth or burns up in the atmosphere. This disposal method will not be available nor feasible for missions beyond low-Earth orbit.

In the Early Phase, it is assumed that no independent facilities exist. Processing and recycling of non-nuclear waste, if any, would be limited to means available on board. Missions in orbit and on the lunar surface may not last long enough for the accumulated human, agricultural, and industrial waste to be processed economically at scale, and therefore it may be taken back to Earth. Some experimentation and testing may be conducted, for recycling planning purpose.

In the Mature Phase, waste will be produced at scale, covering several categories such as grey water, human and agricultural waste, extraction and industrial waste processing, and waste from equipment and infrastructure through both planned and accidental circumstances.

Sub-segment 5-d-4: General Provision Stores, Maintenance, and Repair

In this sub-segment, 'Provision' means any commodity and supply other than Water, Oxygen, Hydrogen, Nitrogen (covered in segment MT5-c). This sub-segment includes:

- Operation of Depot for Supplies of Food, health supplements, medicine, medical supplies
- Operation of Depot for Supplies of Equipment, including medical equipment
- Equipment Maintenance and Repair (equipment, habitation)

In the Early Phase, it is assumed that no independent facilities exist. However, toward the end of the Early Phase, some storage facilities may be built in order to store equipment and some initial supplies that can be re-used mission after mission and replenished accordingly.

In the Mature Phase, facilities are created to handle these services in orbit and on the lunar surface, to address a population of visitors, either tourists, or personnel active in the various sectors of the cislunar and lunar economy, together with their supporting infrastructures.

3.5.1.5. Segment 5-e: Data, Fintech,

Governance

Segment 5-e: Data, Fintech, Governance is comprised of:

- Sub-segment 5-e-1: Data
- Sub-segment 5-e-2: Fintech
- Sub-segment 5-e-3: Governance

The later sub-segment 5-e-3 includes four categories:

- Category 5-e-3-i: Central Moon Port administration
- Category 5-e-3-ii: Environmental and Nuclear protection, Nuclear Waste Treatment
- Category 5-e-3-iii: Moon Traffic Management, Registry, Interference Zoning, Damage Assessment, Policing, Mobile Units for Incident Monitoring
- Category 5-e-3-iv: Education and human physio-psychological resilience for short and long duration visitors

Sub-segment 5-e-1: Data

Data has its own value chain: a human-centered and data-centric model with a large amount of human-machine interaction. Governments, the private sector, all stakeholders, are customers for all manner of data: biosphere, habitat, science, technology, production, logistics, trade and investment, socio-economic development, governance data, as these activities evolve across the board from the Early Phase to the Mature Phase: SRU activities, transactions, security, sustainability. Activities on and around the Moon are conducive to the construction of robust datasets, that in return provide a foundation for improved legal engineering and composable governance, with an option for space law to evolve toward a new Corpus Juris Spatialis.

We retain 9 layers of granularity for this sub-segment MT5-e-1 data:

- Biometrics and health, covering all visitors (tourists and personnel) either in Short or Long Duration Space Travel (SDST or LDST)
- Human activities and location, covering all visitors (tourists and personnel) either in Short or Long Duration Space Travel (SDST or LDST)
- Energy status, covering power generation at infrastructures, and propellant depots
- Habitat and BLSS status, covering structural integrity, BLSS, smart-home functions
- Agri-food status, covering location, production, value chain, waste management
- Provisions and services status, covering various supplies and services.
- ISRU exploitation status, covering location, production, value chain, waste management
- Manufacturing status, covering location, production, value chain, waste management
- Traffic management status, covering location, comms/NPTs, cislunar/orbit, in/out Moon surface, on surface

In the Early Phase, no independent facilities exist, and the datasets develop around missions, visitors, spaceships, and emerging activity. In the Mature Phase, datasets are commensurate to a population of an order of magnitude of a hundred, with socio-economic activity as it develops.

The architecture that provides data most economically may evolve with scalability and adaptability through time as economic activity increases in cislunar space and on the Moon's surface and its vicinity. Quality of service is also key (e.g., low latency, sufficient bandwidth) as quality, quantity and speed of data delivery impacts many other economic activities.

Sub-segment 5-e-2: Fintech

We retain three layers of granularity for this sub-segment MT5-e-2 Fintech:

- Retail payment systems and personal finance, covering all visitors (tourists and personnel) either in Short or Long Duration Space Travel (SDST or LDST)

- Wholesale payment systems and commercial transactions, covering all industrial and logistics transactions
- Machine-to-Machine transactions, covering all Machine-to-Machine economic activities

However, this 'Machine-to-Machine' layer will not be covered in this version 1 of the Lunar Commerce Portfolio. Subsequent versions may include a model for an autonomous systems economy where machines can transact and make decisions between themselves.

While the U.S. dollar is considered to remain the planetary dominant reserve currency in the Early and Mature Phase, various responsible States may still opt to use their national currency for their cislunar and lunar transactions as they would do back on Earth.

In the Early Phase, no independent facilities are assumed. Each mission has an internal expense account. Should there be any transaction or barter between missions, these may be reconciled back on Earth. There is no need for Moon-based financial transaction nor money settlement.

There may be a number of experiments and testing conducted along the process of further digitalization of money on Earth and its regulation as it emerges in the 2021-30 decade, however this doesn't change the fact that the Moon is covered as an extension of Earth. Testing would be intended for future Long Duration Space Travel visitors (either tourist or personnel) who may need to conduct personal finance operations while living off-Earth. However, this need most likely arises beyond the considered time horizon of the LCP.

In the Mature Phase, an agnostic assumption is made that lunar infrastructure may see an evolution parallel to Earth in the process of digitalization of money and the financial system. The lunar economy may be able to function as an 8th Continent economy. The nature of lunar governance, the degree of co-dependence or autonomy from Earth, and evolution of space law in the meantime, may be boiled down to several scenarios. In the eventuality that space law evolves toward a specific Corpus Juris Spatialis, there is a possibility that specific space-based material jurisdiction may be established in cislunar and lunar space. In that case, most residential, agricultural, industrial, logistics, financial nodes on the lunar surface, in orbit, and where relevant in cislunar space, may have their own autonomous legal entities linked to these jurisdictions. With various degrees of affiliation with or autonomy from Earth jurisdictions, they may financially transact between themselves.

However, even if the Moon can function as an 8th Continent economy, currency needs will be driven by numbers, not location. The envisioned Moon population in a 100's magnitude order remains below the required threshold to operate and justify the time, risk and expense to create a 'Lunar Currency'. In comparison, an island like Palau with a population of about 20,000 individuals still has a currency directly pegged to the U.S. dollar. Whether a cislunar and lunar economy develops remain to be seen, but even if substantial, the political decision to create a 'Lunar Currency' would need to be justified in territorial and demographic terms first.

This version 1 of the Lunar Commerce Portfolio also does not include financial activities linked to the cislunar and lunar mercantile economy, nor activities linked to lunar commodities trading platforms and subsequent financial derivatives market. The U.S. economic ratio (60% mercantile economy vs. 40% financial and derivatives markets) indicate there's a potential for some form of financial and derivatives markets activity in relation with the Moon.

Finally, a note on digital currency, crypto-assets, and various emerging trends such as DeFi, NFTs, the Metaverse, etc. First and foremost, it should be understood that, for a certain degree of decentralization to function, a sufficient level of population is required for a network of nodes to develop at scale: this criterion is not met by the LCP's current lunar population assumptions.

Sub-segment 5-e-3: Governance

Category 5-e-3-i: Central Moon Port administration - In the Early Phase, it is considered that no independent facilities exist. As ad-hoc experimental launchpads are planned for construction one by one, there is some degree of coordination and cooperation among countries and operators involved. There is no Moon-based and/or cislunar jurisdiction, nor is there any option to incorporate locally any kind of legal entities.

In the Mature Phase, it is assumed that space law has evolved toward a Corpus Juris Spatialis in ways that it may operate out of a set of space-related cislunar and Moon jurisdiction(s). That allows the Moon Port 'node' to operate as a legal entity, together with other 'nodes' on the surface of the Moon and in cislunar space. The Moon Port is tentatively operated under a 'Port Authority' international Public Private Partnership (PPP) under adaptive governance, with a space law framework that encompass Earth and space jurisdictions. That framework warrants a concept of 'space border 'and custom clearance on or in the vicinity of the Moon.

It becomes the duty of the Moon Port to operate several logistical functions including and not limited to packaging, warehousing, distributing, security, and customs, with a degree of terminal handling which is charged as a service. Land-Park-Launching-Pads may then be managed as part of private 'terminals' under a 'Port Authority' international PPP model.

Category 5-e-3-ii: Environmental and Nuclear protection, Nuclear Waste Treatment - In the Early Phase, it is considered that there exist no independent facilities. Each mission is responsible for mitigating any environmental impact, from projectiles and dust to any kind of waste left behind. Since any (small size) nuclear power generation equipment left behind on the surface of the Moon should be stored as per safety regulations at least as stringent as those on Earth, it is excluded to do so if no storage facilities have been built. In the same vein, there is no nuclear waste treatment taking place in situ in Early Phase.

In the Mature Phase, nuclear protection does make sure that anything from inbound/outbound shipment of radioactive material and equipment is safe, with several contingency plans for transportation accidents. It also covers the security of routine nuclear power generation. Nuclear waste treatment, which may not necessarily take place on the Moon itself, is also linked to the political decision on the type of enrichment technology chosen. If the whole process involves deep burial of ultimate waste, this is likely to be politically sensitive.

Category 5-e-3-iii: Moon Traffic Management, Registry, Interference Zoning, Damage Assessment, Policing, Mobile Units for Incident Monitoring - In the Early Phase, it is assumed that no independent facilities exist. As ad-hoc experimental routes may be planned for construction one by one, there is some degree of coordination and cooperation among countries and operators involved. There is no Moon or cislunar related jurisdiction, nor is there any option to incorporate locally any kind of legal entities.

In the Mature Phase, several safety and sustainability tasks may fall under the responsibility of a Moon Traffic Management Authority, pending the definition and formation of any form of lunar government with a specific degree of affiliation to or autonomy from Earth. It will have de facto a degree of coordination and cooperation with the Moon Port Authority.

Category 5-e-3-iv: Education and human physio-psychological resilience for short and long duration visitors - In the Early Phase, the tourist and personnel who travel through cislunar space to the Moon or its vicinity may already be classified as Short and Long Duration Space Travel visitors. Long duration stays may happen in the Moon's vicinity if they don't happen on its surface yet. In all cases, even for short duration, visitors, made aware of space short- and long-term impact on their physio-psychological resilience, may be required to undertake training and education.

In the Mature Phase, more personnel and some tourists may undertake long duration stays on the Moon or its vicinity. As a Moon community develops on its surface and its vicinity, even if it is only in the 'hundred(s)' order of magnitude, it becomes even more necessary to monitor and coach the community, especially on inter-cultural and linguistic aspects.

3.5.2. Early Phase products and services

3.5.2.1. Segment 5-a - Launchpads Operations and Maintenance

In the Early Phase, there can be expected to be only a few (if any) pads available. Once a spacecraft has landed on a pad, it stays there. There is no way, within the considered time frame, that the spacecraft is going to 'taxi' anywhere else. Therefore, a pad is immobilized as a parking slot till the next launch in an LPLP cycle (Landing-Parking-Launching Pad). This may not matter when there are a couple of missions a year, it matters when there are monthly or weekly missions. Should client/country A damage LPLP X on take-off, client/country B might be tasked to repair and maintain LPLP X made unusable in the meantime, therefore requiring the availability of LPLP Y – pending independent repair facilities unavailable in the Early Phase.

In the Early Phase, sub-segment 5-a-1: ad-hoc experimental pads may be constructed for contingency and tactical purpose as an initial cheaper temporary solution, primarily intended to test landing safety and projectiles and dust mitigation solutions, in addition to performing Land-Park-Launch cycles for initial missions. They may consist of a mix of synthetic resin and regolith, and already include dust mitigating design such as a protective ring (berm). Size and specs may be ad hoc to accommodate spaceships of various size and dust-creating thrust among nations. These may be built starting in Early Phase and could be used for many years of testing until decommission.

Sub-segment 5-a-2: semi-permanent pads may start to be constructed once some market-sharing and regulatory certainty starts to emerge: which country/client operates where with spacecrafts of which size requiring which pads specs, which dust mitigating and other environmental criteria impose which specs, etc.

3.5.2.2. Segment 5-b - Roadways Operations and Maintenance

In the Early Phase, there may only be few (if any) route infrastructure available. This reflects logistical and strategic intent to connect landing zones with areas of ice water and regolith harvesting, areas of industrial treatment, and vital nodes such as power generation, habitat,

In the Early Phase, Sub-segment 5-b-1: ad-hoc experimental routes may be constructed for contingency and tactical purpose as an initial cheaper temporary solution. They may consist into a mix of synthetic resin and regolith and already include dust mitigating design such as protective side barriers. They are a testing ground for environmental impact and testing vehicles both piloted and autonomous which might wear off-course. Size and specs may be ad hoc to accommodate vehicles of various size and possible transportation hazard. This construction may start in Early Phase though these could be used for years of testing and decades of uses until decommission.

Sub-segment 5-b-2: semi-permanent routes may start construction once some market-sharing and regulatory certainty starts to emerge: which country/client operates where with vehicles of which size requiring which routes specs, which dust mitigating and other environmental criteria impose which specs, etc. This may be in the pipeline at the end of the Early Phase already, subject to territorial agreements.

3.5.2.3. Segment 5-c - operation of Depot for Supply of Water, Oxygen, Hydrogen, and Nitrogen

In the Early Phase, there are no independent facilities. Water, Oxygen, Hydrogen, and Nitrogen would be imported from Earth remain within spaceships for each mission on surface and in orbit. At most they may be bartered between missions as part of an international rescue operation.

3.5.2.4. Segment 5-d - Miscellaneous Emergency, Medical, Recycling, Provisions, and Hospitality

Market segment 5-d is split in 4 sub-segments:

- Sub-segment 5-d-1: Emergency/Fire/ Rescue Services
- Sub-segment 5-d-2: Medical/Health/Hyperbaric/Centrifuge facilities
- Sub-segment 5-d-3: Non-Nuclear Waste Processing/Recycling
- Sub-segment 5-d-4: General Provision Stores, Maintenance, and Repair

Sub-segment 5-d-1: Emergency/Fire/ Rescue Services

In the Early Phase, no independent facilities exist. Demand is created by missions' personnel crews and emerging tourism. However, there is already an emerging demand for dealing with any risk and pre-empt any incident as many missions come and go with their own contingency planning for such accidents, which incorporates their demand for hardware and processes as part of mission execution. Since a number of recommendations for codes of sustainable conduct are being formulated internationally, each mission is accountable. Under space law, governments are ultimately liable for the involvement of their private sector or any individual or group of stakeholders for that matter.

Customers in this segment will likely want:

- Equipment for Emergency/Fire/Rescue
- Specification/design/development/test services for hardware and software systems imbedded in a vessel's design
- Emergency/Fire/Rescue process design and development

For the Early Phase, these systems will exist onboard vessels traversing cislunar space and will include equipment that is part of the vessel design (e.g., gas or foam dispensers) or are ancillary equipment (e.g., fire extinguishers). They will be designed specifically for a given vessel and are likely a one-off design.

Sub-segment 5-d-2: Medical/Health/ Hyperbaric/Centrifuge facilities

In the Early Phase, it is assumed that no independent facilities exist. Anything done is through what the mission spacecraft already has on board. Demand is created by personnel and emerging tourism, incorporating equipment and processes already onboard the spacecraft.

Sub-segment 5-d-3: Non-Nuclear Waste Processing/Recycling

In the Early Phase, no independent facilities exist. Demand is created by missions' personnel and emerging tourism. Since waste can only be stored in space crafts, it may be returned to Earth, burned in the atmosphere, or left on the Moon. As many missions come and go with their own protocols for such treatments, these incorporate demand for hardware and processes as part of mission execution. Research may be conducted for future processing, experimentation, and testing, for recycling planning purpose.

Sub-segment 5-d-4: General Provision Stores, Maintenance, and Repair

In the Early Phase, it is assumed that no independent facilities exist. Anything in relation with general provisions, maintenance, and repair, is done through what the mission spacecraft already has on board. Toward the end of the Early Phase, some storage facilities may be built in order to store equipment and some initial supplies that can be re-used mission after mission and replenished accordingly.

3.5.2.5. Segment 5-e - Data, Fintech, Governance

Segment 5-e: Data, Fintech, Governance comprises:

- Sub-segment 5-e-1: Data
- Sub-segment 5-e-2: Fintech
- Sub-segment 5-e-3: Governance

The later sub-segment 5-e-3 including 4 categories:

- Category 5-e-3-i: Central Moon Port administration
- Category 5-e-3-ii: Environmental and Nuclear protection, Nuclear Waste Treatment
- Category 5-e-3-iii: Moon Traffic Management, Registry, Interference Zoning, Damage Assessment, Policing, Mobile Units for Incident Monitoring
- Category 5-e-3-iv: Education and human physio-psychological resilience for short and long duration visitors

Sub-segment 5-e-1: Data

In the Early Phase, no independent facilities exist, and the data sets develops around missions, visitors, spaceships, and emerging activity. The layers of granularity retained include:

- Data for people's biometrics and health, people's activities and location, energy, habitat and BLSS, agri-food, provisions and services status, is confined to spaceships their vicinity.
- Data for ISRU exploitation, manufacturing, and traffic management status, is embryonic since these activities are exploratory and not yet structured nor regulated at scale.

Sub-segment 5-e-2: Fintech

In the Early Phase, no independent facilities are assumed. Each mission has internal expense accounts. Should there be any transaction or barter between missions, these may be reconciled back on Earth, and there is no need for a wholesale payment systems and commercial transactions, covering all industrial and logistics transactions. There may be demand for testing a Moon based ledger with a server networked with Earth-based systems, operating in ways that guarantee the verifiability and immutability of recorded transactions and accounting operations for future Earth-based settlement. Retail payment systems and personal finance, covering all visitors (tourists and personnel) in Short or Long Duration Space Travel, may be tested on board of spaceships, subject to network availability.

Sub-segment 5-e-3: Governance

Category 5-e-3-I, Central Moon Port administration - In the Early Phase, there is no independent infrastructure. However, there is already some degree of coordination and administration of the increasing rate of international missions to the Moon surface and its vicinity, which is a stem of how the future Moon Port may operate.

Category 5-e-3-ii, Environmental and Nuclear protection, Nuclear Waste Treatment - In Early Phase, with no independent facilities, each mission executes standard procedures to secure nuclear hardware inside spaceships while leaving no hazardous material behind.

Category 5-e-3-iii, Moon Traffic Management, Registry, Interference Zoning, Damage Assessment, Policing, Mobile Units for Incident Monitoring - In the Early Phase, with no independent facilities, each mission is confined to operate in and out of its spaceship on the Moon surface. As ad-hoc segments of experimental routes may be planned for construction one by one, there is some degree of coordination and cooperation among countries and operators involved. With no mobile units for incident monitoring, and no resident staff for policing, elementary duties regarding interference zoning and damage assessment are performed under the responsibility of responsible States as can be, while being managed remotely from Earth. To the extent that a registry of cislunar and lunar activity will have been established by the end of the Early Phase, a record of the data may be established as a stem for establishing an international Moon Traffic Management regime.

Category 5-e-3-iv, Education and human physio-psychological resilience for short and long duration visitors - In the Early Phase, with no independent facilities, education and physio-psychological resilience training for short and long duration visitors may be conducted by mission operators, private sector or responsible State government, while a fledgling Moon community emerges.

3.5.3. Mature Phase products and services

3.5.3.1. Segment 5-a - Launchpads Operations and Maintenance

To reiterate, in the Mature Phase, these landing zones may be built, operated, and maintained as a regulated Moon Port infrastructure, under a Port Authority model. Sub-segment 5-a-3: fully regulated pads appear only in Mature Phase, once the Moon Port logistical, regulatory, and financial infrastructure is fully built and has reached a steady state. Assuming the Moon Port follows a model of Port Authority (an international PPP on the Moon), during the transition from Early to Mature Phase, the pad business may move from case-by-case government and/or private sector investment to a solely private sector managed activity.

Furthermore, the Mature Phase may see the apparition of robots to 'taxi' some spacecrafts especially smaller landers toward a standby area, thus liberating a landing pad from its parking occupancy. A need may also exist in the Mature Phase for robotic solutions to remove crashed spacecrafts or landers from a pad.

3.5.3.2. Segment 5-b - Roadways Operations and Maintenance

To reiterate, in the Mature Phase, these common routes may be built, operated, and maintained as a regulated Moon Surface Transportation infrastructure, under a Moon Traffic Management model (see segment MT5-e, Governance). Sub-segment 5-b-3: fully regulated routes appear only in Mature Phase, once a Moon Routes logistical, regulatory, and financial infrastructure is built and reached a steady state. Assuming Moon Routes follows a model of Moon Traffic Management (international PPP on the Moon), during the transition from Early to Mature Phase, the route business may move from case-by-case government and/or private sector investment to a solely private sector managed activity. Furthermore, the Mature Phase may see the apparition of robotic solutions to remove crashed or incapacitated vehicles from routes or their immediate vicinity.

3.5.3.3. Segment 5-c - operation of Depot for Supply of Water, Oxygen, Hydrogen, and Nitrogen

In the Mature Phase, the utility model used for Water may be boiled down to two options:

Hub-Spoke

The pros of this approach are a centralized distribution network (perhaps easier to manage) with only one large-scale processing site. The cons are a need for a complex transport network from resource sites to central processing site (higher transport time and higher difficulty). That may not work if the South Polar region is divided into national operations with little co-operation between them. Only one central Land-Park-Launching site and transport hub with no redundancy, may further aggravate the 'single point of failure' factor.

Point-to-Point

The pros of this approach are a dedicated processing and transport for each site, that allows for multiple different water providers to exist in the area. This option provides redundancy with a larger number of nodes in the production and transport network, with a lesser distance between resource site and processing site (lower transport time and lower difficulty).

The cons of this approach are that individual sites will be more expensive to set up. The economics may not be sustainable if there isn't sufficient demand, in addition to the potential for disputes between different parties on site claims (hence a need for a degree of regulations).

In the Mature Phase, it should also be understood that the provision of lunar water doesn't make it immediately consumable. Lunar Water extracted from e.g., the South Pole ice deposits, requires a pre-consumption treatment to rid it from toxic substances. It requires wastewater treatment post-consumption, before sending water back into life support loops for human and agricultural use (BLSS – Bioregenerative Life Support System). The provision of Oxygen, Hydrogen, and Nitrogen for life support and as propellant, requires as well a carefully designed storage, provision, and distribution system once it has been produced.

3.5.3.4. Segment 5-d - Miscellaneous Emergency, Medical, Recycling, Provisions, and Hospitality

Market segment 5-d is split in 4 sub-segments:

- Sub-segment 5-d-1: Emergency/Fire/Rescue Services
- Sub-segment 5-d-2: Medical/Health/Hyperbaric/Centrifuge facilities
- Sub-segment 5-d-3: Non-Nuclear Waste Processing/Recycling
- Sub-segment 5-d-4: General Provision Stores, Maintenance, and Repair

Sub-segment 5-d-1: Emergency/Fire/Rescue Services

In the Mature Phase, various facilities are being built on surface and in orbit, each of these requires its own arrangements for dealing with emergencies, fire, and rescue services.

Customers in this segment will likely want:

- Equipment for Emergency/Fire/Rescue
- Specification/design/development/test services for hardware and software systems imbedded in a vessel's design
- Emergency/Fire/Rescue process design and development

During the Mature Phase, Emergency/Fire/Rescue (E/F/R) systems will be included as part of a facility's design and will also include ancillary equipment.

Sub-segment 5-d-2: Medical/Health/Hyperbaric/Centrifuge facilities

In the Mature Phase, we may base demand on an analog equivalent of a military hospital unit – a merged, spaceflight training center, and space station health maintenance routine section. For service of a collective nature, such as health impact of LDST, the demand is materialized by all on-going activities at various facilities and in the outdoors, for tourists and personnel.

Medical/Health/Hyperbaric/Centrifuge facilities and capabilities could be employed to support activities such as:

- Medical research
- Variable gravity medical treatment
- Space tourism
- Exploration
- Peaceful security activities
- Lunar commercial activities

Sub-segment 5-d-3: Non-Nuclear Waste Processing/Recycling

In the Mature Phase, facilities are built to handle demand linked to the following activities:

- Bioregenerative Life Support Systems (BLSS) process waste recycling: based on agricultural (vegetal and animal) waste, food waste, human waste, grey water, carbon scrubbing, and linked to population in orbit and on the Moon surface
- In Situ Resource Utilization (ISRU) process waste processing based on ice water, extraction waste/production, metals and volatiles extraction waste/production, misc. manufacturing process waste/production, and linked to activity and production
- Lunar infrastructure decommissioning waste processing based on the nature and material volume of infrastructures,

waste processing ratio, and linked to the rate and frequency of infrastructure decommissioning

- Accidental lunar debris processing based on spaceships, orbital infrastructures, surface vehicles, surface infrastructure volumes, linked to accident rates
- Processing, as a business opportunity, waste/debris from Earth orbit and cislunar space, based on recyclable materials and components volumes usable in lunar, cislunar, and Earth economy, linked to waste/debris volumes and recycling ratio

Sub-segment 5-d-4: General Provision Stores, Maintenance, and Repair

In the Mature Phase, facilities are built to handle demand for commodities and supplies other than Water, Oxygen, Hydrogen, Nitrogen, and demand for Operation of Depot for Supplies of Food and Equipment, including medical supplies and equipment, and demand for Equipment Maintenance and Repair (spacesuits, equipment, habitations). This demand is proportional to the population of visitors, either tourists or personnel. This demand is directly linked to both human and machine economic activity, as required by governmental and private sectors employers, customers, and investors. For services of a collective nature, the demand is materialized by on-going activities at various facilities and in the outdoors, as well as humans and machines. Depending on governance options, consuming humans and machines may not be charged entirely for provision and services, but through the legal entities that support them as employers or customers, in addition to a mutualization model.

3.5.3.5. Segment 5-e - Data, Fintech, Governance

Segment 5-e: Data, Fintech, Governance comprises:

- Sub-segment 5-e-1: Data
- Sub-segment 5-e-2: Fintech
- Sub-segment 5-e-3: Governance

The later sub-segment 5-e-3 including 4 categories:

- Category 5-e-3-i: Central Moon Port administration
- Category 5-e-3-ii: Environmental and Nuclear protection, Nuclear Waste Treatment
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- Category 5-e-3-iv: Education and human physio-psychological resilience for short and long duration visitors

Sub-segment 5-e-1: Data

In the Mature Phase, the architecture that provides data needs to scale in proportion with cislunar and lunar activity, in volume, latency, and bandwidth. Data requires a full array of lunar satellites and infrastructure on the lunar surface and in its vicinity, in terms of sensors, beacons, hardware, software, disaster recovery, continuous power supplies, networking, and maintenance of applications and infrastructure.

In the Mature Phase, all 9 retained layers of granularity are scaling: people's biometrics and health, people's activities and location, energy, habitat and BLSS, agri-food, provisions and services, ISRU exploitation, manufacturing, and traffic management status.

Sub-segment 5-e-2: Fintech

In the Mature Phase, an agnostic assumption is that lunar infrastructure may see an evolution parallel to Earth as the trends towards digitizing money will continue to diversify and achieve greater and greater adoption among the public and the financial system. Retail payment systems and personal finance, covering all visitors (tourists and personnel) either in Short or Long Duration Space Travel, may operate at scale. Governments and the private sector, who will deploy the most personnel to cislunar and lunar locations first, may have made arrangements so that their personnel can access their accounts on secured interfaces, like military personnel dispatched overseas routinely does. Wholesale payment systems and commercial transactions, covering all industrial and logistics transactions in cislunar and lunar space, may benefit from adequate latency and bandwidth. As cislunar and lunar activities increase, they still form a relatively small part of the total Earth-Moon ecosystem economy. Niche service providers may have emerged to provide banking services to a small, but growing extra-terrestrial market, along with forward leaning larger financial players.

Sub-segment 5-e-3: Governance

Category 5-e-3-i: Central Moon Port administration - In the Mature Phase, the Central Moon Port may be operated under a 'Port Authority' type of international Public Private Partnership (PPP). The Central Moon Port operates logistical functions including and not limited to packaging, warehousing, distributing, security, and customs, with a degree of terminal handling which is charged as a service. Land-Park-Launching Pads may be managed as part of private 'terminals' under Port Authority.

In the Mature Phase, we consider that safety and sustainability related duties also fall under the responsibility of the Central Moon Port, regardless of an effectual definition and formation of any form of Lunar government with various degrees of affiliation to or autonomy from Earth.

We selected three duties which are Registry, Interference Zoning, and Damage Assessment, due to their logistical nature: these are covered specifically in Category 5-e-3-iii as they are also a matter of concern for lunar surface traffic management. It is considered space law evolution may warrant registration not only of spacecrafts and any moving or static equipment, but of activities themselves, that serve to build up data set which in return are used for monitoring, safety, sustainability, dispute resolution, etc. Interference Zoning is a necessary step for deconfliction among national and private operators. Damage Assessment is oriented toward both critical landing and take-off accidents, and events, either natural and machine or human-made, that result into damaging of Central Moon Port or any facilities.

Category 5-e-3-ii: Environmental and Nuclear protection, Nuclear Waste Treatment - In the Mature Phase, there may be nuclear power generation facilities on the Moon surface and possibly in its vicinity in orbit.

Nuclear protection services secure any inbound/outbound shipment of radioactive material and equipment, and plan for execution of several contingency plans for transportation accidents. Nuclear protection also covers the security of routine nuclear power generation.

Nuclear waste treatment services, while not necessarily performed on the Moon surface, depend on the type of enrichment technology chosen and the need to bury ultimate waste.

Category 5-e-3-iii: Moon Traffic Management, Registry, Interference Zoning, Damage Assessment, Policing, Mobile Units for Incident Monitoring - In the Mature Phase, roads may have been constructed on the lunar surface to connect the Central Moon Port with economic activity centers, habitats, and tourist destinations, and operated as common routes among international operators from various responsible States. Several safety and sustainability duties may fall under the responsibility of a Moon Traffic Management Authority, to be created pending definition and formation of any form of Lunar government with a specific degree of affiliation to or autonomy from Earth. The Moon Traffic Management Authority will co-operate and coordinate duties with the Moon Port Authority, both on Moon surface and for the vicinity and orbital component of traffic management.

We selected three duties which are Registry, Interference Zoning, and Damage Assessment, due to their logistical nature. It is considered space law may evolve toward registration not only of spacecrafts and any moving or static equipment, but of activities themselves, building up data sets, which in turn are used for monitoring, safety, sustainability, dispute resolution, etc.

Category 5-e-3-iv: Education and human physio-psychological resilience for short and long duration visitors - In the Mature Phase, as a lunar community develops on its surface and its vicinity, it becomes even more necessary to monitor and coach the community during and before a lunar trip. Training services for astronauts, cosmonauts, and taikonauts, may be developed for aspiring members of Moon communities. Extreme military and disaster training experience may come handy for leaders responsible for the survival of others in catastrophic situations.

While living in a sensory deprived environment embedded into such 'magnificent desolation' has its challenges, an ultimate question is whether mammal reproduction will be possible and legalized on the Moon and its vicinity. Even before answering that question, it needs to be asked whether Moon visitors would be able and permitted to bring their families. These questions are out of the scope of the Portfolio, and almost certainly outside of the timeframes envisioned, but should family visits become a practice, Mature Phase may require day care centers and educational facilities for Moon-visiting children and teenagers until they become space faring adults.

3.5.4. Revenue Generation

3.5.4.1. Segment 5-a - Launchpads Operations and Maintenance

Revenue generation for both operations and maintenance cover three functions:

- Landing, parking, launching operations: Pads and roads operations rely on a toll system, based on operations yearly rate.
- Operations data: Based on data volumes and operations rates.
- Maintenance: Based on its cost/price and operations rates.

3.5.4.2. Segment 5-b - Roadways Operations and Maintenance

Categories similar to pads apply for routes, based on toll, traffic and operations yearly rates.

3.5.4.3. Segment 5-c - operation of Depot for Supply of Water, Oxygen, Hydrogen, and Nitrogen

The revenue generation model covers 2 main functions for water, oxygen, hydrogen, and nitrogen: propellants and life support systems. In addition, water may also be used in industrial processes, such as metallurgy, and chemicals. Locations considered include Moon surface and vicinity, cislunar space, and Earth orbit. That model follows closely the activity structure defined by Market 1 – Transportation to and from the Moon. Revenue generation for data flows based on operations rates are included.

3.5.4.4. Segment 5-d - Miscellaneous Emergency, Medical, Recycling, Provisions, and Hospitality

Market segment 5-d is split in 4 sub-segments:

- Sub-segment 5-d-1: Emergency/Fire/Rescue Services
- Sub-segment 5-d-2: Medical/Health/Hyperbaric/Centrifuge facilities
- Sub-segment 5-d-3: Non-Nuclear Waste Processing/Recycling
- Sub-segment 5-d-4: General Provision Stores, Maintenance, and Repair

Sub-segment 5-d-1: Emergency/Fire/Rescue Services

If these services are provided commercially, revenue generation for this segment would be based on operations on surface and in orbit, for resident infrastructures and passing spaceships. It considers probabilities of accident and rates of operations.

Sub-segment 5-d-2: Medical/Health/Hyperbaric/Centrifuge facilities

If these services are provided commercially, revenue generation for this segment would be based on operations on the surface and in orbit, for resident infrastructures and passing spaceships. It considers requirements for such interventions based on human population and rates of operations.

Sub-segment 5-d-3: Non-Nuclear Waste Processing/Recycling

If these services are provided commercially, revenue generation for this segment would be based on operations on the surface and in orbit, for resident infrastructures and passing spaceships. It considers requirements for such interventions based on type of waste (residential, industrial, debris), average quantities and processing prices, and rates of operations.

Sub-segment 5-d-4: General Provision Stores, Maintenance, and Repair

Revenue generation for this segment is based on operations on the surface and in orbit, for resident infrastructures and passing spaceships. It considers aggregate requirements for such provisions and services, average quantities and prices, and rates of operations.

3.5.4.5. Segment 5-e - Data, Fintech, Governance

Segment 5-e: Data, Fintech, Governance comprises:

- Sub-segment 5-e-1: Data
- Sub-segment 5-e-2: Fintech
- Sub-segment 5-e-3: Governance

The later sub-segment 5-e-3 including 4 categories:

- Category 5-e-3-i: Central Moon Port administration
- Category 5-e-3-ii: Environmental and Nuclear protection, Nuclear Waste Treatment
- Category 5-e-3-iii: Moon Traffic Management, Registry, Interference Zoning, Damage Assessment, Policing, Mobile Units for Incident Monitoring
- Category 5-e-3-iv: Education and human physio-psychological resilience for short and long duration visitors

Sub-segment 5-e-1: Data

Revenue generation for this segment is based on operations on the surface and in orbit, for resident infrastructures and passing spaceships. It considers aggregate requirements for data over a number of activities, average quantities and prices, and rates of operations. Activities include and are not limited to energy supply and life support system status, human biometrics and activities, habitat, industrial production and logistics, etc.

Sub-segment 5-e-2: Fintech

Revenue generation for this segment is based on operations on the surface and in orbit, for resident infrastructures and passing spaceships. Linked to population density and economic activity, it considers aggregate requirements for personal finances, commercial exchanges, but doesn't include machine-to-machine transactions in this version 1 of the LCP.

Sub-segment 5-e-3: Governance

Revenue generation for this segment is based on operations on the surface and in orbit, for resident infrastructures and passing spaceships. To the extent where these activities are provided commercially, it considers, wherever appropriate, average quantities and prices of aggregate requirements for these operations: Central Moon Port administration, Environmental and Nuclear protection, Nuclear Waste Treatment, Moon Traffic Management, Registry and Interference Zoning, Damage Assessment, Policing, Mobile Units for Incident Monitoring, and Education and human physio-psychological resilience.

3.5.5. Interdependencies

For ease of understanding, market interdependencies are laid out in the table below.

Table 3.6. M5 market interdependencies

Market 5 Segment	External Market	Interdependency
Segment 5-a: Launchpads Operations and Maintenance	M1	Selling services to Market 1 in/out Moon transportation providers. Buying services from Market 1 to transport 5-a cargo.
	M2	None (MT2 services start at the edge of the pad)
	M3	Buying Comms and PNTs services
	M4	Buying power
	M6	Buying infrastructure repair services
	M7	None (MT6 buyer of MT7 regolith and sintering treatment / construction services)
	M8	None
	M9	None
Segment 5-b: Roadways Operations and Maintenance	M1	Buying services from M1 to transport 5-b cargo
	M2	Selling services to Moon surface transportation providers
	M3	Buying Comms and PNTs services
	M4	Buying power
	M6	Buying infrastructure repair services
	M7	None
	M8	None
	M9	None
Segment 5-c: Operation of Depot for Supply of Water, Oxygen, Hydrogen, and Nitrogen	M1	Buying services from M1 to transport 5-b cargo
	M2	Buying services from M2 to transport 5-c cargo. Selling H2 to M2 Moon surface transportation providers
	M3	Buying Comms and PNTs services
	M4	Buying power
	M6	Buying infrastructure
	M7	Buying H2O, H2, O2, N2
	M8	Selling H2O, O2, N2 to for life support systems
	M9	Selling H2O, O2, N2 to for life support systems
Segment 5-d: Miscellaneous Emergency, Medical, Recycling, Provisions, and Hospitality	M1	Buying services from M1 to transport cargo and personnel
	M2	Buying services from M2 to transport cargo and personnel
	M3	Buying Comms and PNTs services
	M4	Buying power
	M6	Buying infrastructure
	M7	Selling services
	M8	Selling services
	M9	Selling services

Market 5 Segment	External Market	Interdependency
Segment 5-e: Da-ta, Fin-tech, Gov-ernance	M1	Buying services from M1 to transport cargo and personnel. Sell-ing all services.
	M2	Buying services from M2 to transport cargo and personnel. Sell-ing all services.
	M3	Buying Comms and PNTs services
	M4	Buying power. Selling all services.
	M6	Buying infrastructure. Selling all services.
	M7	Selling services
	M8	Selling services
	M9	Selling services

3.6 Infrastructure Construction, Manufacturing

3.6.1. Definition

Infrastructure, construction and manufacturing on the Moon entails:

- **Infrastructure:** Designing and building the Moon's physical system of public works. These include transport infrastructure and public services, e.g., lunar utilities infrastructure. In other words, infrastructure is how the facilities and buildings are 'glued together'
- **Construction:** Designing and building, but not operating, various forms of public and private facilities including buildings
- **Manufacturing:** Designing, building, and in many cases operating, the factories to manufacture building materials (structural elements) and to ultimately produce physical goods

Infrastructure, construction and manufacturing on the Moon directly involves the use of various low cost, low energy consumption construction and assembly methods, techniques, and equipment, like in-situ 3D printing, and self-assembling products.

Infrastructure, construction and manufacturing on the Moon assumes there will be (the following connections to other teams):

- An upstream supply chain for mining and resource extraction on the Moon, transportation of raw materials on the surface, and a supply chain to bring some items from Earth. The upstream portion of the supply chain in general includes the organization's suppliers.[17] These suppliers can include, as an illustrative example, the other market teams of 7. Mining and Resource Extraction on the Moon (M7), 1. Transportation to the Moon from Earth (M1), 2. Transportation on the Moon (M2) and perhaps 3. Communications and Navigation on the Moon (M3).
- A downstream supply chain to operate public works as a service and various types of facilities by different entities to sell/distribute manufactured products to customers. The downstream portion of the supply chain consists of the organizations and processes for distributing and delivering products to the final customers.[18] These distributors can include, as an illustrative example, the market teams of 5. Products and Services on the Moon (M5), 8. Habitation and Storage on the Moon (M8), 9. Lunar Agriculture and Food Production (M9) and 4. Energy and Power on the Moon (M4).

3.6.2. Early Phase Products and Services

Infrastructure, construction and manufacturing needs during the Early Phase are low with almost all physical assets launched from Earth, designed to be self-sustainable or to require relatively little assembly and with experiments studying lunar surface construction and in-situ manufacturing only beginning. Generally speaking, most of these markets will have governments as the customer.

3.6.2.1. Construction

Building Materials

In the Early Phase, building materials are expected to be brought from Earth for assembly, or pure regolith used. Engineering tests for bricks, lunarcrete and others would start in the Early Phase. Demand for building materials will be low due to limited activities on the Moon, but the following activities may emerge.

- Engineering tests for bricks, concrete (lunarcrete), metals and other more specific types of construction elements.

- In-situ built non-hermetically sealed external structures:
  - Landing pads,
  - Antenna mounts,
  - Solar panel mounts,
  - Towers.
- Pure regolith to cover habitation modules for radiation shielding.
- Pure regolith to build barriers around landing pads.

Building of Facilities

Facility modules are assumed to be sent to the Moon with only some interconnections necessary. Most of the building work will be related to assembly rather than construction or manufacturing. This is similar to the way the International Space Station was developed. Demand will again be relatively low. However, the below provides a list of goods and services, divided between Construction & Assembly and Infrastructure.

Construction and Assembly:

- Assembling habitations, research labs, storage facilities, manufacturing facilities, storage tanks, greenhouses etc.[19]
- Deploying inflatable modules.
- Converting some Starships into storage or habitation modules.
- Assembling various structures from elements sent from Earth.
- Radiation shielding, where either regolith, heavy metal residue or a water layer is used as a covering material over roof and walls.[20]

3.6.2.2. Infrastructure

Infrastructure will entail the following elements. However, in the Early Phase, it is almost certain that these elements will be internally incorporated into any surface elements, and that there is therefore no direct market for their individual delivery to end-users.

- Water[21]
- Waste
- Recycling
- Life support (air, CO2, atmosphere)
- Electricity[22]
- Fiber network
- Propellant storage[23]
- Cooling and heating

3.6.2.3. Manufacturing

Manufacture from the Regolith

Only engineering and scientific tests have been assumed for manufacturing from regolith. Use cases for the unmodified regolith have been listed in the previous paragraph of Provision of Building Materials.

Manufacture of Products for Export to Earth

In the Early Phase, only engineering and scientific tests are assumed for products requiring a low-g and a hard vacuum environment for manufacture. We believe demand will be low due to missing research, and corresponding lack of awareness for meaningful products.

It is possible, albeit unlikely, that novelty products made on the lunar surface could be exported to earth, in this case in the expensive luxury class.

Novelty products that could be exported to Earth:

- Moon rocks[24]
- Beer, wine, or whisky aged on the Moon (as has been done on the ISS)

Manufacture of Products for Export to LEO/Lagrange etc.

Only engineering and scientific tests are assumed in the Early Phase. There will likely be demand for a variety of products in LEO and Lagrange points, but this is unlikely to be met by products produced on the surface of the Moon in the Early Phase. Primarily because of the supply challenges compared to launching from the Earth. The only exception to this could be the same novelty products as listed previously.

Manufacture of Products for Sale to Lunar Inhabitants

In the Early Phase, only lunar orbit tourism was assumed, and thus no potential for tourists. Government astronauts are assumed to bring all necessary products with them.

3.6.3. Mature Phase Products and Services

Infrastructure, construction and manufacturing needs during the Mature Phase are of critical importance to ensure the safety, sustainability and expansion of a permanent human presence. Infrastructure will become increasingly complex, new facilities may be constructed exclusively in-situ, and some physical goods may be manufactured locally on the lunar surface.

3.6.3.1. Construction

Building Materials

In the Mature Phase, there will be demand for all kinds of building materials and most of them will be made in-situ on the Moon. Using materials processing techniques, many of the materials themselves will be made from regolith. After that, raw materials will be converted to various construction elements.[25][26]

Construction from Regolith

Regolith may be acquired through Mining and Resource Extraction on the Moon (M7) with the help of Transportation on the Moon (M2). However, most in-situ construction researched to date has focused on the use of autonomous machinery that is able to collect and purpose regolith on-site, without the need for extraction and transportation from elsewhere. Building materials related to ISRU are included in this chapter. Other ISRU fields are listed in later sections. The following elements may be produced using lunar regolith.

- Bricks[27]
- Concrete (lunacrete)
- Glass, mirrors (windows, solar cell cover-glass)[28][29]
- Polymers
- Ceramics (silicon carbide for precision structures etc.)
- Silicon/Silica
- Basalt[30]

Construction elements

The following construction elements may be manufactured in-situ:

- Beams[31]
- Sheet metal
- Pipes
- Wires, cables
- Trusses
- Gears, wheels
- Bolts, screws, nuts

Construction of Facilities

In the Mature Phase, demand for facilities and infrastructure would take off, thanks to the large variety of activities, entities and people on the Moon. Most of the facilities and infrastructure will be built on the Moon from materials acquired on the Moon, lowering the cost and further increasing demand.

Construction and Assembly

In the Mature Phase, there will start to be demand for very large structures on the Moon. Example goods and services related to construction include:

- Habitation elements
- Hotels
- Research labs
- Storage habitats
- Storage tanks
- Space farms / greenhouses
- Optical telescopes
- Radio telescopes in the far side
- Radio antennas
- Power plants
- Processing plants / factories
- Landing pads
- Mass driver[32]
- Tunnels and underground facilities
- Airlocks / de-sterilization

- Radiation shielding (regolith as covering materials over roof and walls, residue of heavy metals or pure protective metal layers, water-storage layer)

3.6.3.2. Infrastructure

In the Mature Phase, there will be demand for new types of infrastructure. Example goods and services related to infrastructure include:[33] [34] [35]

- Water (pipeline system)
- Waste
- Recycling
- Laundry
- Life support (air, CO_2, atmosphere)
- Electricity, electric grid
- Fiber network
- Propellant storage
- Roads
- Bridges
- Cable car
- Cooling and heating
- Emergency shelters (for solar storms and accidents)

3.6.3.3. Manufacturing

Manufacture from Regolith

Manufactured products from regolith are listed below. They are in addition to building materials and bulk uses of unmodified regolith, which have been listed in the previous sections. In other words, this section includes In-Situ Resource Utilization (ISRU) applications which will be in demand in the Mature Phase. It is assumed that mining, resource extraction and transportation on the Moon have already been executed and thus these methods are out of scope here. Carbon and nitrogen may need to be supplied from Earth.

Components and sub-systems

- Batteries
- Solar cells
- Semiconductors, microchips, LEDs
- Magnets[36]
- Circuit boards (copper with composite glass epoxy)
- Electric motors

Manufacture of Products for Export to Earth

Manufacturing of products for export to Earth may occur in the Mature Phase, which require a low-g and a hard vacuum environment for manufacture. These products seem to be the most challenging to estimate, especially from the demand side. One possibility is that lower gravity will improve some products, and manufacturing them on the Moon would therefore be worthwhile. There will also be competition with products made in LEO. No proven research or business models exist as of yet, however.

There could be demand on Earth for the following in-space manufactured products, however, it is far from clear whether there is any economic basis for producing some of these products on the Moon instead of in Earth orbit:

- Semiconductors (low mass, but unknown whether hard fragile vacuum of Moon is a good enough competitive benefit versus Earth or LEO)
- Biotechnology
  - Pharmaceuticals
  - Manufactured organs
- Novelty luxury products[37]
  - Moon rocks
  - Beer, wine, whisky
  - Chocolate
  - Precious minerals

Manufacture of Products for Export to LEO/Lagrange etc.

It is possible demand may arise for lunar-manufactured products to be exported to LEO or Lagrange points in the Mature Phase, possibly manufacturing elements needed for future LEO orbital infrastructure. Less energy (delta-V) is required to travel from the Moon to LEO compared to LEO from Earth. Further, mass drivers could be used, thanks to the lack of a lunar atmosphere, and space elevators are more feasible on the Moon also. This is how Gerard O'Neill envisioned building a gigantic space station at the L5 point. This said, should launch costs decrease sufficiently, it is possible that no feasible economic case could be made for export of products to LEO from the Moon.

In terms of using lunar gravity and high-vacuum, it is currently unknown which products will have practical advantages when compared to microgravity production. There could be a possibility for some temporary markets, depending where the space manufacturing infrastructure is developed first.

Products manufactured for export to LEO and/or Lagrange points:

- Construction elements
- Solar cells
- Propellant

Manufacture of Products for Sale to Lunar Inhabitants

Lunar inhabitants including tourists and astronauts will create demand for a very large variety of products. This may include items produced by 3-D manufacturing of lunar regolith. Most products, however, will be sold by Products and Services on the Moon (M5), but not manufactured in-situ.

Manufacturing from Metals

Metals may be acquired from Mining and Resource Extraction on the Moon (M7) with the help of Transportation on the Moon (MT2). Metals could be transformed into various construction elements using different types of manufacturing and fabrication methods.

Manufacturing and fabrication methods:

The following manufacturing methods are considered across all above elements.

- Casting
- Additive manufacturing
- Welding (robotic)
- Electrolysis
- Anodizing (coatings against corrosion, oxygen, UV-radiation, outgassing)
- Chemical vapour deposition (CVD)

3.6.4. Interdependencies in the Working Group

Infrastructure, Construction and Manufacturing is responsible for building the physical infrastructure on the Moon including making the construction materials. The below table provides an overview of key market interdependencies.

Table 3.7. Interdependencies between Market 6 and other markets

#	Market Team	Product or Service Needed or Provided	Market Team 6 Impact
1	Transportation to/from the Moon	Bring raw materials and equipment from Earth. Subcontracts and uses infrastructure and facilities MT6 has built. Export to Earth	Defines upper limit to import of raw material and export of products, source of demand
2	Transportation on the Moon	Transport materials on the surface between facilities and construction sites.	Potential enabling market
3	Communication and Navigation	Provides communication services for logistics. Uses facilities and infrastructure MT6 has built.	Source of demand, enabling market
4	Energy and Power	Provides power. Uses facilities and infrastructure MT6 has built.	Source of demand, enabling market
5	Products and Services	Needs manufacturing service. Uses equipment, facilities and infrastructure MT6 has built.	Source of demand
6	Infrastructure, Construction and Manufacturing	Equipment transport needed	Increased cargo flights
7	Mining and Resource Extraction	Provides raw materials for construction materials. Uses equipment, facilities and infrastructure MT6 has built.	Source of demand, enabling market
8	Habitation and Storage	Uses facilities and infrastructure MT6 has built.	Source of demand, enabling market
9	Lunar Agriculture	Need manufacturing service. Uses equipment, facilities and infrastructure MT6 has built.	Source of demand

3.7 Lunar Resource Extraction

3.7.1. Definition

Market 7, related to mining and resources extraction, covers the characterization, extraction, processing and refinement of resources available on (and below) the lunar surface. Often referred to as In-Situ Resources Utilization (ISRU), it consists in exploiting the molecules and materials available on the Moon instead of bringing these resources from the Earth. It also includes the extraction of some resources on the Moon for repatriation on the Earth, in the case where such resources are more abundant on the Moon for instance. The main rationale and incentives behind these activities are reduced costs, but also higher autonomy – hence safety – for some applications like life-support.

The work conducted as part of the working group includes an identification of the candidate resources for the analysis, the identification of associated applications that would drive the demand for ISRU, and the sizing of the associated market opportunities. It is important to note that costs are an important driver in the economic viability of ISRU value chains, since the rationale is to provide the resources at a competitive cost per kg compared to Earth-sourced resources. Technology costs (and a fortiori end-to-end mission costs) remain, however, a largely unknown area for the moment, since the most mature concepts are still to be demonstrated in-situ in the coming years – and this is for the most "accessible" resources, namely water and regolith. It is therefore challenging to quantify even the order of magnitude of the local resources after extraction and processing, and the work conducted here did not attempt to define such value (instead, the team based the pricing assumptions on the expected cost/kg delivered to the Moon, detailed in the quantification section of this report).

The mining and refinement processes required for ISRU are part of a larger ecosystem on the Moon and rely on the availability of some upstream and downstream value chains. For instance, it requires the commissioning of various types of equipment and tools on the Moon surface, and most likely the construction of some facilities in the long term (like plants, or storage facilities, transportation facilities etc.). The area of interest for M7 remains, however, focused on mining and refinement activities, meaning that we assume that:

- The equipment and tools required to set-up and run the ISRU are transported from the Earth to the surface, and are directly available;
- The availability of the end product, which is the outcome of the refinement process (whatever the state and level of refinement required, which depends on the end application), is the end of the scope of activity. This end-product can be either transported to or directly used locally by the end user of the product. Therefore, the "customer" of the process can either be directly the end user of the resource (for instance, the vehicle operator to which ISRU-sourced propellant is being delivered) or an intermediate actor handling the product before delivering it to an end user (for instance, if water is transported to a lunar base, and stored for a while before being used for agriculture).

For the sake of non-overlaps between the working groups:

- The upstream logistics operations (before the mining begins) are part of M1 scope (transportation from the Earth to the Moon)
- The downstream logistics operations

associated to the mined resources are part of M2 (Transportation on the Moon)

For the sake of simplicity and to avoid double counting, the customers analysis in Chapter 5 refers only to end users, and not to potential intermediary actors providing logistics operations. Indeed, the customers analysis purpose is to feed the sizing of the economic opportunity, which remains driven by end-users' consumption of lunar resources.

3.7.2. Early Phase Products and Services

This phase is characterized by the following state of activities:

- Prospecting missions are sent to refine our knowledge of lunar resources. There is a shift from remote sensing data gathering (done so far) towards ground truth data (requiring landing, drilling or at least sampling of lunar regolith and analysis of the composition). The purpose of this prospecting phase is in particular to
  - Obtain more reliable data and confirm some assumptions regarding resources concentration and geological structure underneath the first mm / cm of regolith
  - Build a comprehensive map of the resource distribution and concentration in areas of interest (such as polar regions) to allow planning of future ISRU activities and sites
- Technologies for resources extraction and processing are demonstrated by commercial and institutional players;
- Suppliers' missions are not sustainable and depend largely on space agencies contracts and funding (mostly NASA CLPS)
- Limited amounts of resources are being extracted and processed per year, insufficient to supply a full-scale mission

3.7.3. Mature Phase Products and Services

This phase is characterized by the following state of activities:

- ISRU technology has been demonstrated (TRL 8+) for propellant, life support and facilities construction
- Sufficient amounts of water can be provided in a year to supply a full-scale space mission (e.g., a full lander or space tug tank capacity) and sustain all the water consumption from astronauts (although not a limiting factor)
- Basic infrastructures on the Moon surface can be entirely shielded, using regolith where necessary, and finite products can be produced using extracted metals
- In-situ resources suppliers are financially sustainable on their lunar business, and the volume of demand progressively increases

3.7.4. Scoping of the Market

3.7.4.1. Principles

The potential scope of resources and associated applications is relatively wide, and for the purpose of this study, the perimeter of analysis has been defined taking into consideration:

- **The availability and abundance of the resources:** using the current knowledge of the Moon's geological composition, the resources are selected based on their availability in relative abundance

For the resources to be used in space:

- **Their identified applications:** the resources are considered relevant if a market segment is identified for their usage

For the resources to be repatriated on the Earth:

- Whether they are **substantially easier to obtain** from the Moon than on the Earth
- Whether they have a **particularly high value on the Earth**, making a potentially viable business case for the repatriation and a competitive price per kg

3.7.4.2. Availability of Resources

The lunar crust is largely composed of

anorthosite, along with dark mare regions which are basaltic. Water is present in the form of ice in Permanently Shadowed Regions in the polar regions, although recent studies have also found the possibility of water in sunlit regions. The lunar crust is found to be rich in minerals such as iron, titanium, calcium, silicon etc.[38] Unprocessed lunar soil, also called regolith, can be turned into usable structural components. The presence of REEs along with Phosphorus and Potassium are confirmed to be present in lunar KREEP. Materials on the Moon's surface contain helium-3 at concentrations between 1.4 and 15 ppb in sunlit areas, and may contain concentrations as much as 50 ppb in permanently shadowed regions.[39] The abundance of helium-3 is thought to be greater on the Moon than on Earth, having been embedded in the upper layer of regolith by solar wind over billions of years, though still lower in abundance than in the Solar System's gas giants.[40]

Following this approach, the resources shown in Table 3.8. have been included in the scope:

3.7.4.3. Availability of PGM's, KREEP and other Metals

While the presence of many of the resources have been confirmed by the Apollo missions and remote sensing data, the estimation of the reserves is largely based on remote sensing data and less on ground truth. The concentrations are given below:

- The typical composition of KREEP includes about one percent, by mass, of potassium and phosphorus oxides, 20 to 25 parts per million of rubidium, and a concentration of the element lanthanum that is 300 to 350 times the concentrations found in carbonaceous chondrites.[41] With the current data, the REEs from the KREEP terrain appear to occur in lower concentrations compared to Earth, although they are still deemed minable
- Iron (Fe) is abundant in all mare basalts ~14-17% per weight, while free iron also

Table 3.8. MT7 Qualitative level of confidence for resources availability on the Moon

Resource	Confidence	Rationale
Water	High	Evidence of presence in many locations (poles and rest of the Moon), on the surface, under various forms.
Raw regolith	High	Available everywhere
Metals	Medium	Evidence of presence of common metals like Fe, Al, Ti Foreseen applications for manufacturing of equipment, but remain to be confirmed, and with some challenges on technical feasibility.
Platinum Group Metals (Pt, Pd, Ir, Rh, Ru, Os)	Limited	Higher concentrations based on current remote prospection data, but remains to be confirmed with in-situ characterization. Strong challenges on viable costs per kg for repatriation due to re-entry constraints for large volumes.
KREEP (K, P, Rare Earth Elements)	Limited	Strong challenges on viable costs per kg for repatriation due to re-entry constraints for large volumes.
Helium-3 (3He)	Limited	Strong challenges on viable costs per kg for repatriation due to re-entry constraints for large volumes. Large uncertainty on the timeline for nuclear fusion feasibility Demand volumes for other applications to be confirmed

exists in the regolith 0.5% by weight[42]

- The vast flood basalts on the northwest nearside (Mare Tranquillitatis) possess some of the highest titanium contents on the Moon, harboring 10 times as much titanium as rocks on Earth do[43]
- Silicon (Si) is an abundant metalloid in all lunar material, with a concentration of about 20% by weight. It is of enormous importance to produce solar panel arrays for the conversion of sunlight into electricity, as well as glass, fiber glass, and a variety of useful ceramics. Achieving a very high purity for use as semi-conductor would be challenging, especially in the lunar environment[44]
- Aluminum is found with a concentration in the range of 10-18% by weight, present in a mineral called anorthite ($CaAl_2Si_2O_8$), the calcium endmember of the plagioclase feldspar mineral series.[45] Aluminum is a good electrical conductor, and atomized aluminum powder also makes a good solid rocket fuel when burned with oxygen. Extraction of aluminum would also require breaking down plagioclase ($CaAl_2Si_2O_8$).
- The reserves of PGMs are still debated, with some figures deeming lunar surface minable while others arguing against this claim[46]
- By one estimate, the solar wind has deposited more than 1 million tons of helium-3 (^3He) to the Moon's surface.[47] Materials on the Moon's surface contain helium-3 at concentrations estimated between 1.4 and 15 parts per billion (ppb) in sunlit areas, and may contain concentrations as much as 50 ppb in permanently shadowed regions. For comparison, helium-3 in the Earth's atmosphere occurs at 7.2 parts per trillion (ppt).
- Based on remote observations by radar instruments aboard Chandrayaan-1 and LRO, the lunar poles contain over 600 billion kilograms of water ice.

3.7.5. Identified Applications

In parallel to the resource selection, the applications show in Table 3.9 were identified as relevant (or potentially relevant for the most distant ones).

3.7.6. Market Segmentation

As a result, the analysis activities conducted in MT7 are structured along the market segments shown in Table 3.10.

3.7.7. Link With Other Lunar Markets

The different aspects and assumptions described above enable the clarification of the bounds of analysis for M7 and to define the interfaces with other markets. In particular, the border between M7 and the downstream exploitation of resources is the availability of ready-to-use input materials for the following applications:

- Purified oxygen and hydrogen molecules for the manufacturing of propellant
- Purified water and purified oxygen that be breathed and consumed for life support
- Purified water that can be used for irrigation for agriculture
- Processed regolith (if needed) for construction processes
- Isolated and purified metal molecules for manufacturing
- Purified PGMs, KREEP and He3 molecules before export to the Earth, with a trade-off between the attainable performance for such purification and the remaining extra-mass that is transported before being refined on the Earth.

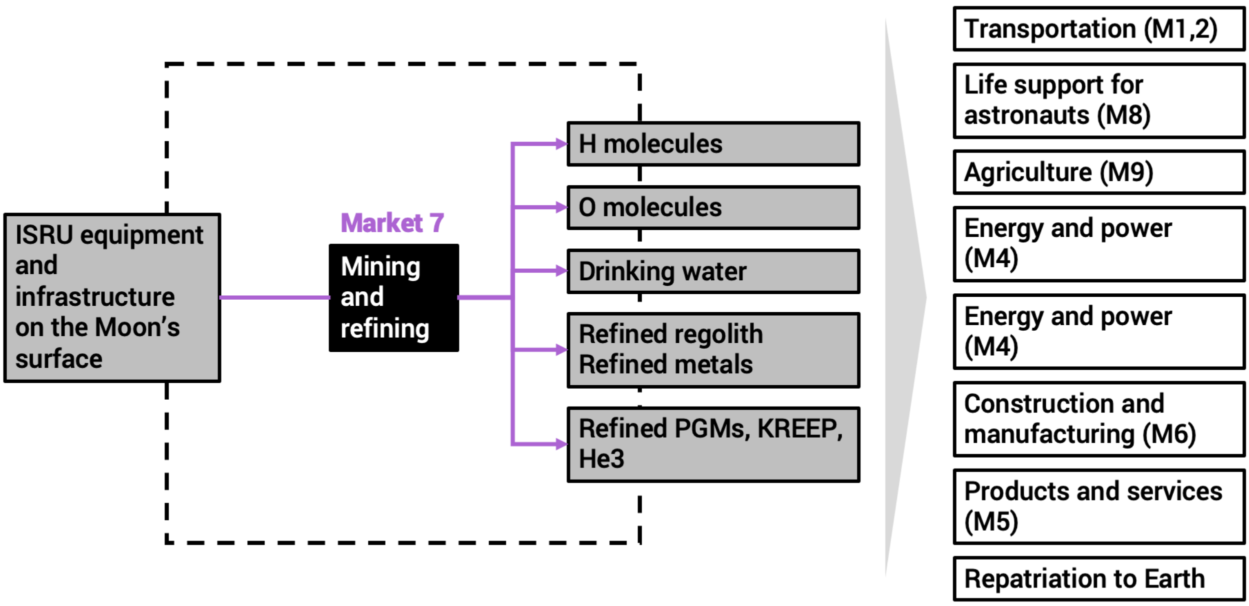
Table 3.9. MT7 identification of applications for lunar resources

Resources	Description of usages	Expected volumes (yearly Mature Phase, indicative)
Water – H2O	Water (as a whole molecule) can be used for life support applications. This includes drinking water for astronauts, as well as water consumption for astronauts' daily life in general (hygiene, cooking). Water can also be used for agriculture activities overall and for plants Current experience from the ISS and ground research projects suggests a high level of recycling, and some limited needs for annual resupplies[48]	Low to moderate, depending on population
Oxygen - O	Pure oxygen is used as the oxidizer in many propulsion systems, including launchers, lunar landers and orbital vehicles The constraint is to maintain it as a liquid for the mix in the engines, hence, it requires cryogenic equipment. Oxygen is also used for life support, to resupply breathing air to astronauts Oxygen can be obtained from electrolysis of water	Very large (hundreds to thousands of MT)
Hydrogen - H	Hydrogen is used in cryogenic propulsion systems as the fuel (mixed with oxygen), used in some launchers and potentially in some landers and orbital vehicles Hydrogen can be obtained from electrolysis of water	Moderate to large (few to dozen of MT)
Regolith	Building of infrastructures and facilities on the Moon surface for various purposes: landing pads, roads, radiation shielding, or other facilities for energy production, storage, shelters etc. Depends however on the construction techniques selected, and the role of imported infrastructures	Large to very large (few to hundreds of MT), depending on population
Metals: Fe, Co, Al, Si	Manufacturing of tools and equipment for in-situ needs, for supporting ISRU operations or for other needs from lunar people. Remains, however, vague at the moment, depending on the level of refinement of the metals, and the types of equipment and tools required	Low to moderate (few hundred kg to few MT), depending on population
Pt, Pd, Rh, Ru, Ir, Os	Chemical catalysis is the main driver, in particular for Palladium and Rhodium (80% of the demand) and Platinum to a smaller extent (40%) (commodity chemicals, ammonia oxidation, pharmaceutical chemicals, environmental catalysis or agricultural chemicals). Non-catalytic applications exist for jewelry and industrial usage (chemicals, medical and dental, electronics, glass production).[49]	Moderate (annual global market of around 400 MT)
KREEP	Electronics, clean energy, aerospace, automotive and defense. Manufacturing permanent magnets is the single largest and most important end use for REEs, accounting for 29% of forecasted demand in 2020.	Moderate (variation is observed in individual elemental distribution but lower abundance compared to earth)
3He	3He is already used today, for research in cryogenic research in medical, industrial processes or super/quantum computing. It is also used in particle colliders for subatomic research, and in medical imagery combined with MRI.[50] 3He is also investigated as a fuel for nuclear fusion, although the process is still far from being industrially mature.	Very low

Table 3.10. M7 market segmentation

Market	Application	Market segment
1 - In Space propellant	Fuel for rockets, servicers, landers and rovers	1.1 - Cislunar missions
		1.2 - Lunar surface landers
2 - Life support	Drinking and breathing	2.1 - Lunar space stations
		2.2 - Lunar bases
	Irrigation and food production	2.3 – Agriculture
3 - In-situ manufacturing	Construction and facilities	3.1 – Pure regolith construction
		3.2 – Human facilities and habitats
		3.3 – Other facilities construction (antenna and solar panels mounts, landing pads, roads
	Manufacturing of equipment	3.4 – Tools and machines for resources mining
		3.5 – Equipment for other infrastructures (pipelines, waste, electricity grids, comms networks etc.)
4 - PGMs (on Earth)[51]	PGMs terrestrial applications	4.1 – Catalyst, jewelry, industrial
5 - KREEP (on Earth)	KREEP applications	5.1 – clean energy, aerospace, automotive and defense, electronics, glass production, gunpowder, fertilizers etc.
6 – 3He (on Earth)[52]	Energy research and production	6.1 – Nuclear fusion
		6.2 – Neutron research
	High tech	6.3 – Quantum computing and cryogenic research, medical imagery, security applications

Figure 3.4. Interface between M7 (Mining and resources) and other domains of the lunar economy



3.8 Habitation and Storage

3.8.1. Market Description

Demand for Habitation and Storage on the Moon will be driven by every activity that involves humans on the surface of the Moon and in the Moon's orbit.

We define "habitation" as a pressurized, protected environment on the surface, under the surface, or orbiting the Moon, where people can live and work.

We define "storage" as pressurized and unpressurized enclosed spaces for vehicles, stock of materials necessary for lunar activities and life on the Moon and/or its orbit, and for equipment of a different nature including robotics.

For the purpose of Market 8, excluded from storage is:

1. Fuel storage and fuel station facilities (see MT2 - "Moon Surface Transport")
2. Water storage (see MT5 - "Lunar products and services")

The services provided by this market segment will include:

1. Lease and management of building and orbital stations for commercial, storage and residential use (permanent and medium-term) to private individuals, companies, and government agencies
2. Selling real estate to private individuals, companies, and government agencies
3. Hotel services to people for short and medium stays on the Moon's surface and orbit

It should be noted that this market produces no physical products, as the construction of all facilities including storage is part of the scope of M6 - "Infrastructure, Construction, and Manufacturing".

3.8.2. Early Phase Products and Services

The services that will be in demand in the Early Phase will be:

1. Management of orbital facilities (space stations)
2. Lease of orbital facilities for scientific studies
3. Management of surface facilities, which in this phase will be limited to landers and return vehicles
4. Lease of surface facilities. For example, one business case could be the SpaceX Starship Human Landing System (HLS) version by SpaceX reused after Artemis 3 (Starship departs from the Moon surface, docks to the Orion capsule and transfers the crew, then lands back to the Moon and becomes a base that can be leased to government and commercial entities to host other crews)

Existing plans to reach the Moon with the purpose to orbit and / or land which can plausibly be considered a Habitation or Storage unit by 2030 are listed in Table 3.11.

In this phase, we expect tourism to be just orbital, and not on the Moon's surface. Furthermore, tourism in the Early Phase is considered under M1 if the service happens to be hosted in a vehicle launched from Earth and returning to Earth, and not orbiting the Moon (a Free-Return trajectory).

There are several missions to the Moon planned to happen by the year 2030, but these will not demand services of habitation and storage. The key missions are listed in Table 3.12.

3.8.3. Mature Phase Products and Services

This market relies on the safety and the minimum comfort necessary for accept-

Table 3.11. Mission within the year 2030, with possible demand for services within the MT8 market

Company	Mission Name	Launch date	Description
NASA	Artemis 3	Q3 2025	1st crew to land on the Moon since 1972. Gateway is no longer part of this mission, so the transfer of the crew will be by direct docking between Orion and the Starship lander. In this case, the supplier and the customer are the same entity, NASA. Crew on the surface will be living in the lander.
NASA	Artemis 4	Q3 2026	A 4-person lunar orbit and delivery of Lunar Gateway modules
NASA	Artemis 5	Q2 2027	Lunar landing and delivery on another module of the Lunar Gateway.
NASA	Artemis 6	Q2 2028	tba
NASA	Artemis 7	Q2 2029	tba
NASA	Artemis 8	Q2 2030	tba

Table 3.12. Other mission within the year 2030, not in the scope of MT8

Company	Mission Name	Launch date	Description
Space X	Dear Moon	2023	Orbital Tourism, free-return trajectory, so NO part of the scope of MT8
NASA	Artemis 2	Q2 2024	Crewed test Orion, free-return trajectory, so NO part of the scope of MT8
Roscosmos	/	2029	Orel Spacecraft, Crewed free-return orbit to the Moon, so NO part of the scope of MT8. RSC Energia is manufacturing
Roscosmos	/	2030	Crewed landing. No info about the lander. RSC Energia is manufacturing.

able living conditions of human life on the Moon, where astronauts, workers, researchers, tourists, will stay for prolonged periods of time. In the "Mature Phase", the services provided are expected to expand to surface habitat facilities.

In terms of the services that will be demanded by commercial and government actors, they will be similar, but expanded beyond the previous Early Phase:

- Management of orbital facilities (space stations)
- Lease of orbital facilities for scientific studies, tourism, and prospecting of lunar resources
- Management of surface facilities
- Lease of surface facilities for the purpose of exploration, tourism, scientific studies, and resource utilization operations, including storage of tools and samples

It is expected that habitation in the Mature Phase will also include restaurants, bars, casino, entertainment, leisure facilities (sports, arts), etc. Furthermore, it is possible that specialized storage might be needed for long-term archival purposes.

3.8.4. Revenue Generation

Income to the companies providing services in this market will be generated by:

Leasing out commercial facilities, including laboratories, offices, and manufacturing spaces to companies, private individuals, and government agencies and the outfitting of such facilities.

- Leasing out housing to companies and government agencies for short/medium term space workers
- Renting lunar housing to medium and long-term tenants
- Lease of storage spaces and units to private individuals, companies, and gov-

ernment agencies
- Hotel customers, paying for the room/ unit for short stays
- Sales of real estate, including houses, storage units, hotels, offices, laboratories, and other commercial facilities, limited to installed, fabricated, or excavated facilities excluding surface area
- Fees can be charged to sellers of real estate. For example, if a contractor bought a lunar housing facility x years ago, and now is moving back to Earth or to another orbital facility, they may decide to sell the property in the market. A seller fee can be charged by the Estate Agent, either in a percentage of the value or as a one-off fee

3.8.5. Interdependencies in the Economy

The below table details market interdependencies for M8

3.8.6. Assumptions

Assumptions used to draft the MT8 report are noted in Table 3.14.

Table 3.13. Interdependencies between Market 8 and other markets

#	Market Team	Product or Service Needed or Provided
1	Transportation to/from the Moon	• The stream of people coming from Earth or orbital facilities in the cislunar environment will need a pressurized space to live and work. Inflows of people will need to be subdivided into short stays, medium- and long-term stays. This will need to be coordinated with the supply of hotels and housing on the Moon's Orbit and surface. • In some cases, MT1 Customers will be companies leasing, managing, and selling real estate in our market segment. For example, the company managing a space station or a hotel can purchase transport services to arrange a comprehensive package including transfer to/from Earth for its clients. • Tourists, scientists and generally individuals going to the Moon and back to Earth within a spacecraft without inserting into a stable lunar orbit and/or landing on the Moon's surface (essentially meaning the spacecraft is on a free-return trajectory) are not within the scope of MT8. Such services fall within the scope of MT1.
2	Transportation on the Moon	• Connections between lunar properties and facilities will need to be catered to by Moon surface (and underground) transportation companies or suppliers of vehicles to companies, privates, and government agencies. As for MT1, occasionally, clients of MT2 may be companies leasing, managing, and selling real estate, and arranging for their clients a comprehensive package including transport on the surface of the Moon to/from the property. • MT2 companies may become customers of the MT8 if they require storage for their vehicles.
3	Communication and Navigation	• In the initial phase, there may be a commercial relationship between companies providing and operating the communication and navigation infrastructure and the companies providing Habitation and Storage services. • However, in the mature stage (along with the growth of the industrial stack on the Moon) companies within the scope of the MT5 will become the middlemen between the companies managing the infrastructure and the receivers of the Communication and Navigation services. This would reflect the management structure on Earth, where the company managing the internet cables in the oceans and satellites in orbit are not the same supplying the broadband and GPS service to a private or corporate customer. • MT3 companies may become customers of the MT8 if they require storage for their activities.

#	Market Team	Product or Service Needed or Provided
4	Energy and Power	• All housing and storage units will need power, so effectively a utility supplier will be needed, and the housing and storage market will generate revenue for the supplier. • Again, similarly to interdependencies with MT3, it is likely that a direct commercial relationship is established in the Early Phase of the settlement efforts, and then in the mature stage a company providing energy services with the cooperation of MT5 will be the middleman between the company managing the powerplant and the property management companies. • MT4 companies may become customers of MT8 if they require storage for their activities.
5	Products and Services	• Potentially, a synergy exists between MT4 (energy producer) and MT5 (utility supplier), especially in the later stage. • MT5 will need to manage the supply running water to habitation and potentially to storage as well. In the early stages, every unit may have an individual water source (Closed Loop ELCSS), but in the long term, a centralized water provider may become more profitable/efficient. • MT5 companies may become customers of MT8 if they require storage for their activities.
6	Infrastructure, Construction and Manufacturing	• MT8 will use the products from the construction activities of MT6 to offer services to private, corporate, and governmental actors. MT8 will therefore be a key potential customer of the construction companies listed in MT6. Income for the companies in the MT6 segment can be generated by developers buying facilities of different kinds, or a lease with purchase option, where a property can be leased, with an optional agreed purchase option. • MT6 companies may become customers of MT8 if they require storage for their activities.
7	Mining and Resource Extraction	• MT7 companies may become customers of MT8 if they require storage for their activities.
9	Lunar Agriculture	• The lunar food production system will need to support the population using habitation services and products. Therefore, the level of food production will need to closely follow the market demand for housing and tourism, and probably allow for reserves. • MT9 companies may become customers of MT8 if they require storage for their activities.

Table 3.14. Assumption Table

Assumption	Validation / Rationale
Tourism	In the Early Phase, we consider t ourism to be purely orbital, and not on the Moon's surface. This aligns with the fact that current missions of landing on the Moon are planned by the end of the '20s, so realistically no habitation will be ready by 2030 on the Moon to host tourists.
Habitation	For habitation, we define a pressurized, protected environment on the surface, under the surface, or orbiting the Moon, where people can live and work.
Storage	For storage, we define pressurized and unpressurized enclosed spaces for vehicles, stock of materials necessary for lunar activities and life on the Moon and/or its orbit, and for equipment of different nature including robotics.
Missions data	Mission dates, names, vehicles are correct at the date of issue of this report, but they may change.
Free-Return trajectory	We consider part of the MT8 scope spacecrafts and stations orbiting the Moon with a stable orbit. Spacecrafts launched from Earth and returning to it, with a so-called Fee-Return trajectory, are considered within the scope of the MT1 - inbound and outbound transport services between Earth and Moon.

3.9 Lunar Agriculture

3.9.1. Introduction

Human presence on the Moon and in cislunar space, whether over a short or extended period of time, requires the biological needs of human life to be met. While slightly less pressing than a breathable atmosphere and water, food supply is a vital requirement for any crewed mission with a duration of greater than a few hours. For a permanent human presence outside of Earth's gravity well to be feasible in the long term will require the capability to produce food in-situ. There are assumed to be lunar activities for a sustainable presence being conducted by a diverse array of international operators, including those from the U.S., China, India and Europe. To assist in the planning process, there are some analogs which are a good source of data, including Antarctic settlements, nuclear submarines and space stations, including the ISS. The experiments performed by Wamelink et al, 2014 show that plants are able to germinate and grow in lunar soil simulants for a period of 50 days without any addition of nutrients.

In October 2021, at a forum operated by the National Space Society, Bryce Meyer provided some valuable information on space farming. For instance, the basic nutritional cycle for an average person is an input of 2,000 kcal per day (0.6 Kg dry biomass), 0.8kg of Oxygen and 2.6 Kg water (in drinking and food), with an output of 1.1 Kg of CO2, 2.6 kg water and 0.2 kg solids. In his proposed space farm, Meyer proposed providing the food inputs from a variety of plants (Arugula, roots, rice, pinto bean, tomatoes) and fish in the form of tilapia and silver carp, and shrimp. He also pointed out that insects are a more volume-efficient source. In addition, he advocated adding a wide variety of herbs and spices to the diet. In the case of the animals, he pointed out that it would take a very large settlement for large animals to make sense; and rodents would be a better initial source of proteins than big animals. In the case of big animals, they should initially be used for milk. He developed a varied-diet menu that might eventually be possible on the Moon, with the following logistics, assuming a settlement of 100 people:

1. Live mass in farm per settler 266Kg
2. Surface area 7 hectares

Space Resources and Space Settlements (NASA SP-428, 1979) provides the following metrics for a human space settlement.

- Food per person:
  - Natural – 2.245 kg
  - Dry – 1.238 kg
  - Freeze-dried – 1.308 kg
- Community area and volume per person
  - Plant growth – 44 m2, 660 m3
  - Animal area – 5 m2, 75 m3
  - Food processing – 4 m2, 60 m3
  - Agriculture drying – 8 m2, 120 m3

3.9.2. Market Definition

Lunar agriculture is defined as productive activities undertaken using living things (plants, animals, cells etc.) on the lunar surface or in cislunar space , primarily focused on (but not limited to) the provision of food / nutrition for humans. It is the science or practice of farming, including cultivation of the soil for the growing of crops and the rearing of animals to provide food, wool, and other products.

This definition is applicable primarily to the Mature Phase. Due to lack of data, most Early Phase activities will center on experimental modules similar to those on space stations such as the ISS.

3.9.3. Early Phase Products and Services

Lunar agriculture activities in the Early Phase are primarily those undertaken on scientific research modules. A lack of permanent human presence on the Moon in this phase precludes the need for in-situ food production, as short-duration sorties are expected to bring all required foodstuffs with them from Earth.

Research activities will be focused around testing suitability, scalability and proof-of-concepts. Tailoring of crop varieties for use in space will be a key activity in this phase. Examples of these experiments include NASA's Veggie program currently operating on the ISS.

Possible (minimal) space tourism-related revenue is a possibility from Lunar Gateway if any dockings are planned (If food from experimental modules, if any such modules are indeed part of the planned Lunar Gateway, is sold to the tourists).

3.9.4. Mature Phase Products and Services

Demand for lunar agriculture products and services is assumed to be almost exclusively in the Mature Phase, with permanent human presence being a prerequisite for demand for in-situ food production.

It is anticipated that there will be food provisions for lunar inhabitants, both on the lunar surface and in lunar orbit, of four types:

1. Vegetables, produced by both hydroponics and more traditional forms of agriculture (plant growth)
2. Animal husbandry – providing supplies of milk, eggs and meat (dairy, beef & small animals)
3. Fish farming – for supplies of protein; and (aquatics)
4. Insects

In each of these categories, it is necessary to understand how to optimize the calorie content for the growing number of lunar inhabitants, and to assess the needs in terms of infrastructure to be able to provide the food. We need to derive an understanding of the power requirements, particularly during the lunar night, the water needs and the acres needed. Furthermore, the planning must take account of what knowledge exists about growing plants and animals (including fish) in low-g situations. For instance, the French Research Institute for Exploitation of the Sea has been working to design a lunar fish farm, and has found that seabass might be a good potential choice for lunar seafood, but are also considering invertebrates, such as mussels and shrimp for that purpose.

Customers for lunar agriculture are assumed to be primarily on the lunar surface and in cislunar space. It may also be cost effective to export food to LEO installations as opposed to shipping it from the earth's surface (Delta-v of 6.29km/s from the lunar surface -> LEO vs 9.53 km/s Earth -> LEO delta-v) and possibly a small volume of luxury/exotic produce to the earth market for its novelty value.

Products of lunar agriculture are nutrition in the form of RDI units (Required Daily Intake). These products provide the required daily intake of nutrition for humans in Cislunar space, with demand expected to scale linearly with the population of cislunar space for any given day.

Services provided by lunar agriculture (when taken as part of a Bio-regenerative Life Support System, or BLSS, in a crewed habitat) include cycling carbon dioxide into oxygen, treatment of waste/gray water, disposal and the recycling of waste biomass into edible food.

3.9.5. Revenue Generation

While the provision of nutrition is primarily concerned with providing sufficient energy in the form of calorie count, dietary sources must also provide sufficient nutrients and vitamins for the long-term wellbeing of lunar inhabitants. This cannot be all provided by one calorie-dense product or monoculture: it must be obtained from a balanced diet containing sufficient amounts of proteins and fats to ensure human wellbeing. This rules out use of an intensive mono-culture of one crop / food production method.

Price per calorie as a unit food intake has been suggested as the basis for calculating needs and revenues. As this does not account for other dietary requirements such as those of macro & micro-nutrients, it is worth looking into use of a Unit of RDI (Recommended Daily Intake) i.e., One person's recommended intake per day based on the WHO and FAO's reports on RDI. One Unit RDI would therefore correspond to the full nutritional requirements for one person for one day. One RDI is between 0.8 and 1.23 kg of dry food per person or up to 2.245 kg natural food per person.

Total revenue is based on demand for the products and services provided by a BLSS. The majority will come from the sale of produce, the demand for which is expected to scale almost linearly with lunar population. A demand of one RDI unit per person per day can be assumed, averaged according to the male/female population ratio (differing nutritional requirements between sexes). Annual requirements are then simply a matter of multiplying the sum of RDI units consumed by their price point.

Service based revenue can also be expected if the BLSS contributes to habitat life support. Prices per unit of each of the outputs need to be determined via correspondence with other MTs based on interdependencies.

3.9.6. Market Group Interdependencies

Table 3.15. lays out primary market interdependencies.

3.9.7. Assumptions

Food, as well as oxygen and potable water, can be either imported from Earth or be produced on the Moon (or in cislunar space) it-

Figure 3.5. Market driver tree for food demand

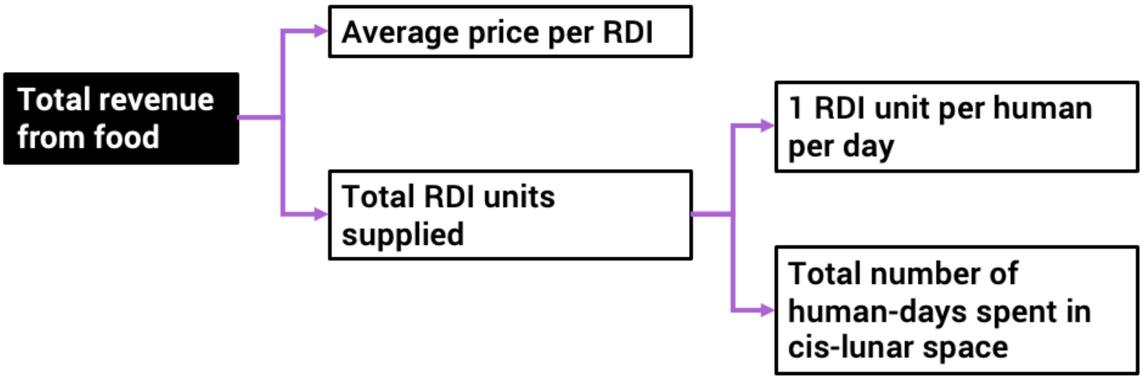


Figure 3.6. Basic example of a BLSS from SSP SH 2020 report on lunar agriculture

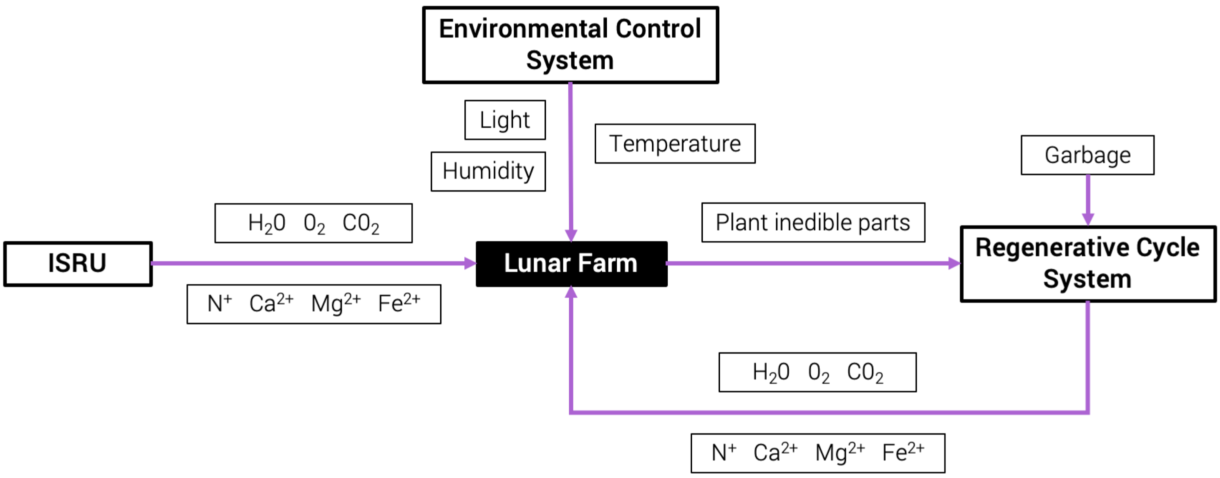


Table 3.15. Interdependencies between Market 9 and other markets

#	Market Team	Product or Service Needed or Provided
1	Transportation to/from the Moon	Responsible for supplying initial pre-requisites such as seed stock etc., from Earth.
2	Transportation on the Moon	Logistical transport provision
3	Communication and Navigation	Communications for agricultural facilities
4	Energy and Power	Supply inputs needed for MT9's ongoing operations
5	Products and Services	Primary interdependency is with MT5, specifically segments 5-c & 5-d: • Segment 5-c: Operation of Depot for Supply of Water, Oxygen, Hydrogen, and Nitrogen • Segment 5-d: Miscellaneous Emergency, Medical, Recycling and Provisions
6	Infrastructure, Construction and Manufacturing	Responsible for supplying initial infrastructure
7	Mining and Resource Extraction	Supply inputs needed for MT9's ongoing operations
8	Habitation and Storage	Key demand driver

self. While import of food makes sense for short-duration stays (and Early-Stage activities), the logistical requirements of feeding a permanent human population with imported produce will quickly become uneconomical compared to developing in-situ production capacity.

Given the assumption of a permanent human presence, food production as part of a BLSS means the productive activities of lunar agriculture will be intertwined with (and indeed a key part of) the life support system for any inhabited base. The focus of providing nutrients to humans is therefore intertwined with the recycling of oxygen, water & carbon.

It can be assumed that even an efficient BLSS will not be fully self-contained & will require inputs in the form of top-ups of elements in circulation, to be either supplied from earth or by lunar ISRU.

Early Phase

- Minimal human presence on Moon and in cislunar space
- Lunar Gateway in operation - 4 people up to 105 days (reference Artemis Program Design Reference Missions), some transitory activity. No permanent human presence on lunar surface. 2 to 4 astronauts on the lunar surface for up to 31.8 days.
- Most food will be brought with astronauts from earth
- Agriculture activities focuses around testing suitability, scalability and proof-of-concepts
- Commercial activities such as space tourism will bring all their food with them
- Any food produced will have national astronauts as the only likely customer
- No permanently occupied facilities in Early Phase (facilities may be permanent, i.e., long-lived and reusable)
- Only solar and fuel cells for power generation

Mature Phase

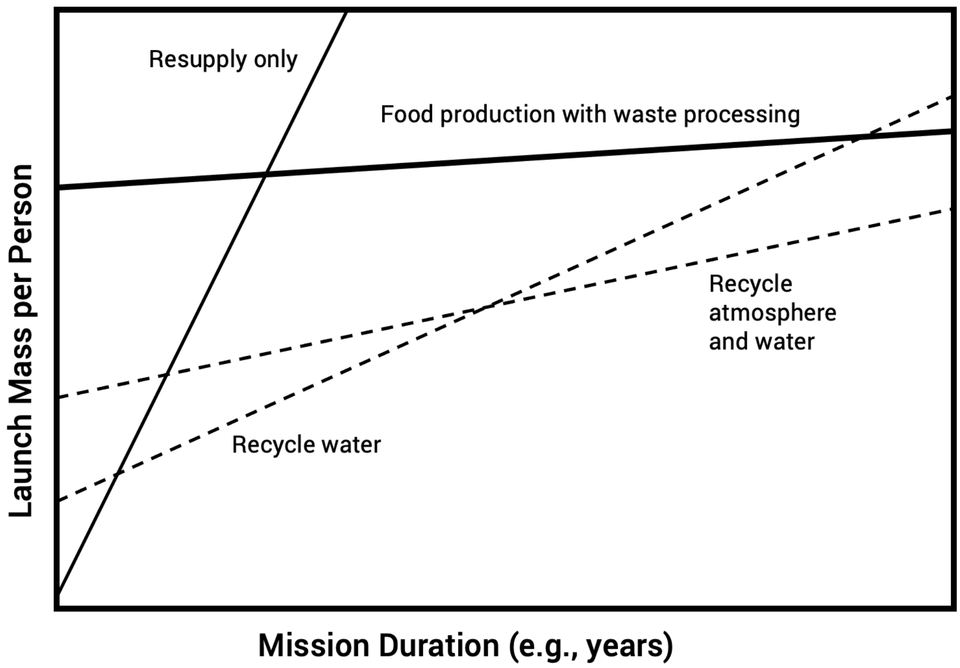
- Mature phase lunar agriculture will be part of a bio-regenerative life support system (BLSS), recycling carbon & water as well as producing oxygen
- Permanent human presence on lunar surface, in cislunar space and LEO + GEO

- Human presence will be sustained by the Moon's resources, and not dependent on a logistical supply chain of life-sustaining deliveries from the Earth. Recurring deliveries of inputs from earth should be minimized
- Experimental solar and nuclear power. Assume freely available energy
- Lunar surface permanent residents may be between 10 on the low end and as high as 200 on the high end.

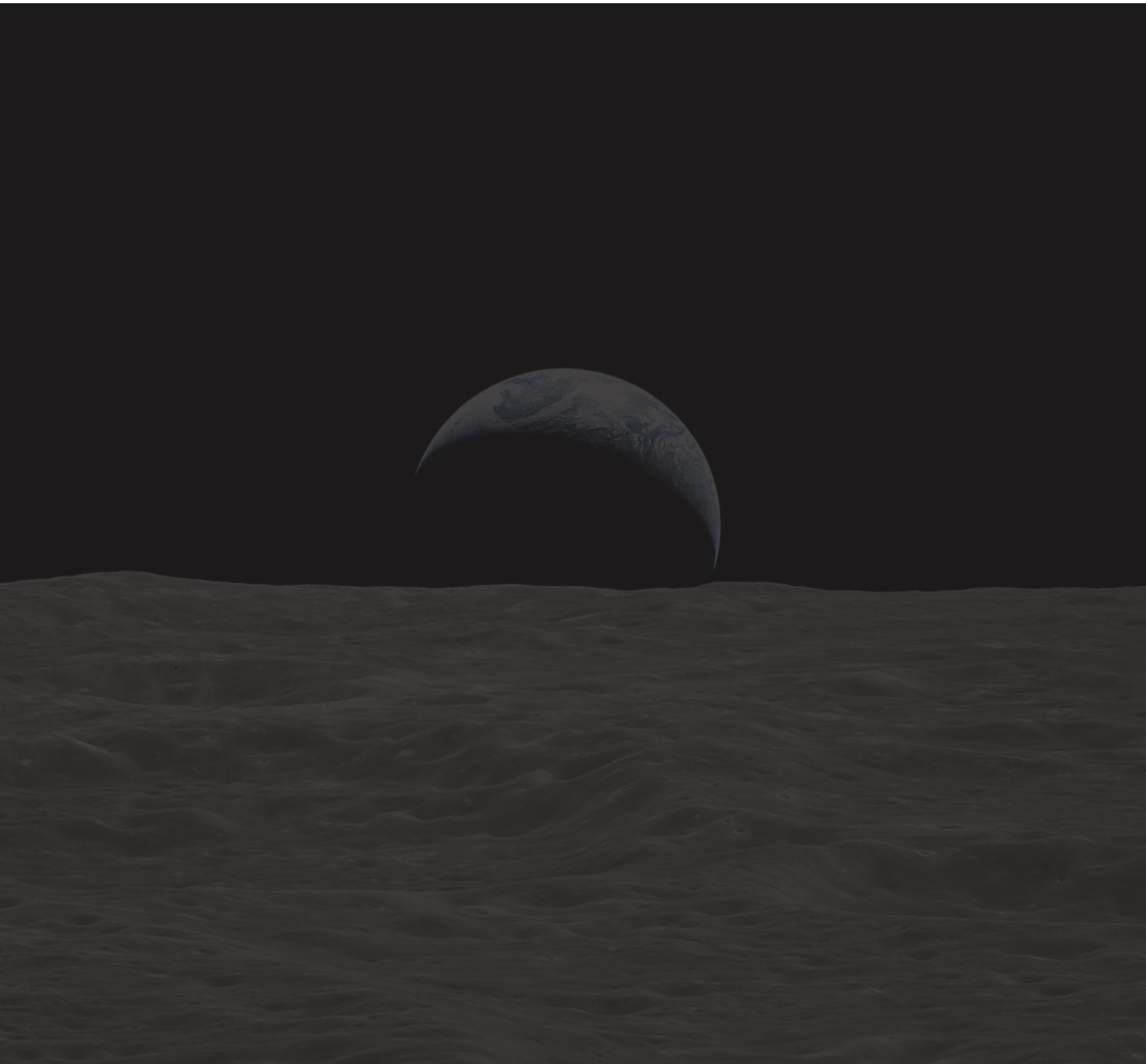
Further Assumptions:

- Assumptions: 98% water recycle and 100% oxygen recycle with perhaps 1% loss for each
- Food and water transported to Gateway from the Earth or Moon in the Mature Phase has the same value as cargo from the Earth to Gateway: 630 to 20,786 $/kg. If the Moon can't meet or beat that price, then it comes from the Earth.
- Food revenue on the lunar surface in the Early Phase is: 2,030 to 106,263 $/kg
- Food Production has transportation (to the Moon and on the Moon) between the Earth and Food production in the value chain.
- Food processing, distribution and preparation are between Food Production and the consumer.
- Surface transport is between the consumer and Bio-regenerative life support system.
- Bio-regenerative life support feeds back to Food Production

Figure 3.7. Illustration of principles involved in determining mission duration at which recycling is economically beneficial Adapted from Bonting (1999)



4. Customers



4.1 Transportation To and From the Moon

4.1.1.Customer Segments

Market 1, Transportation to/from the Moon and Lunar Vicinity, has defined two customer tiers. Tier 1 customers need transportation to pursue science, space exploration, and national security investigations and commercial venture development. Tier 2 customers, LCE WG Markets 2 through 9, are lunar service providers to Tier 1 customers and Market 1 (Figure 4.1.).

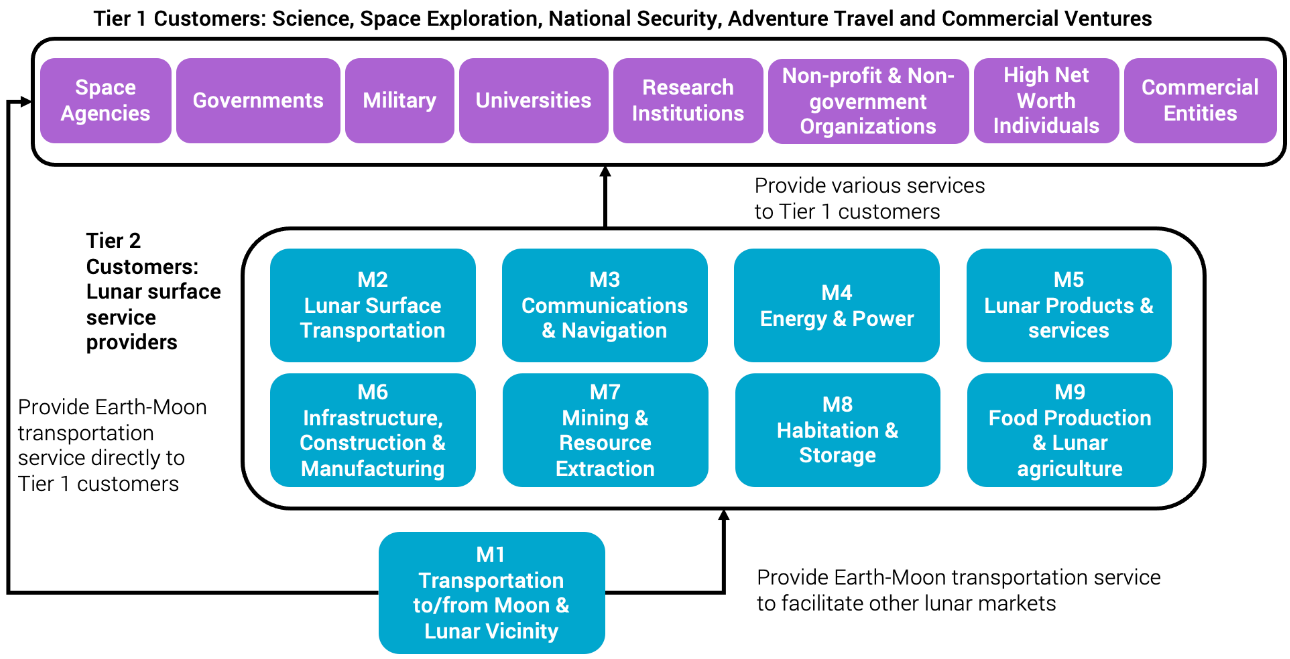
4.1.2. Early Phase

Potential Early Phase customers are primarily Tier 1 entities with some Tier 2 entities emerging in response to space agencies moving from system procurements to service procurements. Tier 2 customers provide services to Tier 1 customers using equipment transported to the Moon.

Tier 1 customers are subdivided into eight segments: space agencies, governments, military, research institutions, universities, non-profit organizations (NPO), high-net-worth individuals and commercial enterprises. Space agencies, governments and military are fully supported by national space budgets. Research institutions, universities and non-profit organizations received funding from national budgets and donations. Commercial entity funding comes from debt, equity and national budgets. From the Addendum, we note that lunar space tourism will contribute between 5 and 130 tourists per year into lunar orbit, with associated cargo. This will take place in both the Early and Mature Phases, with the uncertainty being a consequence of the range of possible pricing. In the Mature Phase, there will be an additional 1 to 10 lunar surface tourists each month, staying for an assumed 2-week period.

Tier 2 customers come from a few of the eight other Markets defined by the Lunar Commerce and Economics Working Group. NASA's Lunar Terrain Vehicle service for the

Figure 4.1. Potential Market 1 customers include science, space exploration, national security and commercial entities (Tier 1) as well as lunar surface service providers to Tier 1 customers (Tier 2).



Artemis Base Camp is an example Tier 2. customer,[53] Lunar Surface Transportation, providing an unpressurized rover for astronaut and autonomous transportation service to space agencies (a Tier 1 customer). The Lunar Terrain Vehicle launch is targeted for 2027. Other Tier 2 customers may emerge from Communications & Navigation (M3), Energy & Power (M4), Mining & Resource Extraction (M7) and Habitation & Storage (M8).

4.1.3. Mature Phase

Mature Phase Tier 1 customer segments are the same as in the Early Phase while Tier 2 customers will come from all the other defined Markets. Demand from each segment will be higher in the Mature Phase than in the Early Phase.

4.1.4. Commercialization Plan

Current launch licensing policies and practices are sufficient for Market 1 activities during the Early Phase. There may be a need for space traffic management policies and procedures prior to the Mature Phase due to the expected increase in transportation demand and providers.

Additional clarification and international agreements may be necessary before M7, Mining & Resource Extraction, can move beyond the demonstration phase to establish sufficient capacity to support permanent lunar communities and propellant requirements for transportation from the Moon during the Mature Phase.

4.2 Transportation On the Lunar Surface

M2 customers can, on a high level, be segmented by the products they are purchasing (see 5. Suppliers). These product groups are, on a high level:

- Robotic surface transportation
- Crewed surface transportation
- Spacesuits

4.2.1. Customer Segments

While there is considerable overlap between the organizational customers that will be procuring services within each of these product groups, each also sports unique customer segments. These customer segments are as follows:

Robotic surface transportation

- Space agencies e.g., NASA, ESA, AfSA, etc.
- Academic and research institutions
- NGOs
- Lunar service providers (M5), who may utilize robotic surface transportation for logistical purposes to transport goods
- Lunar construction and manufacturing companies (M6), who, similarly, may use robotic transportation services for logistical purposes to transport raw materials for construction
- Lunar resource extraction companies (M7), who may utilize robotic transportation services to deliver end-products to customers or launch pads
- Lunar agriculture (M9), whose suppliers may utilize transportation services to deliver centrally produced foodstuffs to customers

Crewed surface transportation

- Space agency astronauts
- Lunar services crew and contractors (M5), who may require surface transportation to service assets or move between bases
- Lunar tourists

Spacesuits

- Space agency astronauts
- Lunar services crew and contractors (M5)
- Lunar tourists. The Addendum provides the information that, during the Mature Phase there may be between 1 and 10 lunar surface tourists, each month, and a proportion of them will be customers for crewed rover missions to tourist sites.

4.2.2. Commercialization Plan

The lunar surface transportation market is expected to be commercially functional from the Early Phase, with commercial customers already confirmed for several existing robotic transportation service providers.

However, for the scaling necessary to reach the Mature Phase to occur, several conditions may need to be met. Most prominent may be governance conditions, specifically a lunar surface traffic management framework that allows for increased traffic in dense activity areas without harmful interference. This will likely require both traffic management protocols specific to actor-specific spheres of operation (traffic management for multiple assets from the same operator) and between disparate actors in areas that see considerable multi-actor activities (traffic management for inter-actor coordination). Related to this development condition, infrastructure for seamless navigation will also become more necessary, making transport infrastructure provided by M7 a soft requirement for expanded commercial activities in the Mature Phase.

As the range and load requirements of vehicles increase in the Mature Phase, the requirement for a functional energy and resources market may also become more pressing. Therefore, further commercial expansion within M2 is likely dependent on developments in tandem within M4 and M7.

4.3 Communications and Navigation

This section of the report provides a description of the different customer segments, types, and profiles that are relevant to the Communication and Navigation market along with an accompanying justification as to their roles in both the Early and Mature Phases.

4.3.1. Overview of Customer Segments

There are a wide variety of different customer segments that are relevant to this market across both the early and Mature Phases. In broad terms, the market includes segments such as Space Agencies, National Militaries, Universities, Research Institutes, NPOs, and Private Companies, each with a different budget, frequency of mission, and requirements as seen in the top-level customer segmentation mapping seen in Figure 4.2.

4.3.2. Customer Profiles

This section dives further into the specific profile of each type of expected customer for both the Communications and the Navigation sector.

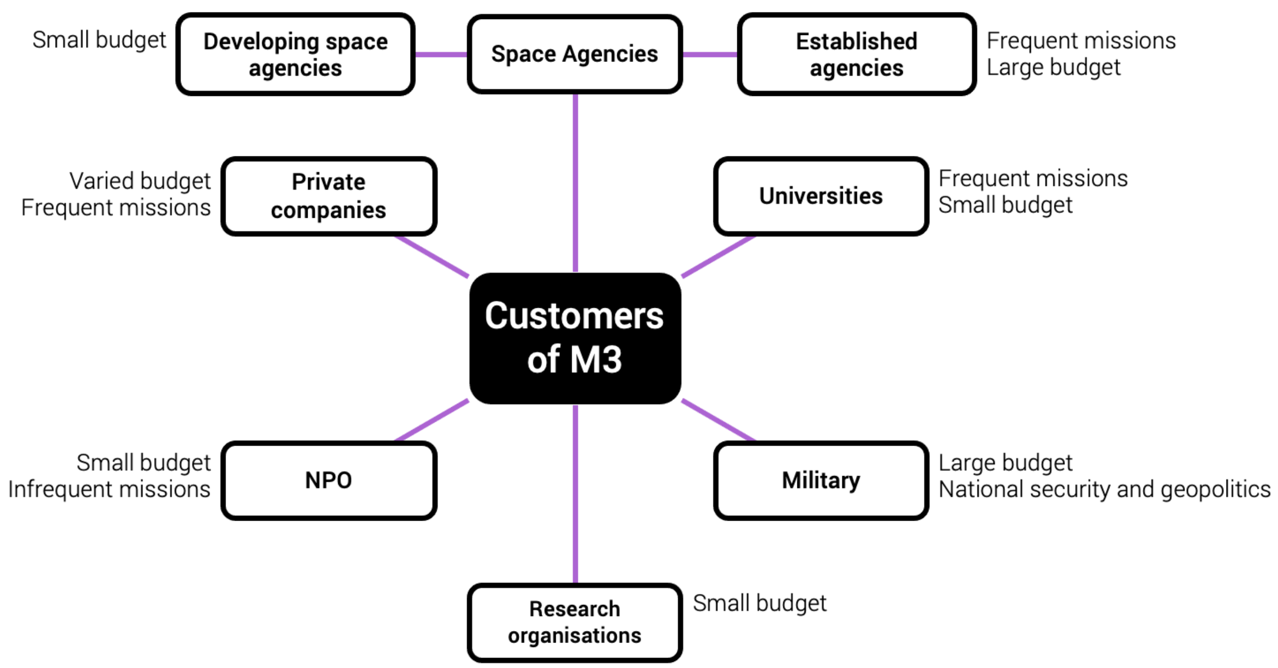
4.3.2.1. Space Agencies

Government organizations are actively investing in cislunar and lunar communications platforms like designing and building communication satellites for Earth-Moon-based communications. These organizations could be divided into the established players and upcoming players.

Established players stand for agencies with a long history of missions and experience in the field. Some of these are:

- NASA (National Aeronautics and Space Administration).
- ESA (European Space Agency).
- JAXA (Japan Aerospace Exploration Agency).
- CNSA (China National Space Administration).
- Roscosmos, Russia.
- Canadian Space Agency (CSA)

Figure 4.2. Future Lunar Communications Customer Segments



Upcoming players are relatively new agencies collaborating in different missions and expanding their knowledge by partnering with other actors, being public and private. No fewer than 13 countries have established new space agencies in just the past decade with the purpose of filling niches in which NASA and other agencies are not active. These agencies are partnering with the commercial sector and other public institutions to expand their activities in the space economy. Some examples are:

- LSA (Luxembourg Space Agency).
- UAESA (United Arab Emirates Space Agency).
- PhilSA (Philippine Space Agency).
- NZSA (New Zealand Space Agency).
- ASA (Australian Space Agency).

Due to large budgets foreseen for the upcoming years, it is expected a high frequency in the missions aimed at extending the use of lunar resources. Its role will be of utmost importance in both Early and Mature Phases.

4.3.2.3. Defence Entities

Defense agencies are in charge of critical systems for the nations' security. Systems such as navigation and communications will be crucial for these types of organizations.

Military demand is expected to start in the Early Phase and continue in the Mature Phase, driven by increased interest in cislunar space. Owing to high budgets, the frequency of defense missions is expected to be high.

4.3.2.4. Private Companies

The surge of new space has increased the number of private companies focused on space-related activities. Private companies will be one of the key components for lunar and cislunar development. Importantly, other markets of the lunar economy, such as the lunar mining industry, tourism and lunar exploration will be primary customers for communications and navigation services, increasing the demand and the attention for private companies to focus on this specific sector.

Commercial companies are already coordinating with national agencies, establishing plans for the Early Phase. For example, commercial space companies, such as the ones active through NASA's Commercial Lunar Payload Services and Lunar Catalyst program may act as both future commercial customers and suppliers of communications and navigation services:

- Astrobotic Technologies
- Blue Origin
- Ceres Robotics
- Deep Space Systems
- Draper
- Firefly Aerospace
- Intuitive Machines
- Lockheed Martin
- Masten Space Systems
- Moon Express
- Orbit Beyond
- Sierra Nevada Corporation
- SpaceX
- Tyvak Nano-Satellite Systems

On the grounds that private companies will be supported by governments and space agencies, the frequency foreseen for their missions is very high, along with their budget.

The Addendum provides data on the numbers of lunar surface tourists during the Mature Phase residing on the surface at any one time. These lunar surface tourists will be demanding customers for communications including IT and high-speed Internet capability.

4.3.2.5. Universities and Research Institutes

Universities are one of the key actors for the continuous innovation that the space sector requires.

The missions conducted by universities do not tend to dispose of a large budget, but the number of missions driven by this type of organization along with the frequency of these missions is expected to grow in the future as barriers to entry are reduced.

4.3.3. Commercialization Plan

Generally, the space industry has experienced a great evolution throughout the last decades, opening the lunar activities market not only to government agencies but also to private companies and organizations, democratizing the access to space and lowering the barriers to entry to different subsectors. This trend is predicted to be maintained, affecting the Navigation and Communications sector and the players and products involved. It will require a robust commercialization plan for both the early and mature market phases and will contribute to the following objectives;

- Creation of new markets, products and services
- Customer segmentation and value definition
- Reduction of time to market and market de-risking of new lunar communication and navigation product and services
- TRL maturation

During the Early Phase the focus of the commercialization strategy will be on the

- Creation of first-time markets, customer segmentation and value definition
- Commercial end-user requirements mapping and first-time technology demonstrations with first-time commercial customers
- TRL of the product/services maturation

While, during the Mature Phase the focus of the commercialization strategy will be on the:

- Reduction of time to market and market de-risking of new lunar communication and navigation product and services
- Scalability of the communications/navigation products and services

The set of activities required to start this phase involves different products and services that will be focused on improving the reliability of the communication and navigation systems. Apart from the regulatory measures that are required to make this market more mature and attractive for the institutional and private investors, an increase in competition between the communication and navigation service providers is expected. A surge in the set of products, services and innovative technologies is expected in order to move forward to the Mature Phase, as well as improvements regarding the coverage, availability and performance in the Navigation and Communications services.

4.4 Energy and Power

4.4.1. Introduction

As discussed in Chapter A, the Market of Energy and Power is broken down into 4 main categories, based on its location in the supply chain:

- Power Generation
- Power Transmission
- Power Distribution
- Power Storage

For the purpose of this chapter, a consolidated viewpoint including all categories is more relevant as most of the customers and supply-chain, for each category, will follow an identically mapped path towards full-realization of their potential value. We examined how the existing, Earth-based supply chains for the power industries functions and developed a path considering roadblocks associated with regulations, legal policies, commercially viability, and maintaining sovereign interests. This is less relevant for the Early Phase where such roadblocks are comparatively less intrusive as each mission will predominantly include its own power system that encompasses all four categories.

However, in the Mature Phase, the supply chain becomes more complicated, and requires a stepwise, methodical, and well-thought-out commercialization plan. It is obvious that several space agencies, government organizations, and commercial companies will be the end-customers for the power systems. However, before the generated power reaches the end-user, it goes through several 'bodies' in the supply chain to reach a maximum and optimum value-added end-product. For the scope of this chapter, we focus on examining the necessary bodies that need to be in place for lunar commercialization of the market. The proposed viable path and the necessary bodies are discussed in this chapter

4.4.2. Commercialization Plan & Customers

Space practitioners and analysts when considering the Moon and the cislunar marketplace have primarily focused on studies about a commodity transaction for space and energy sources. In particular, the Colorado School of Mines and several private companies have argued for the use of propellant and the requirement to purchase propellant as a starting point for creating commercial customers. The bottom line is that considering energy as a commodity is pragmatic, and has to first be fully recognized by the terrestrial organizations like the International Monetary Fund (IMF) and the World Trade Organization (WTO).

Recognizing energy as a commodity will necessitate two foundational blocks or main customers that will control and regulate the overall power market:

- Governing Body or Council - a governing body has to be formed that regulates and maintains every aspect of lunar commercialization. For this draft, it is postulated that the governing body will essentially work with brokerages to create demand and control how business is carried on the Moon.
- Brokerage Firms - Energy as a commodity necessitates a level of brokerages capable of representing, investing, and liquidating from the potential energy systems placed into operation on the Moon, and if delivered - on the Earth as well. The regulations and standards for such brokerage firms to operate need to be perfected to ascertain public confidence.

The above two building blocks will be supported by several other sub-contracts that, in turn, will be Tier-1 customers for the building blocks and, by extension, customers for the power market. These include:

- Legal and Consulting Firms - Space law and policy is a critical aspect of space commercialization, not just for Earth orbits, but also for Lunar and solar-system exploration. Currently, some may argue that the issue of space debris in the LEO could have been curbed by an order of magnitude if proper regulations were in place for all payloads and associated equipment sent into space. An understanding of space law and policy is now for any company in the space industry intending to derive value off-world. Currently, a few large consulting firms, and many boutiques, provide management consulting services in the space industry. However, there are few dedicated to the Moon in a manner that can address financial, corporate, and transactional consulting requirements, and greater service availability could benefit businesses going to the Moon.
- Utility Providers - These are the final piece of the puzzle before the end-user receives power. They are the customers interested in regulating pricing, conducting technological and monetary assessments, and managing growth, alongside consulting firms and brokerages. Utility companies around the world have become a lucrative customer for expanding business lines and relying on local, regional, and national relationships to increase revenues. Once the power market is fully established, utility and supplier partnerships will be the biggest contributor to the overall portfolio of the Energy and Power market.

The utility providers shall directly interact with the end-customer. Note that for each of the other markets, there shall be associated partners that will be customers for the power industry. These include four main categories:

- Space Agencies - e.g., NASA, ESA, JAXA, CNSA, Roscosmos, CSA, ISRO.
- Federal Agencies - e.g., DOE
- Educational and Research Organizations - e.g., Idaho National Laboratory, Canadian National Laboratories, University of Toronto.
- Private Companies - e.g., SpaceX, BWXT, Blue Origin, General Atomics, Lockheed Martin, Astrobotic, Eternal Light, Axiom, ispace

4.5 Supplies and Services

As noted earlier, for the special case of MT5, more detail is provided than is currently capable of being quantified.

4.5.1. Segment 5-a: Launchpads Operations and Maintenance

In the Early Phase, each mission operates autonomously with governments as umbrella customers in broad terms even when private sector operators are largely involved. However, there is already an emerging market for tourism in lunar orbit. The customers for these Early Phase pads are represented by the 'Transportation Providers' as detailed in Figure 4.1. of the Market 1 'Transportation to/from the Moon' Value Chain analysis.

The Mature Phase sees a fully regulated Moon Port infrastructure steady state. The market structure does not change although 'Transportation Providers' may see new actors appear:

All entities known as of 2021-2022:

- NASA
- ESA
- Roscosmos
- CNAS
- JAXA
- ISRO
- CLPS providers
- LETS providers
- ULA
- Blue Origin
- SpaceX
- CSDC
- Ariane Space

4.5.2. Segment 5-b: Roadways Operations and Maintenance

The Mature Phase sees fully regulated routes as part of a regulated Moon Traffic Management steady state. The market structure may not change much, although 'Moon Surface Transportation Providers' may see new actors appear in the Mature Phase.

4.5.3. Segment 5-c: Operation of Depot for Supply of Water, Oxygen, Hydrogen, and Nitrogen

This segment addresses two distinct markets: propellant use, life support.

4.5.3.1. Market Propellant Use:

This market's products consists of Liquid Hydrogen and Liquid Oxygen Cryogenic Propellant. The market addressed inscribes itself into the value Chain of Market Team 1 'Transportation to/from the Moon' i.e., Propellant Providers.

In both the Early and Mature Phase, Propellant Providers are identified as below:

- Earth transporters
- ULA
- CSDC
- TransAstra

4.5.3.2. Life Support

Life Support addresses the following sub-markets

- Human Life Support i.e. non-toxic drinkable water and non-toxic breathable air (Oxygen, Nitrogen)
- Agricultural Life Support i.e. non-toxic water for irrigation, breathing and feed media

In the Early Phase no independent facility is assumed. Each mission brings their own Life Support capacities including what they need to conduct experiments on agriculture and food production.

In the Mature Phase, there is a fully deployed human, animal, and vegetal ecosystem to support, on the surface of the Moon but also in its orbit and in cislunar space.

4.5.4. Segment 5-d: Miscellaneous Emergency, Medical, Recycling and Provisions

Potential customers of the below systems and services include but are not limited to:

- Space agencies e.g., NASA, ESA, Roscosmos
- Industry research organizations
- SpaceX
- Blue Origin

4.5.4.1. Sub-segment 5-d-1: Emergency/Fire/Rescue Services

Customers in this segment for both the Early and Mature Phase will likely want:

- Equipment for Emergency/Fire/Rescue
- Specification/design/development/test services for hardware and software systems imbedded in a vessel's design
- Emergency/Fire/Rescue process design and development

For the Early Phase, these systems will exist onboard vessels traversing cislunar space and will include equipment that is part of the vessel design (e.g. gas or foam dispensers) or are ancillary equipment (e.g. fire extinguishers). They will be designed specifically for a given vessel and are likely a one-off design.

During the Mature Phase, Emergency/Fire/Rescue (E/F/R) systems will be included as part of a facility's design and will also include ancillary equipment.

4.5.4.2. Sub-segment 5-d-2: Medical/Health/Hyperbaric/Centrifuge facilities (and services)

In the Early Phase, no independent facilities exist. Demand is created by missions' human crews and emerging tourism, incorporating equipment and processes already onboard the spacecraft, including for crew or passenger death.

In the Mature Phase, we may base activity assumptions on an analog equivalent of a military hospital unit, spaceflight training center, or space station health, maintenance, and routine section.

Medical/Health/Hyperbaric/Centrifuge facilities and capabilities could be employed to support activities such as:

- Medical research
- Variable gravity medical treatment
- Testbed for Mars systems
- Space tourism
- Exploration
- Military activities
- Lunar commercial activities

4.5.4.3. Sub-segment 5-d-3: Non-Nuclear Waste Processing/ Recycling

In the Early Phase, no independent facilities exist.

In the Mature Phase, we may base demand assumptions on analog equivalent of waste production. Currently, "…waste disposal methods on the International Space Station rely on astronauts manually processing trash by placing it into bags then loading it onto a designated vehicle for short term storage, which depending on the craft, returns the trash to Earth or burns up in the atmosphere. This disposal method will not be available for missions beyond low-Earth orbit."

4.5.4.4. Sub-segment 5-d-4: General Provision Stores, Maintenance, and Repair (GPS/M/R)

In the Early Phase, no independent facilities exist. Demand is created by missions' human crews and emerging tourism. In the Mature Phase, we may base demand assumptions on analog equivalent of provisions.

4.5.5. Segment 5-e: Data, Fintech, Governance includes 3 sub-segments

4.5.5.1. Sub-segment 5-e-1: Data

Demand for data is understood as both demand for activity and demand for supporting infrastructure, primarily information systems.

In the Early Phase, no independent facilities are assumed. In the Mature Phase, there is a fully fledged ecosystem of data aligned with the amplitude and requirements of a steady state of lunar and cislunar socio-economic development: SRU activities, transactions, security, and sustainability.

4.5.5.2. Sub-segment 5-e-2: Fintech

Demand for fintech is understood as both demand for activity and demand for supporting infrastructure, primarily information systems. Fintech consists primarily of banking services, and lunar currency management if relevant.

In the Early Phase, there is no market for Moon-based financial transactions nor money settlement. Likely beyond the Mature Phase, the lunar economy may be able to function as an 8th Continent economy that is resources and logistics oriented.

4.5.5.3. Sub-segment 5-e-3: Governance

Demand for governance is understood as both demand for activity and demand for supporting infrastructure, primarily information systems This sub-segment may be further split along 4 categories of activity.

Category 5-e-3-i: Central Moon Port administration

In the Early Phase, no independent facilities are assumed. In the Mature Phase, governance is aligned on an administrative and economic model of a fully regulated Port Authority: an international Public Private Partnership (PPP) for a fully-fledged Moon Port (with its cislunar nodes), which should be reflected in its information system as well. Customers are the transportation providers ecosystem.

Category 5-e-3-ii: Environmental and Nuclear protection, Nuclear Waste Treatment

In the Early Phase, no independent facility is assumed. In the Mature Phase, environmental protection is fully regulated, and involves all socio-economic actors. This potentially indicates a role for a PPP structure.

Category 5-e-3-iii: Moon Traffic Management, Registry, Interference Zoning, Damage Assessment, Policing, Mobile Units for Incident Monitoring

In the Early Phase, no independent facility is assumed. In the Mature Phase, the governance is aligned on an administrative and economic model of a fully regulated Moon Traffic Management Authority. It may oper-

Table 4.1. Data customers

Data Customers	Data Types
Early Phase	
National governments (including federal agencies with investment arms) financial institutions, commercial providers of space products and services, commercial companies looking to expand into cislunar and lunar markets, investors, universities, research organizations	• Lunar Scientific Data: composition, geology, history of the moon, location of various natural resources • Cislunar Economic Data: Economic Activity Indicators, Jobs & Income, Wealth & Savings, Taxes, Trade • Information about current and future projected cislunar and lunar activities across the commercial and scientific spectrum
Mature Phase	
National governments (including federal agencies with investment arms) financial institutions, commercial providers of space products and services, commercial companies looking to expand into cislunar and lunar markets, investors, universities, research organizations, lunar based entities	• Lunar Scientific Data: composition, geology, history of the moon, location of various natural resources • Cislunar Economic Data: Economic Activity Indicators, Jobs & Income, Wealth & Savings, Taxes, Trade • Information about current and future projected cislunar and lunar activities across the commercial and scientific spectrum

Table 4.2. Financial services customers

Financial Services Customers	Financial Services
Early Phase	
National governments that are business investment leaders: U.S., Britain, Germany, Japan, China, India, etc., investors, financial institutions, banks, companies seeking investment (startups or established), commercial companies that package and sell data on cislunar and lunar activities, law firms, accountants, consultants	• Information for economic development and investment for cislunar and lunar businesses and activities (using the data types discussed in the Data section) • Information analysis and packaging for investment purposes
Mature Phase	
Investors, financial institutions, banks, companies seeking investment, trading exchanges, institutional investors, commercial companies that package and sell data on cislunar and lunar activities, national governments	• Information for economic development and investment for cislunar and lunar businesses and activities (using the data types discussed in the Data section) • Information analysis and packaging for investment purposes

ate as a Public Private Partnership, whose customers are the entire economic ecosystem, including industrial operators, residents, and tourists.

Category 5-e-3-iv: Education and human physio-psychological resilience especially for long term Moon residents

In the Early Phase, this market is emerging, and human physio-psychological resilience is a matter of routine training for every mission crews. Tourists may undergo some training (ISS benchmark).

In the Mature Phase, demand may be generated by lunar residents (and to some extent fees paying tourists). Government or private sector actors may provide this service for which customers are either individuals or organizations.

4.6 Infrastructure, Construction, Manufacturing

4.6.1. Customer Segments

A full documentation of potential customers for infrastructure, construction and manufacturing is provided in Annex A. The below provides a general overview of these customer groupings.

4.6.1.1. Infrastructure

In this area, the analysis will be the network that will connect different markets, in which a common understanding is needed to determine what and how much is needed to supply the demand of public works.

Electricity networks need to be analyzed as well, such as solar or nuclear distribution and safety, which will work with the energy production market. Additionally, a computer and systems infrastructure is needed like fiber networks, sensing and navigation on the Moon. Finally, the management of residual products is needed in a waste & recycling process that needs to interface with each activity on the Moon.[54]

The customers included here, like SpaceX or NASA, are space launch organizations that design, manufacturer and provide services in rockets, satellites, and communication, among others, with budgets reaching $5.0 billion dollars for rocket development[55] or $2.9 billion dollars for the next lunar lander,[56] or the $30.0 billion that SpaceX is going to invest in Starlink over the next years.[57]

4.6.1.2. Construction

Customers that may purchase construction services in the near future include NASA, which for example, has the ambition to establish the Artemis Moon Base. With an annual budget of $23.2 billion in Fiscal Year 2021, the Artemis program estimated cost is $28 billion between 2021 and 2025. With this budget NASA plans to continue his partnership with SpaceX, Dynetics', Blue Origin, among others, to procure the various systems needed in the Moon South Pole. NASA and organizations participating in programs such as Artemis may well become customers of organizations such as Made in Space, which has developed a device to demonstrate the potential for 3D printing with regolith feedstock material in microgravity.[58]

4.6.1.3. Manufacturing

Customers of lunar manufactured products depend on the product in question.

Lunar-bound Products

Simple, 3D printed components, tools and spare parts may be used by almost all organizations with ongoing operations on the lunar surface. 3D printing experiments conducted on the ISS have demonstrated the capability to produce tools and spare parts in microgravity, including a wrench and torque tool.[59] Such products may be used by commercial and governmental astronauts to conduct specialized, routine, and emergency maintenance and repairs. This said, it is possible, indeed likely, that this group would not purchase individual products, but would instead lease a 3D printer to manufacture their own products as needed.

The Mature Phase may see the capability to manufacture more sophisticated components in space. Lunar power and energy companies may become customers for solar cells and batteries manufactured in-situ using local resources, for example.

Earth-bound Products

Should the Earth-bound products listed in Chapter 3 be economically and technically feasible in the Mature Phase, their customers will be wholly institutional. If a technical and business case can be made to produce semiconductors on the lunar surface instead of in LEO, these will likely be highly-specialized application-specific integrations circuits (ASIC) or application-specific standard products (ASSP) sold to organizations such as defense technology firms and other organizations with a need for high-end chips produced using dry resist fabrication processes. Biotechnology products, should they be manufactured on the Moon, would fall within the broader terrestrial pharmaceutical value chain. Novelty luxury goods would be distributed to terrestrial wholesalers and retailers.

Products for Export to LEO/Lagrange etc.

Spacecraft operators and satellite manufacturing and integration companies of various types would be the key customer group for this product class. Structural elements for very large spacecraft could be demanded by space agencies (for example in the construction of very large telescopes) or commercial operators (for example in the construction of SBSP plants). The possibility also exists, should low-cost manufacturing be achievable, that demand may arise from satellite operators and manufacturers for elements such as solar cells. Propellant, however, seems to be the product deemed most likely to be in commercial demand by spacecraft operators. Should a market arise for lunar propellant, companies offering in-space propellant depots will be the key immediate customer group.

4.6.2. Commercialization Plan

For the past years, lunar activities have changed from a public endeavor to a commercial activity, in which opportunities and constraints are faced in the production, distribution and consumption of goods and services.[60] But this is a market that is still not regulated, and government agencies like NASA and many private companies will engage in commercial partnerships detailed on a well-developed plan. This will have strong government principles and help to capitalize on space resources on a consensus on a property regime, leading to a sustainable extraterrestrial development. This formality is important because a permissionless approach threatens national security and inhibits the growth of a formal economy, like the activities not regulated in many countries on earth. After these requirements are met, investors will have more trust to invest in these already risky endeavors.[61]

For manufacturing in particular, the key hurdles to any form of lunar commercialization for products bound anywhere but the lunar surface are technical and commercial. It is not at all clear whether a business case can be made for the manufacture of goods on the Moon instead of in LEO, and each specific product-class requires a dedicated analysis of any unique benefits of lunar production and of the business case. There are, however, also legal aspects needing to be addressed prior to capital investment in space manufacturing, which are the lack of space regulation and the duality of two legal systems of international space law and patent law.[62]

4.6.3. Potential Customers in the Mature Phase

After the Early Phase is finished, with an established lunar base and a market driven approach, a more developed self-sustained period may start with more participants and more advanced in-situ manufacturing methods to increase infrastructure capacity, construction resources, and manufacturing tools and equipment to offer products that can be used on the Moon, or sent back to the Earth customers.

This also includes recreational spaces, cultural, artistic and fashion industry development, hotels, and so on. During this period, across an approximate timeframe, "establishing a permanent human presence on the Moon with a minimal need for supplies from Earth is an economic inevitability of sustained lunar activity."[63] A scenario of growth is considered after the main platform has been set up and it is considered that construction, repair, and robotics will be further developed. The Addendum provides the information that, for the Mature Phase, it will be necessary to build and outfit a lunar surface space hotel capable of supporting between 1 and 10 tourist customers for two weeks at a time during the lunar day, depending on price.

New customers in this phase may include space agencies of developing economies like Mexico, Brazil, Colombia, Chile, Egypt, India, Saudi Arabia, Australia, South Africa, South Korea, among others. These organizations will work with the developed countries' agencies as partners or customers/suppliers of goods and services. In other words, they will be participating until the stage where “one or more of these countries with no current launch capability may pay to fly to the Moon in order to facilitate rapid development and leapfrog to the front of the emerging space programs".[64]

Additionally, sources of customers at this stage include some academic research institutions and universities, as well as high income individuals, who are potential customers, like space enthusiasts and founders of space companies that have a high tolerance of risk.

4.7 Lunar Resource Extraction

4.7.1. Overview of Customer Segments

The identification of customers for M7 has been conducted by market segment, following the taxonomy described above (see market description). We present in Table 4.3. the identified customers for the markets of in-situ sourced materials for in-space propellant, life support, in-situ manufacturing, PGMs & KREEP, and 3He.

The synthesis of these results is presented in the table below, while details on the screening and selection process for each market segment are provided in the following para-

Table 4.3. Synthesis of potential customers for in-situ resources extraction

		Institutional customers		Commercial customers	
Market	**Segment**	**Space agencies**	**Military**	**Space companies**	**Terrestrial companies**
1 – In-Space propellant	1.1 – Cis-lunar missions	CALT – CZ-9		• Relativity Space – Terran R • Orbital services • CSDC – Space Tugs	NA
	1.2 - Landers			Launchers • SpaceX – Starship • Blue Origin – Blue Moon Orbital services • CSDC – Moon Shuttles • Dynetics – DHLS • Intuitive Machines – Nova-C	NA
2 – Life support	2.1 – Lunar Space stations	International – Lunar Gateway		NA	NA
	2.2 – Lunar bases	ESA - Moon Village CNSA - ILRS		NA	NA
3 – In-situ manufacturing		NA		• ICON • Astroport Space Technologies (XArc) • Liquefier Systems Group • Helios • Pacific International Space Center for Exploration Systems • Maana Electric • COSM • Lunar Resources	NA
4 – PGMs (on Earth)		NA		NA	NA
5 – KREEP (on Earth)		NA		NA	NA
6 – 3He (on Earth)		NA		NA	NA

graphs.

4.7.2. Customers of In-Situ Propellant

The market for propellant addresses the needs of a variety of potential vehicles and structures, covering: rockets, capsules, orbital tugs and services vehicles, orbital modules (like the gateway), Moon landers, Moon "hoppers" (taking off from the surface to land in another location) and rovers on the surface of the Moon.

The screening was performed on the current plans from institutional and commercial players to develop such vehicles. The relevant vehicles were then selected on the condition that they exploit either oxygen or hydrogen, the 2 molecules that can be extracted from water. Other propellants were not considered eligible as these were deemed too complex to manufacture on the Moon.

The list of actors and their vehicles which were reviewed can be found in Annex A, with the outcome decision (potential customer or not for ISRU) and a quick rationale for the decision.

4.7.3. Customers of Water for Life Support

Customers for life support include the people spending time in space, from lunar orbit to the lunar surface, as well as the agriculture activities.

They have followed a similar screening process, first mapping the current or potential / expected initiatives involving astronauts or agriculture, and then filtering the initiatives deemed relevant for consumption of in-situ water. The list of initiatives reviewed and the rationale for their selection, or not, can be found in Annex A.

The Addendum provides the information that, for both the Early and Mature Phases, there will be between 5 and 130 lunar orbit tourists needing oxygen and water (either brought from Earth, or from the lunar surface). And in the Mature Phase a further 1 to 10 tourists on the lunar surface will also need life support provisions.

4.7.4. Customers of Resources for In-Situ Manufacturing

The identification of in-situ manufacturing customers has been conducted segregating between customers for construction and customers for manufacturing, as they exploit distinct types of resources for distinct types of applications:

- Customers for construction include the companies involved in civil engineering and facilities construction on the lunar surface. This construction can be based on raw regolith, or construction using cement-like aggregates or – to a smaller extent – metals.
- Customers for manufacturing include the companies involved in production of equipment, tools and any other piece of infrastructure that is not considered civil work, but can be manufactured locally. They intend to primarily serve astronauts activities and other industrial activities on the Moon (mining and extraction, energy plants, habitats maintenance etc.). They primarily exploit metals but not raw regolith.

The identification of these customers was based on a screening of companies already identifiable as positioned on this segment, as well as on the inputs from M6 (Infrastructure, Construction, Manufacturing) to align on more generic categories of customers.

The customers identified are actors that would consume local resources for construction and manufacturing. However, it should be noted that construction companies which plan to use and transform regolith (typically for sintering processes) are customers of their own resource supply, since their concepts include the collection of the regolith. They are listed here but will not constitute a revenue stream for resource providers (based on our understanding, only the construction and manufacturing based on metals will require a preceding supply step, hence some revenues). A list of actors which were reviewed can be found in Annex A, with a quick rationale for the decision to retain them or not.

Taking a step back, it is important to remember that the identification of these customers is conducted in order to quantify the demand. However, the volume of demand for these resources will not be driven by these customers, and will actually be driven by another community further down the value chain, which we can label as the “end users”. Therefore, on top of identifying these customers, characterized as “consumers of the resources for their business”, we recall in Annex A the envisaged end users which have been identified, which, put simply, constitute our customers’ customers.

4.8 Habitation and Storage

4.8.1. Customer Segments

In the context of the Habitation & Storage market, we will use the following market segmentation criteria:

- By type of product used:
  Customers willing to buy a facility on the Moon will have different needs to the ones just looking to lease or rent a property.
- By end-user:
  Government agencies, commercial actors, and private individuals are all segments with different needs, especially from a political and financial viewpoint.
- By geography:
  Segment the customer base by its geography can prove useful to understand the "hot markets". the substrate that connects these customers is usually a blanket of state policies and initiatives that create a fertile ground for private equity investments, government funding, and wealthy individuals' part of the local SME environment.

4.8.2. Early Phase Segments

The main actors in the initial phase, up to 2030, will be mainly national space agencies, with commercial tier 1 and 2 partners.

As of 31 July 2022, signatories to the Artemis Accords include 22 national space agencies from the following countries: Australia, Bahrain, Brazil, Canada, Columbia, France, Israel, Isle of Man, Italy, Japan, Luxembourg, Mexico, New Zealand, Poland, South Korea, Romania, Singapore, Saudi Arabia, Ukraine, United Arab Emirates, United Kingdom, and United States.

We are assuming that government-only missions, that include the management and lease of orbital facilities, will not be included in the customer list. No private companies are known to have a deal to use the only orbital facility of the Early Phase, the Lunar Gateway.

Therefore, in the Early phase, there are no customers for the MT8 Market.

4.8.3. Mature Phase Segments

4.8.3.1. National Space Agencies

The assumption here is that government space agencies with the budget for human space exploration are considered as potential customers to lease, rent, and potentially buy (if the legislation will allow) facilities on the Moon surface and orbit. An emerging country with a limited budget will have a space program that consists mainly of launching satellites for national security, reconnaissance, survey, communications, TV, etc. so they will not be likely to have astronauts trained to go in deep space, and/or participate in international programs for human space exploration, however, with low-cost commercial infrastructure, barriers to entry may be reduced.

National space agencies that have already launched astronauts in space will have the technical know-how, economical capacity, and political will to send their astronauts to lunar facilities, therefore becoming potential customers of the suppliers of Moon orbital and surface facilities. To become clients, they will also need to have the financial capacity to send a crew as a national mission using their own budget. To find the final list of space agencies, we cross-referenced 2 sets of data. The full list can be seen in Table 4.4.

- A list of national space agencies that already sent astronauts to space.
- The agencies' yearly budgets for the last 3 years (2018-2019-2020) and their 3-year average. This allows to smooth out bumps due to the "Black Swan" event in 2020 (Covid Pandemic).

Table 4.4. National Space Agencies that flew an astronaut, in order of descending budget

National Space Agency	Annual Budgets in M$			3-years average
	2020	2019	2018	
National Aeronautics and Space Administration (NASA)	$38,289.00	$40,000.00	$41,000.00	$39,763.00
China National Space Administration	$11,000.00	$11,000.00	$8,000.00	$10,000.00
European Space Agency	$9,520.00	$8,310.00	$9,350.00	$9,060.00
Roscosmos	$2,770.00	$2,600.00	$3,380.00	$2,916.67
Indian Space Research Organisation	$1,890.00	$1,760.00	$1,600.00	$1,750.00
German Aerospace Center	$1,960.00	$1,860.00	$1,400.00	$1,740.00
Japan Aerospace Exploration Agency	$1,690.00	$2,000.00	$1,460.00	$1,716.67
National Centre for Space Studies (France)	$1,570.00	$1,310.00	$1,580.00	$1,486.67
Korea Aerospace Research Institute	$516.00	$756.00	$593.00	$621.67
Italian Space Agency	$370.99	$795.60	$645.40	$604.00
Canadian Space Agency	$249.56	$264.67	$299.66	$271.30
Instituto Nacional de Técnica Aeroespacial (Spain)	$215.69	$212.80	$222.55	$217.01
State Space Agency of Ukraine	$92.40	$75.80	$88.30	$85.50
UK Space Agency	$91.83	$69.51	$83.06	$81.47
Polish Space Agency	$77.67	$77.67	$52.50	$69.28
United Arab Emirates Space Agency	$50.75	$46.56	$55.00	$50.77
Mexican Space Agency	$50.00	$50.00	$50.00	$50.00
Aeronautics and Space Research Organization-LAPAN (Indonesia)	$41.30	$55.00	$48.15	$48.15
Brazilian Space Agency	$29.70	$45.00	$39.35	$38.02
Swedish National Space Agency	$33.84	$31.87	$29.01	$31.57
Belgian Institute for Space Aeronomy	$20.90	$18.63	$20.78	$20.10
Israeli Space Agency	$12.70	$14.80	$10.60	$12.70
Netherlands Institute for Space Research	$11.49	$11.29	$11.68	$11.49
Iranian Space Agency	$8.00	$8.00	$6.30	$7.43
Vietnam National Space Center	$2.00	$2.00	$2.00	$2.00

4.8.3.2. Private Customers

From the Addendum, we note that there will be a need for the lease of enough habitable space for the lunar space tourism hotel, for restaurants, bars, casino and leisure (sport and arts) facilities for between 1 and 10 tourists on the lunar surface for two weeks at a time during the lunar day (depending on price levels).

4.8.4. Commercialization Plan

The first and essential step to ensure the possibility of making the habitation market on the Moon open to commercialization consists in proceeding with a profound and systematic innovation of the space law regarding ownership rights.

More precisely, in order to make this market segment effectively functional, it is essential that the possibility is recognized, for those who will be owners or who will use the facilities on the Moon for residential purposes to enjoy, if not the full right of ownership, at least a protection similar to it that allows a peaceful, tendentially exclusive and prolonged use of the place where the structure used as a dwelling stands.

It should be noted that this innovation, with regard to the provisions of the Outer Space Treaty, must necessarily be adopted at the international level. National legislation governing this aspect of space law, although shared and implemented in the context of multinational initiatives, can play a positive role in encouraging intergovernmental debate and, in some cases, obtaining the status of international law through customary use by the world community, do not have the strength to lawfully change the provisions of the Treaty on their own.

In summary, since the Moon, its resources, and its surface are subject to international law, and since it is not possible to unilaterally create national colonies outside Planet Earth, to ensure the proper functioning of the market linked to the lunar habitation, an intervention by the international community is essential, so that sufficient rights are ensured to guarantee the peaceful and tendentially exclusive use of the facilities in compliance with the regulations and the will of the global community.

4.9 Lunar Agriculture

4.9.1. Overview of Customer Segments

There will be a combination of different customers, at different points in the supply chain, as the lunar agriculture and food production industry becomes established. Certainly, in the initial period up to 2030 it is not expected that any customer of these products will be dependent on them as a matter of life and death, but they may be interested in purchasing the results of experiments and samples.

Customer segments may be broadly split by location: Lunar surface (corresponding to Zones 1, 2 & 3 of the Moon village reference architecture), Low Lunar Orbit (LLO) & cislunar space (corresponding to zones 4 & 5).[65]

These location-based customer segments can then be subdivided into Governmental and Private / Commercial segments, with further variations added based on the differing scenarios described by the scenarios task force. We therefore conclude that the list of customers for lunar agriculture and food will include:

1. Government astronauts
2. Lunar orbit tourists
3. Lunar surface tourists
4. Research Institute scientists conducting food and other areas of research
5. Government contractors and commercial entrepreneurs

4.9.2. Early-Stage Market Segmentation

Customer segments are sparse in the Early Phase. In all scenarios Early Phase missions are short enough for food to be brought with them for the duration of the mission, precluding the need for food to be produced in-situ on the lunar surface.

At present, there are only a few experiments anticipated related to lunar food production, which have been manifested on missions to the Moon under the rubric of the Artemis program, with the government as customer. NASA CLPS missions include some experiments, as will Chinese and Indian missions, and ongoing ISS experimentation.

For lunar space tourists in this Early Phase, the effective customer will be the space tourism operator, who will provide the food in lunar orbit and on the surface for the tourists. The assumed numbers of lunar orbit tourists in this phase could be as low as 5 and as high as 130, depending on transportation options and pricing (see Addendum assumptions). They could spend 10 to 30 days in lunar orbit based on NASA HLS Design Reference Missions.

Taken together, no meaningful demand is expected in the Early Phase.

4.9.3. Mature Phase Market Segmentation

In the Mature Phase – not expected to start until at least 2040 - there will be a series of customers, both governmental and commercial, for the output of the lunar agriculture and food business. Furthermore, this industry is expected to become itself a customer for some of the waste-recycling products generated elsewhere on the Moon, or in lunar orbit. There is expected to be a direct, almost linear relationship between numbers of lunar inhabitants, the area needed for food production, energy and water requirements, and the revenues generated from the operation. At least initially, the pricing of these services will reflect a virtual monopoly business (unless constrained by international regulatory provisions). There will probably need to be differential pricing between the food products delivered to lunar surface customers, and to those in lunar orbit, to reflect the costs of supply missions from the Moon to the orbiting station. Probably, the most useful classification for customers in this sector will be:

1. Permanent lunar inhabitants (mostly governmental or government contractors)
2. Short-term (lunar tourist) inhabitants
3. Inhabitants in lunar orbit

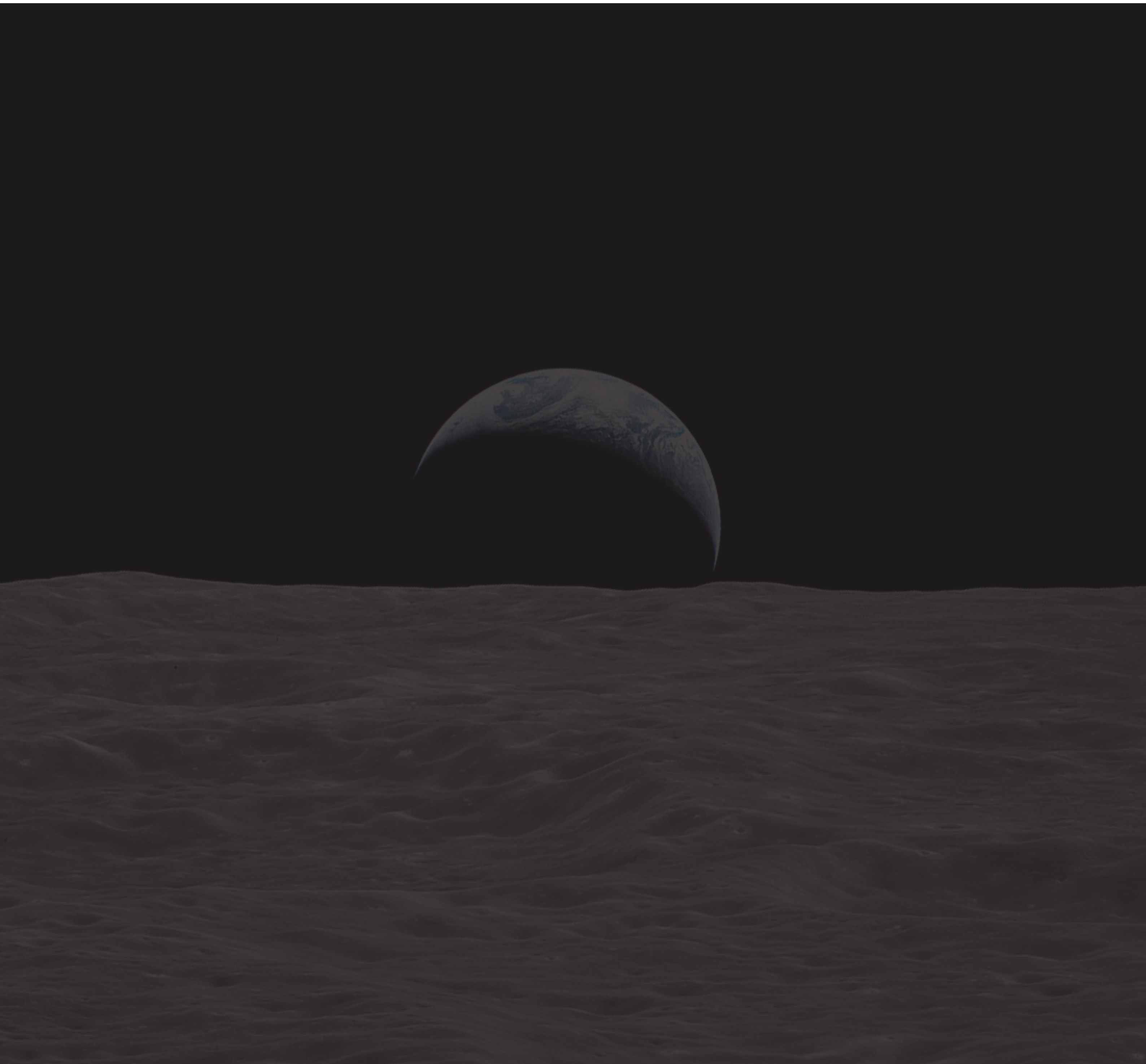
There is also a potential entrepreneur category where a commercial operator may create a premium market on the Earth for customers with an interest in high-end food products cultivated on the Moon. The customers in this sub-category will be limited in number but will be generally price insensitive. Permanent residents may be between 10 for a small research station and 200 for a community.

The assumed numbers of lunar surface tourists in this phase (see Addendum for the assumptions on pricing, etc.) are between 1 and 10 tourists on the lunar surface, staying for two weeks at a time, during the lunar day, depending on price levels. To these lunar surface tourists must be added to the lunar orbit tourists as described earlier with reference to the Early Phase.

4.9.4. Commercialization Plan

During the Early Phase, it is expected that there will be a gradual increase in agriculture-related experiments both on Earth in hydroponic labs and vertical gardening facilities, and on low-scale lunar missions. These experiments will be conducted and financed in general by government sources. However, in order to achieve the conditions required in the Mature Phase, where human lives will be dependent on the successful outcome of these activities, there will need to be a scaling-up of the technological testing and demonstration on the Moon, requiring the establishment of the entire value chain with non-governmental actors contributing and even leading the initiatives. In particular, it will be necessary to establish the adequacy of oxygen and water supplies derived from lunar ISRU, and to be confident in choices of plants and animals which can survive in the lunar 1/6 g environment. When human life is dependent on the functioning of this lunar agriculture technology, it will be necessary to ensure that all lunar inhabitants will be able to have access to the food supplies, and that mutual-assistance procedures and regulations are in place. If the lunar farm is a monopoly provider, then there will be a need for pricing regulation in order in particular for providers of lunar surface tourism to have confidence in their cost structures.

5. Suppliers



5.1 Transportation To and From the Moon

5.1. Transportation To and From the Moon

The Transportation to/from the Moon and Lunar Vicinity has identified 57 potential cislunar transportation service suppliers. The team has divided these potential suppliers into five distinct segments extending from Earth launch and recovery sites to Moon landing and launch sites. Included amongst these suppliers are the NASA robotic landers under the CLPS program (eg., Astrobotic, Deep Space Systems, Firefly Aerospace, Intuitive Machines, Moon Express and Orbit Beyond), and the NASA Human Landing System studies contracted to Dynetics, SpaceX and Blue Origin. The list of suppliers is available in Annex B.

5.1.1.Supplier Segments

Five transportation service supplier segments are defined extending from Earth to the Moon. These segments are Earth Launch and Recovery Sites, Launch Service, Cislunar Transportation, Personnel Carriers, Moon Launch and Landing Sites. Identified providers include commercial and government entities. Government entities primarily provide service to government customers. Commercial providers serve commercial and government customers.

5.1.2. Early Phase

Early Phase suppliers exist in all segments, with Moon Launch and Landing Sites Segment coming on late in the period.

5.1.3. Mature Phase

Mature Phase segments are identical to Early Phase segments. Some Early Phase suppliers may disappear and new ones may emerge during the Mature Phase.

5.1.4. Commercialization Plan

Commercial space ports and launch service providers currently exist and they operate in parallel to government facilities so there is no need for a commercialization plan for these two supplier segments. They have come about from past government support and encouragement as well as independent developments based on perceived market opportunities.

The commercial cislunar transportation segment is in its early stages in large part thanks to the NASA Commercial Lunar Payload Services (CLPS) and Human Landing System Programs. NASA provided early support to start-up lunar lander companies through data buy contracts and Centennial Challenges and through Human Landing System concept and risk reduction studies. NASA has awarded seven payload delivery contracts to four different providers and plans to award two payload delivery missions per year. The Human Landing System precursor studies will evolve into the Lunar Exploration Transportation Services (LETS) contracts after the first demonstration mission. NASA expects to conduct one human landing mission per year as well as supportive surface hardware deliveries, which may also use landers developed under the HLS umbrella. Space to space transportation as a service has yet to develop but there are companies pursuing that market. Reusable lander propellant needed at the Lunar Gateway may be a driver for commercial space-to-space transportation, which may also lead to a change in how GEO satellites are delivered and designed.

A limited commercial market for personnel carriers to the Moon exists today as Japanese billionaire Yusaku Maezawato has ordered a trip to the lunar vicinity from SpaceX for 2023. NASA is not supporting or encouraging human transport to the Moon as they will deliver astronauts to the Gateway using their SLS/Orion system under the Artemis Program. Even so, there are other companies pursuing space-to-space personnel transportation as a service.

Lunar landing and launch pads as a service are foreseen and may become real near the end of the Early Phase. At least two companies are pursuing technologies and processes applicable to building lunar landing and launch pads. The impetus is based on research by Phil Metzger at University of Central Florida predicting severe surface erosion and regolith being ejected into lunar orbit by large lunar landers. This market segment is dependent of successful development of the necessary technologies, the reality of ejecta predictions and establishing one or more permanent lunar facilities.

5.2 Transportation On the Lunar Surface

Suppliers of lunar surface transportation services can be segmented into 3 broad supplier categories:

1. Robotic surface transportation
2. Crewed surface transportation
3. Spacesuits

Considerable nuance exists within each of the above supplier segments.

Robotic surface transportation platforms can take the form of rovers or hoppers. Rovers themselves can come in a range of weight classes, which for the purposes of ease of understanding are classified as follows, based on commonly understood satellite weight classes:

- Nanorovers: >1kg - 10kg
- Microrovers: >10kg - 100kg
- Small rovers: >100kg - 500kg
- Medium rovers: >500kg - 1000kg
- Large rovers: >1,000kg

While no commonly accepted standard exists for rover payload hosting, it is generally accepted that standardized sizes and rover interfaces would lower barriers to entry for organizations seeking to deploy payloads, and therefore increase the potential addressable market. Some companies, for example Astrobotic (Annex B), have begun providing standardized offerings (in Astrobotic's case, the company's Cuberover is offered in 2U, 4U and 6U configurations, based on the CubeSat standard common to other spacecraft).

Crewed surface transportation systems can similarly come in the form of wheeled or tracked surface transportation, or (though no examples were found) as crewed hoppers. These vehicles themselves can also be pressurized or unpressurised and will exist on a broad spectrum in terms of their life support capabilities and expected lifespan on the lunar surface. Additionally, unpressurised crewed rovers in particular will likely almost all have the ability to operate uncrewed, and so may double as robotic surface transports that can operate autonomously or be teleoperated.

Spacesuits are generally conceived of in two design philosophies: hard, soft or hybrid pressure suits and mechanical counterpressure (MCP) suits. Pressure-based suits protect crew from the vacuum of space by internally pressurizing the suit, while MCP suits apply constant pressure against the skin in order to compress the body in a vacuum. Both teams selected to deliver spacesuits to NASA for the initial run of Artemis landing missions are developing pressurized suits (Annex B). However, development is ongoing of MCP suits, most notably under MIT's Bio-Suit programme led by Dava Newman.[66]

5.2.1. Suppliers in the Early Phase

Robotic surface transportation service providers are expected to provide primarily nanorover payload hosting and data provision services, largely as a function of market demand. All commercially available platforms with known weights are in the nanorover class (Annex B). While companies such as Astrobotic have announced development of rovers such as the Volatiles Investigating Polar Exploration Rover (VIPER) in higher weight classes (VIPER itself is a small rover of 430kg), these appear to be, at least for the moment, one-off developments to host dedicated NASA experiments. This is not to say, however, that these larger platforms will not become widely available to a range of paying customers in future.

While one hopper mission has been identified amongst current suppliers (Intuitive Machine's MicroNova, see Annex B), these provision of hopper-hosted robotic transportation services is not expected to be as widespread as those offered through rover platforms in the Early Phase.

The following providers of lunar robotic spacecraft are being funded under the NASA CLPS program:

- Astrobotic Technology
- Blue Origin
- Ceres Robotics
- Deep Space Systems
- Draper
- Firefly Aerospace
- Intuitive Machines
- Lockheed Martin Space
- Masten Space Systems
- Moon Express,
- Orbit Beyond.
- Sierra Nevada Corporation
- SpaceX
- Tyvak Nano-Satellite Systems

In addition, the Chinese Chang'e landers and Yutu rovers are currently operating on the Moon

Crewed surface transportation services are similarly expected to be largely unpressurized. Almost all currently identified suppliers are developing unpressurised vehicles. These are all envisioned as flexible, modular platforms that will be able to transport crew, but also be teleoperated or operate autonomously in order to transport payloads, either for logistical purposes or in order to conduct surface experiments. While at least one pressurized rover (Toyota's Lunar Cruiser / JAXA crewed pressurized rover (CPR)) may enter service before 2030, this is not guaranteed, and it is not clear whether pressurized transportation services will be made commercially available.

Spacesuits in the Early Phase are expected to follow the pressurized design philosophy.

5.2.2. Suppliers in the Mature Phase

As a function of increased technological capability and expanded demand, further services are expected to be brought to market in the Mature Phase. Specifically:

Robotic surface transportation providers are likely to increase the size and payload capability of available transport vehicles, allowing for more sophisticated payloads with greater power requirements, able to be transported to greater ranges. This also allows for logistical transport, though this function may be fulfilled by flexible platforms also able to transport crew. To the ends of increasing transport distance, hoppers may be used more extensively. However, given dust generation concerns, and the increased range associated with improved power sources for rovers, this is not guaranteed. Hoppers, may however, be employed despite these concerns for time sensitive transport, for example of medical supplies and equipment between bases.

Crewed surface transportation providers are likely to provide both pressurized and unpressurised transportation services. Pressurized vehicles can to some extent be seen as mobile surface habitats, enabling, for example, government astronauts to conduct extended exploration missions across hundreds of kilometers, for maintenance crews to access dispersed surface assets, and for lunar tourists to purchase multi-day surface "tours".

Spacesuit design trajectories are somewhat difficult to predict and it is possible, indeed likely, that a range of suits bearing a spectrum of design choices may be available. For example, astronauts may use pressurized suit elements for their limbs and torso, but utilize MCP gloves due to the tactile and dexterity advantages these would offer. The fundamental offer of a spacesuit as a service is unlikely to change, however, though some providers of crewed lunar surface access, for example lunar tourism providers, may choose to purchase and operate their own suits, or develop these in-house, rather than renting them from a provider.

5.3 Communications and Navigation

5.3.1. Introduction

This section of the report identified what sort of organizations the suppliers are in the market, what they are supplying, how they capture revenue etc. Its primary purpose is to give readers an understanding of existing and future players, and organize suppliers in a way that makes sense and is easily understandable.

5.3.2. Supplier Segmentation

The literature review on existing and Early Phase demands, products, and services outlined in Chapter 3 form a baseline from which to build an overview of the segmentation of suppliers. The following subsection outlines the different elements that require supplying and it is followed by a subsection identifying the suppliers in each segment and then finally a section featuring a database of potential suppliers.

5.3.2.1. Possible Network Elements

This subsection provides a summary of potential elements that make up the early and Mature Phase navigation and communication networks.

- Space Elements: Space elements are defined as any elements that are in lunar or earth orbits.
  - GNSS satellite constellations including; ESA's Galileo, NASA's GPS, China's BDS, Russia's GLONASS,
  - Lunar-orbiting GNSS satellite constellations,
  - Designated orbiting spacecraft that act as relays,
  - Piggybacked spacecraft whose relay functionality is secondary.
- Lunar Network Elements: Lunar network elements are defined as any elements that are on the lunar surface.
  - Lunar terminals, surface relays, and management controllers,
  - Stations such as geophysical, PNT, and inhabited stations,
  - Vehicles such as robotic surface rovers, crewed rovers, exploration rovers, and landers,
  - Science-based experiments, telescopes, and other related equipment.
- Earth Network Elements: Earth network elements are defined as any elements that are on Earth, these are mostly operated by governments, but there are some which are privately owned.
  - NASA's ground stations including: NASA's DSN 34m stations and Lunar Exploration Ground Stations (LEGS) 18m stations, DSN affiliate stations such as Morehead State University's (MSU) 21m station and the Sardinia 64m station,
  - Network operations: DSN's Deep Space Operations Center at JP.
  - ESA's European Space Tracking network (ESTRACK) with its European Space Operations Centre in Darmstadt, Germany and its 35m deep space antennas at New Norcia, Australia, Cebreros, Spain, and Malargüe, Argentina;
  - JAXA's Ground Network (GN) including the 64m antenna at the Usuda Deep Space Center, Nagano and the 54m Ground Station for Deep Space Exploration and Telecommunication (GREAT);
  - ISRO's Indian DSN (IDSN) facility located near Bangalore and has 11m, 18m and 32m antennas,
  - KARI's Korea Deep Space Antenna (KDSA) (under development to support the Korea Pathfinder Lunar Orbit-

Table 5.1. Supplier Segmentation Description

Segment	Segment Description
Satellite operators	An entity that provides satellite services
Satellites manufacturers	An entity that manufactures satellites
Transmitter and receiver manufacturers	An entity that manufactures hardware (receivers, transmitters, antennas) for capturing and processing a variety of communication signals (x-band, s-band, Ka-band, optical, UHF, etc.)
GNSS supplier	An entity that manufactures hardware or hardware and software for capturing and processing GNSS signals
LTE supplier	An entity that builds and operates cellular networks
Ground station supplier	An entity that operates ground stations

Table 5.2. The Open System Interconnect Reference Model

Layer No.	Layer Name	Description
7	Application	Consists of standard communication services and applications that everyone can use
6	Presentation	Ensures that information is delivered to the receiving machine in a form that it can understand
5	Session	Manages the connections and terminations between cooperating computers
4	Transport	Manages the transfer of data and assures that received and transmitted data are identical
3	Network	Manages data addressing and delivery between networks
2	Data Link	Handles the transfer of data across the network media
1	Physical	Defines the characteristics of the network hardware

Table 5.3. The Open System Interconnect Reference Model

OSI Ref Layer No.	OSI Layer Equivalent	TCP/IP Layer	TCP/IP Protocol Examples
5,6,7	Application, Session, Presentation	Application	NFS, NIS+, DNS, telnet, ftp, rlogin, rsh, rcp, RIP, RDISC, SNMP, and others
4	Transport	Transport	TCP, UDP
3	Network	Internet	IP, ARP, ICMP
2	Data Link	Data Link	PPP, IEEE 802.2
1	Physical	Physical Network	Ethernet (IEEE 802.3) Token Ring, RS-232, others

er, KPLO);

- CNSA: China's Queqiao L2 relay provides support to China's Chang'e missions.
- SSC's South Point and Dongara 13m stations with the SSC's Network Management Centers (NMC) located in Kiruna, Sweden, Horsham, PA, and Chantilly, VA.
- Goonhilly Earth Station with 32m, 30, and 18m antennas,
- Networks owned by SpaceX and Amazon Web Services (AWS),
- The Irish National Space Centre Limited 32m antenna near Midleton, County Cork.

5.3.2.2. Segmentation

Now that the elements have been listed, an initial segmentation of the relevant suppliers could be conducted. The results of segmentation can be seen in Table 5.1.

5.3.3. Mechanisms of the Supply Chain

A consultation has been conducted with various stakeholders throughout the supply chain as part of the research conducted for this report. This stakeholder consultation was conducted with the aim of understanding which suppliers would potentially offer products and services in this market and to understand what evolutions would need to take place in order for the products to work on the Moon.

5.3.3.1. Principle of Interoperability

The lunar communication and navigation market is expected to be similar to the terrestrial markets in that no one single company will provide all the services, instead, it will be constructed in the form of layers upon layers where different companies provide a specific component of a service that appears unified to the end users.

5.3.3.2. Terrestrial Analog

For an analog on earth, the open systems interconnect reference model or the TCP/IP protocol architecture model can be examined.[67] This can be seen in Table 5.2. and Table 5.3.

5.3.3.3. End User Experience

As described earlier, it is expected that for a theoretical Earth-Moon data transfer, the end user wants to pay a specific price to send a specific set of data from the lunar surface to Earth as seen below in Figure 5.1.

In reality, a system in the Mature Phase would be more akin to the system outlined in the figure below which showcases the underlying system, including a potential 5 proposed different services that would be packaged together to provide a unified service to the end user.

5.3.4. How Suppliers Can Fit Into the Ecosystem

Following the stakeholder consultation, there are several potential methods identified by which the suppliers could fit into the diagram seen above. There are two overall concepts which have been suggested so far, one where whole systems and services are

Figure 5.1. What the end user sees when transferring

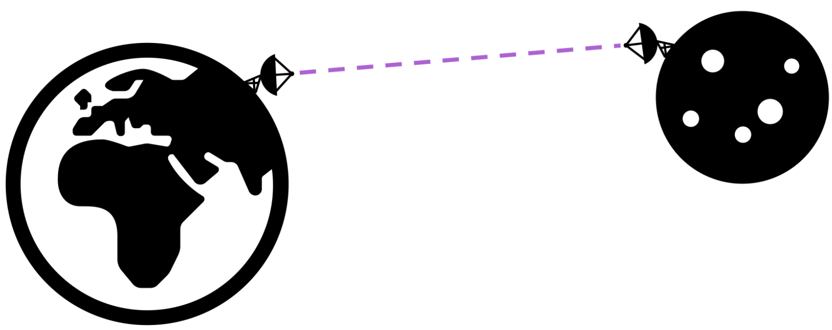


Figure 5.2. The underlying system facilitating the end user experience

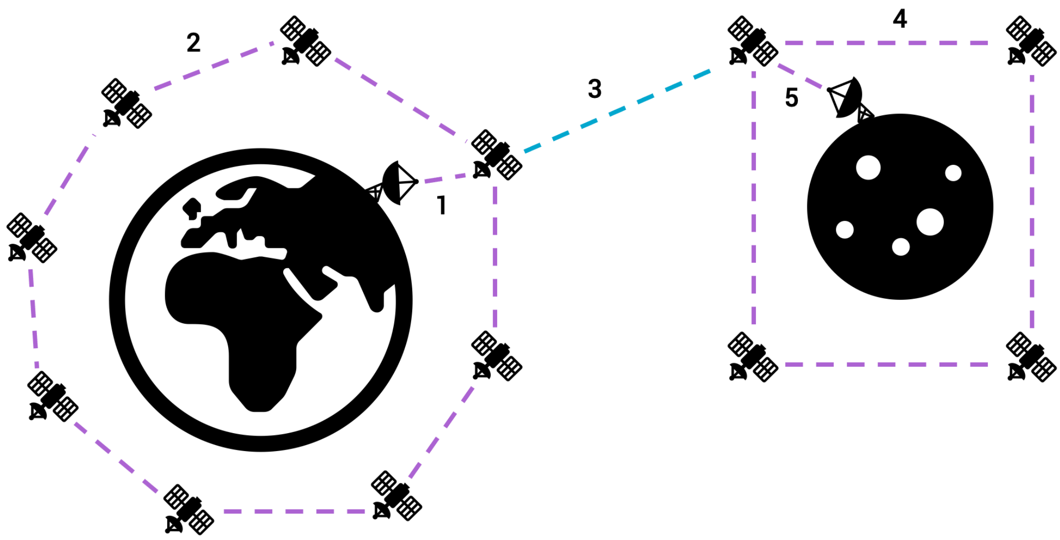


Table 5.4. Explanation of the different segments seen in the figure above

Layer No.	Layer Name	Description
1	Earth Surface - Earth Orbit	This segment of the market is the most mature and features existing supply chains and products - most commonly using SHF banded transmitters and receivers.
2	Earth Orbit - Earth Orbit	This segment of the market is currently seeing rapid development, with several potential mega-constellations being developed that would provide adequate bandwidth for data to be passed around the Earth in order to allow the recipient or sender to be communicated with, regardless of their position.
3	Earth Orbit - Lunar Orbit	This is a relatively new market segment with some upcoming developments - the current solutions have insufficient bandwidth to fully serve even the early market.
4	Lunar Orbit - Lunar Orbit	An entirely new market that has cutting edge research projects with the aim of providing the ability to transfer data to a satellite at any time from any place on the lunar surface.
5	Lunar Orbit - Lunar Surface	This is technically possible today, as previous and current lunar missions have transmissions that pass from the surface to orbit, but as per 4, the bandwidth and functionality of these methods and facilities are too limited to support a developed market.

provided by one supplier, and one where a mixture of suppliers work together providing individual components and hardware, with some form of cooperation agreement or consortium-led project, ideally by an academic or public sector lead.

5.3.4.1. Suppliers of Whole Systems for the Lunar Market

There exist several upcoming services being developed by suppliers which would be theoretically suitable, an example of which is the ÆTHER Network being developed by Kepler Communications Inc. (See Table 5.5.) This system is intending to remove the need for end user ground stations through the launch of a constellation of satellites that utilize Kepler's S, Ku, and optical services to provide telemetry, tracking and command to satellites in orbit, providing data uplinks and downlinks to Earth, and to transfer large volumes of data across the Earth.[68]

Each of these three services mentioned above, provided that there is a business need to resolve problems related to radiation and dust hardening, would belong in one of the five layers outlined in the diagram and accompanying table in the end user experience section. It would be potentially feasible for an evolved version of the ÆTHER Network to form the backbone of all or part of the early and mature lunar communication networks.

Table 5.5. Suitable Kepler Services

Service	Details
Ku Band Service	160 MSPS class Ku-Band Software Defined Radio with peak data rates up to 700 Mbps - a turnkey solution that does not require additional licensing and that can be used to provide a high-speed link direct to a payload or acting as a 'store and forward' data transmission with 500 GB of included storage.
S Band Service	A software-defined S-Band radio solution designed for telemetry, tracking, and commanding LEO satellites - including two patch antennas, providing omnidirectional coverage and full duplex capability. This includes an internet connection that can access and program LEO satellites' onboard computers and the provision of intersatellite links with a user-friendly design.
Optical Data Service	Optical connection providing Gbps speed in burst, ideal for large volumes of data to be made available terrestrially. This is an upcoming service that does not yet have published datasheets.

5.3.4.2. Suppliers of Partial Systems Hijacked by the Lunar Market

Even if the ÆTHER Network (or similar service) is not expanded to the Lunar Market, the current plans for these systems would be able to provide services that belong in layers 1, 2, and 3, with only new services to be developed for layers 4 and 5. It is best to ensure that future services are compatible with the upcoming terrestrial networks to reduce the overall system development costs.

5.3.4.3. Suppliers of Individual Components

A third type of supplier would be the supplier of the individual components. An example of this would be the provision of hardware and services from suppliers such as Alen Space, Kepler Communications Inc, Tethers Unlimited, Nokia, or Honeywell Aerospace Inc. Given notice, these suppliers would be able to make the required changes to their products and services to enable lunar operations.

A specific example of a communication product or service that would be able to be integrated into a future lunar system would be the Alen Space TOTEM Software Defined Radio. This is a platform with flight heritage that would be suitable for small satellites in a lunar orbit. Advanced Space, of Boulder, Colorado, specializes in navigation systems.

5.3.4.4. Considerations on the Business Case for Suppliers

Now all three options have been briefly explored, it is essential to be aware of the different business cases behind each of the options. The greater the amount of services a single company supplies, the larger risk for that company in terms of new product and service development.

A potential overreliance on a single supplier should be avoided - this is seen in upcoming lunar projects which often run two parallel system designs, with multiple competing and segregated consortiums being chosen to ensure that there isn't a single point of failure. Despite the risks, it might be recommended to have a limited number of suppliers in order to increase system compatibility.

This report does not seek to dictate the terms of any such project, instead merely to provide a list of potential suppliers that ideally would work together in the future for the betterment of the lunar economy.

5.4 Energy and Power

5.4.1. Introduction

During the Early Phase, potential suppliers will be any company or institution that is contracted by a national government agency. During this phase, there will be no pure private suppliers to support energy requirements on the Moon. Once the energy framework for the Moon is established, i.e., during the Mature Phase, countries will likely provide a consortium approach to delivering supplies and services for lunar operations. This is very similar to how energy suppliers meet demand requirements on Earth.

In this chapter, the team highlights different companies that service the different market segments previously identified.

5.4.2. Suppliers in the Early phase

During the Early Phase, the power module may be combined with the propulsion element just like it is for the Lunar Gateway program. Companies like Maxar Technologies, Aerojet Rocketdyne, Spectrolab, etc. have extensive OPEX and legacy equipment that has been in operations for decades that can be leveraged for development of power on the Moon during the Early Phase. Technologies like RTGs, high-efficiency space solar cells and, solar panels could cover most of the power generation equipment supplied during the Early Phase. As previously assumed, due to the nature of power systems developed for specific missions in the Early Phase, there is no market for power transmission. However, this may be a chance for suppliers to seek funding and mature power transmission technologies that could be used during the Mature Phase. Several missions will also be focused on maturing power technologies for application during the Mature Phase. As part of a NASA contract, three consortia have won contracts for conceptual design work for a full flight-certified transmission power system :

1. Lockheed Martin in partnership with BWXT and Creare
2. Westinghouse in partnership with Aerojet Rocketdyne
3. Intuitive Machines and X-Energy in partnership with Maxar and Boeing

5.4.3. Suppliers in the Mature phase

Energy Generation:

- AGPower92: AGPower92 is proposing to develop a small (5 to 10-MWe), utility power source, a Mini Modular Reactor with an integrated control and distribution system, appropriate for use in a variety of terrestrial surface and subsurface applications
- Ultra Safe Nuclear: Ultra Safe Nuclear is taking space based nuclear energy systems to market
- Maana Electric: Maana's technologies offer a real and short-term solution to solving the biggest problem the Earth experiences today. Maana aims to build large scale solar parks in deserts around the world to power our ever-growing demand for electricity
- Solaren: Solaren plans to develop, launch, and operate the world's first SBSP (Space-Based Solar Plant) plant and sell electricity. To accomplish this, Solaren is organized into three main groups: 1) SBSP Systems, 2) SBSP Operations, 3) Electricity Sales, and an R&D support group – Advanced SSP Technologies
- Shimizu Corporation: Planning to make maximum use of resources on the Moon to build a lunar power plant. The sand on the moon is an oxide compound, so it would be possible to produce oxygen and water if hydrogen were brought from the earth. Moreover, we could produce cement by mixing water with sand and gravel to produce concrete. It would

also be possible to use the heat from the sun to produce blocks and glass fiber

- X-Energy: X-energy is an American private nuclear reactor and fuel design engineering company. It is developing a Generation IV high-temperature gas-cooled nuclear reactor design
- Zeno: Developing a next-generation radioisotope power system that converts the heat from recycled nuclear waste into electricity
- Regher Solar: Regher Solar is revolutionizing the access to power in space with space tolerant ultrathin silicon solar panels, which for the first time on the market, will have both high efficiency and low cost in a single light-weight and flexible package
- Ion Power Group: Ion Harvesting Technology – a new and better way to generate clean electricity on extraterrestrial bodies by utilizing patented carbon nanofiber to extract useful electricity from ions native to a planet's atmosphere
- Howe Industries: Develop space-based power systems, which include radioisotope fueled systems and reactor-based systems
- LONGi Green Energy

Energy Transmission:

- Extra Terrestrial Power: Delivers power on the last critical mile. ETP is focusing on power transfer options to deliver energy in space to fix or moving objects, like rovers, and even into permanent shadow regions of the Moon
- Photonicity: Developing a power transfer technology (wireless or wired) that is a power solution for remote vehicles operating in highly challenging environments (long-range or severe pressure or temperature or radiation) for extended periods

Energy Distribution:

- Instarz: Design and manufacture self-sustainable space habitats and space technologies

Energy Storage:

- ADA Technologies Inc.: Focus on research, development, and manufacturing of a range of custom energy storage products
- EaglePicher: EaglePicher is battery manufacturer, who has seen products flown in space with some of most well-known space exploration missions, including Mars rovers (Curiosity, Spirit and Opportunity), missions to Venus and Mars, the Hubble Space Telescope and the International Space Station. EaglePicher offers the most advanced lithium carbon monofluoride battery technology for space and many other applications
- Infinity: Infinity produces next-generation air-independent fuel cells and regenerative fuel cells, and has received support of NASA and several other US government agencies
- Manna Electric

5.5 Supplies and Services

As noted earlier, for the special case of MT5, more detail is provided than is currently capable of being quantified.

5.5.1. Segment 5-a: Launchpads Operations and Maintenance

Operations and maintenance are performed in Early Phase on an ad-hoc basis, since no independent facilities are assumed. Such pads operation facilities may appear in Mature Phase, requiring design, engineering, and construction themselves. In addition, maintenance and repair may also require more construction and more interventions by handling, processing, and special test equipment providers.

Suppliers are numerous A&E firms as well as specialized equipment providers in the market.

5.5.2. Segment 5-c: Operation of Depot for Supply of Water, Oxygen, Hydrogen, and Nitrogen

5.5.2.1. Propellant

This segment consists of Liquid Hydrogen and Liquid Oxygen Cryogenic Propellants. In the Early Phase, the market addressed inscribes itself into the value Chain of Market Team 1 'Transportation to/from the Moon' i.e. Propellant Providers.

In both the Early and Mature Phase, sole Earth-based propellant producers are: Linde, the Big 3, and Air Liquide.

Space propellant suppliers are: TransAstra and OffWorld (identified as company goal as of 2021-22)

5.5.2.2. Life Support

In the Early Phase, water is supplied from Earth only by transportation providers, themselves supplied by water firms. Breathable air is supplied from Earth only by space agencies and firms such as Air Liquide.

In the Mature Phase, water is supplied by Earth, space, and Moon-based producers. Breathable air is supplied by space and Moon-based producers, with as little reliance on Earth as possible.

5.5.3. Segment 5-d: Miscellaneous Emergency, Medical, Recycling and Provisions

For the below sub-segments, potential suppliers include:

- Space agencies e.g., NASA, ESA, JAXA
- Potentially defense agencies
- Commercial emergency, medical and recycling providers
    - Medical research organizations, universities, drug companies, medical device companies
- Commercial actors broadly engaged in space tourism e.g. SpaceX, Blue Origin

5.5.3.1. Sub-segment 5-d-1: Emergency/Fire/Rescue Services

Service suppliers are lunar (or cislunar) based while hardware / software producers will almost certainly be Earth-based.

Suppliers will likely need to provide in this segment for both Early and Mature Phase:

- Equipment for Emergency/Fire/Rescue
- Specification/design/development/test services for hardware and software systems imbedded in a vessel's design
- Emergency/Fire/Rescue process design and development

For the Early Phase, these systems will exist onboard vessels traversing cislunar space and will include equipment that is part of the vessel design. In the Mature Phase, Emergency/Fire/Rescue systems will be included as part of a facility's design and will also include ancillary equipment.

5.5.3.2. Sub-segment 5-d-2: Medical/Health/Hyperbaric/Centrifuge facilities

In the Early Phase, no independent facilities exist. In the Mature Phase, suppliers may follow an analog equivalent of a military hospital unit, merged with a spaceflight training center, and a space station health maintenance section.

Suppliers may be split among providers of treatment of non-lethal and relatively benign conditions treatable on the Moon, and intensive care units. Hardware and personnel may include remote treatment.

5.5.3.3. Sub-segment 5-d-3: Non-Nuclear Waste Processing/Recycling

In the Early Phase, no independent facilities exist. In the Mature Phase, suppliers follow demand assumptions on analog equivalent of non-nuclear waste production.

Service providers are lunar (or cislunar) based while hard/software producers are almost certainly Earth-based. Humans operate together with machines.

5.5.3.4. Sub-segment 5-d-4: General Provision Stores, Maintenance, and Repair

Suppliers may be split among these categories: suppliers for commodities and products other than Water, Oxygen, Hydrogen, Nitrogen (see 5-c), services providers for the operation of depots for supplies of food and equipment, and services providers for equipment maintenance and repair (equipment, habitations), backed by hard/software and process suppliers.

5.5.4. Segment 5-e: Data, Fintech, Governance

5.5.4.1. Sub-segment 5-e-1: Data

Demand for data is understood as both the demand for activity and demand for supporting infrastructure, primarily information systems.

In the Early Phase

- Government space agencies are data buyers but might also be data suppliers
- OffWorld is a suppliers of mining data
- The business model of Japan/Luxembourg's iSpace includes the value chain of mining/SRU data
- Several ventures currently offer future data services in particular for mapping, safety zones, etc.

Support infrastructure in the Early Phase such as information system are primarily the information systems of the data provider, since there is no independent facility assumed. Hardware, software and data services are needed such as internet connectivity and an Earth-Moon communication systems.

In the Mature Phase, companies in the business of data infrastructure and hardware / software solutions 'at scale' on Earth may expand to space.

5.5.4.2. Sub-segment 5-e-2: Fintech

Potential fintech suppliers are indicated in Table 5.7.

5.5.4.3. Sub-segment 5-e-3: Governance

Category 5-e-3-i: Central Moon Port administration

In the Early Phase, there is no Central Moon Port Administration to supply, however activities related to initial pads may still fall under the below category <iii>.

In the Mature Phase, demand for governance under a Port Authority model is reflected in the supply of its information system. The ability to intervene in-situ is covered in below category <iii>.

Category 5-e-3-ii: Environmental and Nuclear protection, Nuclear Waste Treatment

In the Early Phase, the execution of tasks involved in Environmental and Nuclear Protection is supported by suppliers inherent to

Table 5.6. Data suppliers

Data Providers	Data Types
Early Phase	
Public Entities: 1st world governments that are leaders in space activities: U.S., ESA, China, India, etc.	• Lunar Scientific Data: composition, geology, history of the moon, government funded lunar research, location of various natural resources • Cislunar Economic Data: Economic Activity Indicators, Jobs & Income, Wealth & Savings, Taxes, Trade • Information about current and future projected cislunar and lunar activities across the commercial and scientific spectrum
Private Entities: commercial companies that package and sell data on cislunar and lunar activities	
Mature Phase	
Public Entities: 1st world governments that are leaders in space activities: US, ESA, China, India, etc.	• Lunar Scientific Data: composition, geology, history of the moon, government funded lunar research, location of various natural resources • Cislunar Economic Data: Economic Activity Indicators, Jobs & Income, Wealth & Savings, Taxes, Trade • Information about current and future projected cislunar and lunar activities across the commercial and scientific spectrum
Private Entities: commercial companies that package and sell data on cislunar and lunar activities	

Table 5.7. Fintech suppliers

Financial Services Suppliers	Financial Services
Early Phase	
Public and private entities that take the types of data generated in the Data section and package it for use. These entities include governments, non-profits and for-profit companies	• Information for economic development and investment for cislunar and lunar businesses and activities (using the data types discussed in the Data section) • Information analysis and packaging for investment purposes
Mature Phase	
Public and private entities that take the types of data generated in the Data section and package it for use. These entities include governments, non-profits and for-profit companies	• Information for economic development and investment for cislunar and lunar businesses and activities (using the data types discussed in the Data section) • Information analysis and packaging for investment purposes

each mission integrated system (monitoring, prevention).

In the Mature Phase, fully regulated environmental protection depends on monitoring equipment and information system providers.

Category 5-e-3-iii: Moon Traffic Management, Registry, Interference Zoning, Damage Assessment, Policing, Mobile Units for Incident Monitoring

In the Early Phase, no independent facility is assumed. In the Mature Phase, governance must be aligned on an administrative and economic model of a fully regulated Moon Traffic Management Authority. Again, this entails devices monitoring activities and information systems capable of supporting tasks such as enforcement of protocols for interference zoning, damage assessment, policing. Besides information systems, suppliers may emerge supporting a rapid intervention task force made of mobile units for incident monitoring: vehicles, spacesuits, and recording devices.

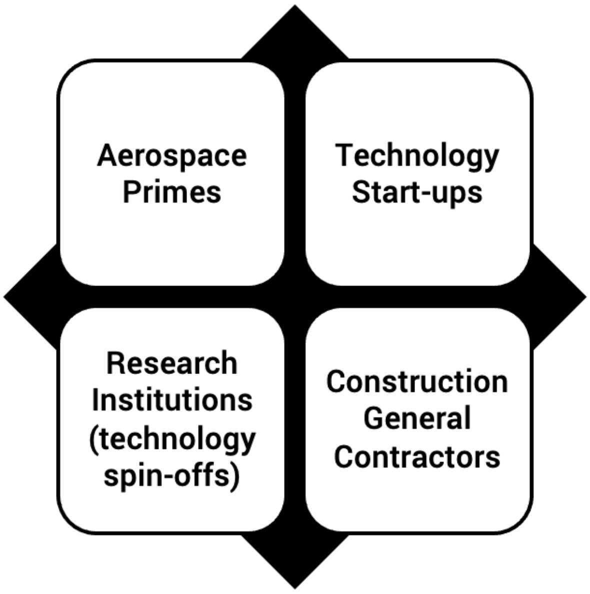
Category 5-e-3-iv: Education and human physio-psychological resilience especially for long term Moon residents

In the Early Phase, human physio-psychological resilience routine training for every mission crew is supported by mission suppliers. Tourists may undergo some training at Earth-based facilities. In the Mature Phase, there may be facilities such as a physio-psychological resilience training center.

5.6 Infrastructure, Construction, Manufacturing

In the field of lunar infrastructure, construction and manufacturing, a wide range of suppliers can be expected to produce the goods and services in this field. This section seeks to categorize said suppliers, characterizing what organizations can be expected to capture revenue in this market. This is further informed through a list of companies that currently are conducting R&D or early-stage tests to supply these goods and services. A list of identified potential suppliers for M6 can be found in Annex B. The below provides further narrative and context to potential emerging supplier groupings.

Figure 5.4. Graphic illustrating major groups of companies that can enter this segment



5.6.1. Early Phase

With concrete plans in place for the beginnings of a U.S.-led lunar base in the late 2020s, and the preparations for a crewed Russo-Chinese presence on the Moon from the mid-2030s, a supplier base providing infrastructure, construction and manufacturing services to service the Early Phase, as defined by the working group, is already well in development. Perhaps the most mature element of this grouping is suppliers of pre-fabricated lunar habitation. However, with the recognized need for building materials for base safety, and testing of manufacturing technologies, a broader eco-system of suppliers in this category can be identified, even in the Early Phase.

With contacts for surface habitation yet to be awarded by any one space agency, current products are largely self-funded or in development under research and innovation funding. Nevertheless, a collection of likely suppliers in the Early Phase can be deduced by observing awarded funding, as well as current product and technology portfolios. Among the potential suppliers are Redwire, Cislunar Industries, Penguin Automated Systems, Moonrise Inc., AI Space Factory, AECOM, Relativity Space and Bechtel.

5.6.1.1. Infrastructure and Construction

Provision of Construction Materials: Several companies have conducted on-Earth demonstrations of technologies utilizing simulated regolith to produce usable construction materials and structures. ICON, a U.S.-based construction company, for example, recently 3D-printed a prototype rocket landing pad for NASA, which was specifically designed to disperse exhaust plumes to minimize risk to nearby structures. In Europe, Regolight, a consortium funded by the European Commission demonstrated 3D printing technologies for the purposes of sintering lunar regolith.

However, based on current plans for national lunar bases, it is likely that, if at all, suppliers of lunar building materials will be doing so in a proof-of-concept capacity. Based on current concepts, for example, NASA's foundational surface habitat will likely not incorporate building materials derived from lunar regolith. Initial operations in the early period are unlikely to require, nor close contracts with suppliers for, further infrastructure requiring lunar building materials such as landing pads or lunar roadways.

Most early-stage suppliers of building materials are either already in construction, or are in the aerospace manufacturing or space transportation business, and are using complementary technologies to develop lunar building material manufacturing capabilities.

Construction and Assembly: Given their considerable heritage, TRL of existing technology, and the risk profiles of the primarily government customers contracting lunar facilities, traditional primes in aerospace manufacturing are likely to be the primary suppliers of lunar facilities in the Early Phase. Companies such as Thales Alenia Space and Northrop Grumman have already been contracted to construct habitation elements of the Lunar Gateway, for example. While no contracts have been awarded thus far for surface elements, both companies, and others like them, would be likely prominent suppliers of the various types of facilities required.

This said, with the growth of new space and the success of more recently established space companies, particularly the awarding of large NASA contracts to such players, it is plausible that the provision of habitation and other facilities will extend to aerospace manufacturing companies beyond the traditional players. Bigelow Aerospace, for example, prior to its cessation of operations in March 2020, had proposed the First Base lunar base concept. Sierra Space's inflatable modules could be prime contenders for both orbital and surface habitation elements. It is conceivable that companies such as these may at least supply proof-of concept modules (such as the ISS BEAM module) to Early Phase lunar bases.

5.6.2. Mature Phase

5.6.2.1. Infrastructure and Construction

Provision of Construction Materials: Companies conducting tests regarding the provision of building materials in the early stage are likely to become fully-fledged suppliers of such materials in the Mature Phase. In addition, however, three further groups of likely suppliers can be identified. Firstly, there are the potential entities commercializing manufacturing techniques currently being developed in an academic setting. The market in the Early Phase for the products of these technologies is likely to immature for commercialization. However, at the Mature Phase, sufficient scale should be present for commercialization to be feasible. Second are current aerospace players who may not yet be in the business of providing building materials, but whose technology is highly complementary to this market segment. Relativity Space is an example here, as the company received funding from NASA for anomaly detection in 3D printed lunar structures. Last are current terrestrial building material companies, whose products do not present such high technological barriers to entry that entry into the lunar market would be infeasible.

Construction and Assembly: As the volume of people living on the Moon increases, so does the number of companies providing facilities for their survival. Given the existence of self-sufficiency in the Mature Phase, the provision of facilities will extend beyond small habitats, to a variety of facilities necessary for sustaining life (such as agricultural containment units). Therefore, we expect the variety of suppliers to extend beyond traditional aerospace manufacturers to companies that may have started out terrestrially, for example producing climate-controlled enclosures for food production. Notable is also that facilities in the Mature Phase are unlikely to be purely functional, and aesthetic, human-centered and livable design is likely to become more of a focus. Therefore, design and architecture firms, which at present are producing conceptual facilities, may play a more important role in the value chain of lunar facility provision.

5.6.2.2. Manufacturing

It is likely, though not certain, that certain components and parts may become more economical to produce locally, rather than import from Earth, in the Mature Phase. This opens up the possibility for certain firms specializing in ISRU production to manufacture such items from regolith for local use. These will by necessity be bound by materials made available by mining entities on the lunar surface at this stage. However, current companies with particular expertise in terrestrial ISRU, or 3D manufacturing techniques using easily sourced raw materials that are adaptable to a low gravity environment would both be likely candidates for future supplier status.

We identify three primary cases of lunar manufacturing for export to Earth. First is the value add of novelty and luxury products. Second is the production of parts, components etc. for export to Earth orbit, for example for satellite servicing purposes, or for the production of large orbital structures (e.g., space-based solar power stations). Third is the production of products that benefit from the lunar environment, for example due to its low gravity environment. This final category exhibits considerable uncertainty, given it is yet unclear whether in-space manufacturing for export to Earth will be dominated by orbital facilities. However, should lunar manufacturing for export to Earth occur, we see a high likelihood that similar players will operate in both domains. What this means for supplier types is that the Mature Phase is likely to see a mixture of traditional aerospace manufacturers, companies early-phase space startups focused on manufacturing, and consumer product manufacturers who are able to profit from lunar manufacturing.

Lunar inhabitants, once colonies are self-sufficient in basics required for survival, are likely to demand a wider range of products extending beyond the purely functional. Therefore, producers may also enter the market to specialize in consumer products and processed foodstuffs. Among likely producers, therefore, are current terrestrial beverage producers who may wish to sell their products to lunar tourists in particular. As in other areas, 3D printing is likely to be the dominant technology for production of physical products for sale to inhabitants. However, companies' commercialization of alternative production techniques, such as fungal colonies, for other products like chemicals and plastics, are also possible entrants.

5.7 Lunar Resource Extraction

5.7.1. Overview

The identification of suppliers for MT7 has been conducted following the same approach as for the customers, through a mapping and filtering process when companies are already positioned, and through more generic profiles for activities still too immature to have players officially working on it. The different is that instead of following the previous taxonomy and market segments, the review has been conducted per type of resource (molecules) to be supplied:

- Water, serving propellant and life support markets
- Regolith, serving construction and manufacturing market segment
- Metals, serving construction and manufacturing market segment
- PGMs and KREEP, serving this market
- He3, serving the energy market

The synthesis of these results is presented in Annex B, while details on the screening and selection process for each molecule are provided in the following paragraphs.

5.7.2. Suppliers of water – for in-situ propellant and/or life support

The identification of potential suppliers for in-situ propellant and life support markets have been identified based on a desk research-based screening of companies developing (or seemingly developing) technologies for water extraction. The results are very likely not exhaustive, but provide a first mapping of most of the potential actors that would likely be positioned on the market in a few years.

The selection of the most relevant players has been done mostly on the clear plans to address water with the technology developed, as well as clear plans to address the lunar market.

5.7.3. Suppliers of resources for in-situ manufacturing

As mentioned in the corresponding section in customers, suppliers of regolith and suppliers of metals have a different meaning for MT7. Because regolith is by definition readily available on the lunar surface, the only variable would be the regolith composition that varies with the location on the surface. Companies foreseeing to process regolith (for any application) which have been reviewed all seem to include the collection of the regolith for their own needs. They would just need to locate their operations in the right spot to have access to the right input material. Therefore, there is no case of a player identified as a regolith supplier.

The situation is different for metals, which are not readily available on the surface as an input material. Beside raw regolith and metals, there is no other material that has been identified as an input for construction and manufacturing processes (at least so far). The suppliers identified in this section are therefore suppliers of metals only.

There are a great many institutions studying, often under NASA contract, the possibilities of lunar mining, including New Mexico State University, and the Colorado School of Mines, and the following commercial entities:

Orbit Fab, Galactic Mining, Safbai, Xiphos Technologies, Deltion Innovations, Honeybee Robotics, Masten Space Systems, Ball Aerospace, Asteroid Enterprises, OxEon Energy, Teledyne, Sierra Space, Built Robotics, Austere Engineering, WGM, Bechtel, Terraxis, Kilncore, Caterpillar, Blazetech, Lockheed Martin, Etiam, TransAstra

5.8 Habitation and Storage

5.8.1. Supplier Segments

In the context of the Habitation & Storage market, the supplier segments are:

- By type of product used:
  Customers willing to buy a facility on the Moon will have different needs to the ones just looking to lease or rent a property.
- By end-user:
  Government agencies, commercial actors, and private individuals are all segments with different needs, especially from a political and financial viewpoint.

5.8.2. Early Phase Segments

Potential suppliers in the initial phase, up to 2030, will be mainly national space agencies, that will allow other nation or private companies to work and use their facilities in a partnership. Potential suppliers who have demonstrated an interest include: Penguin Automated Systems, Orbit Fab, ESA's Igluna initiative, Planetary Shelter, LLC, Wasp (Italy) and Astroport Technologies.

5.8.3. Mature phase segments

5.8.3.1. National Space Agencies

The assumption here is that government space agencies with the budget for human space exploration are considered as potential customers to lease, rent, and potentially buy (if the legislation will allow) facilities on the Moon surface and orbit. An emerging country with a limited budget will have a space program that consists mainly of launching satellites for national security, reconnaissance, survey, communications, TV, etc. so they will not be likely to have astronauts trained to go in deep space, and/or participate in international programs for human space exploration.

National space agencies that already have launched astronauts in space will have the technical know-how, economical capacity, and political will to send their astronauts to Moon facilities, therefore becoming potential customers of the suppliers of Moon orbital and surface facilities. To become clients, they will need to have also the financial capacity to send a crew as a national mission using their own budget. To find the final list of space agencies, we cross-referenced 2 sets of data:

- A list of national space agencies that already sent astronauts to space.
- The agencies' yearly budgets for the last 3 years (2018-2019-2020) and their 3-year average. This allows to smooth out bumps due to the "Black Swan" event in 2020 (Covid Pandemic).

5.8.3.2. Private Companies

In the Mature phase, resource-prospecting companies will become part of the customer base. There are no plans at the moment for private companies to do this before 2030.

5.9 Lunar Agriculture

5.9.1. General Supplier Segments

This section is intended to give an overview of the existing and anticipated future players amongst lunar base lunar agriculture and food production suppliers. To the extent possible, the potential suppliers will be associated with their likely market sub-segments, and an indication given of the maturity level of the supplier offerings.

5.9.2. Potential Suppliers: Early Phase

There is likely to be a specialized segmentation between suppliers working through various national space agencies to service the needs of government astronauts in lunar orbit and on the surface, and suppliers focusing on the private sectors related to lunar space tourism – assumed to be in lunar orbit only for this phase. The following companies are operating in ways that will allow the development of the lunar agriculture value chain:

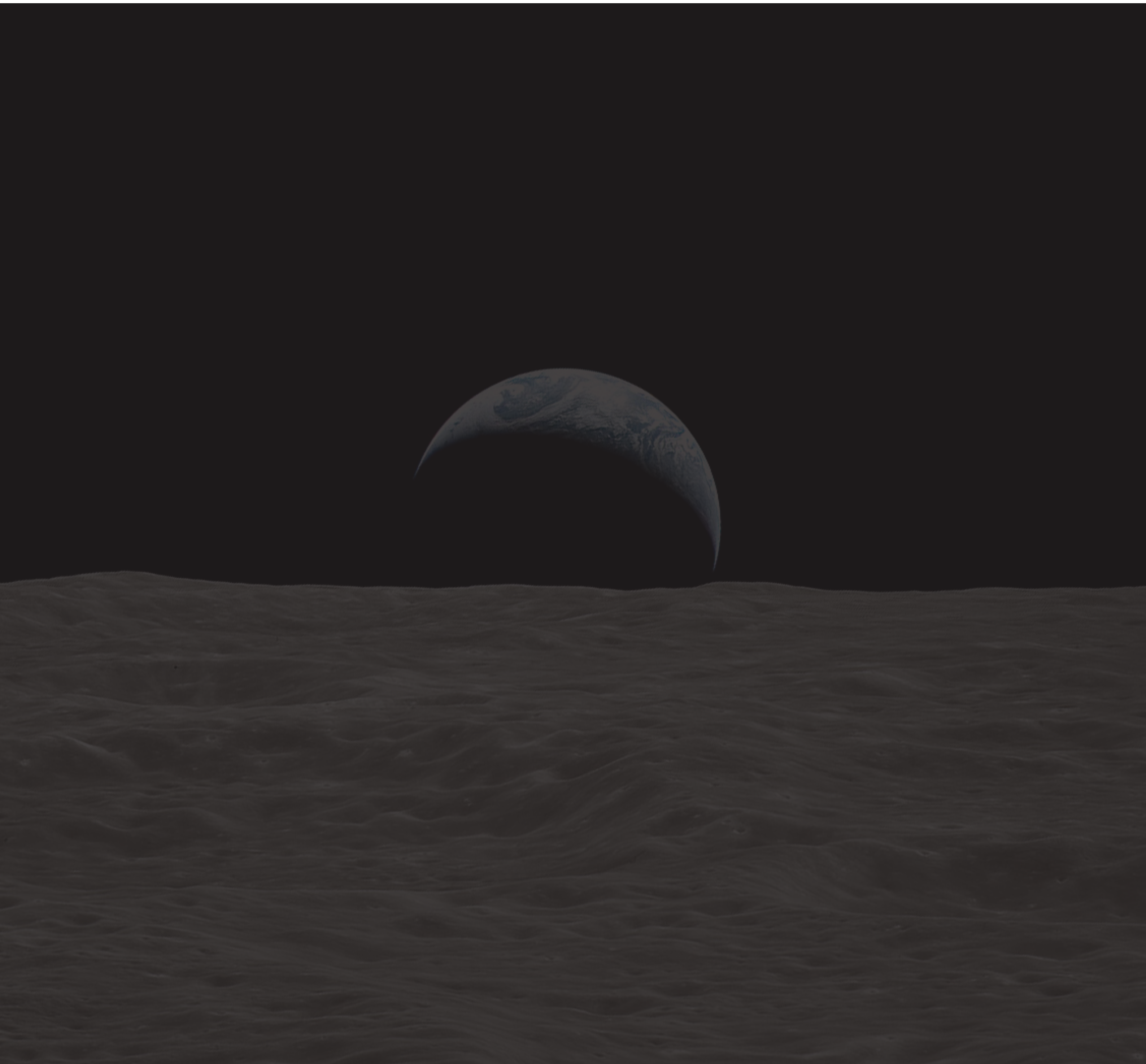
- Orbital Farm (Toronto, Canada) – Universal Food Project with climate change focus. Studying aquaculture, hydroponics, vertical farming, closed loop farms, agro-robotics, with a test project at Spaceport America (New Mexico, USA).
- Interstellar Labs Biopods (Ivry, France) – Constrained environment models for crop-cultivation, closed-loop regenerative production, AI controls
- Aerofarms (Newark, USA) – Founded 2004. Vertical farming, sustainable food system operation.
- In Farm (Amsterdam, Netherlands) – Vertical farming, urban farms, AI controls
- CropOne (Millis, USA) – Hydroponics, sustainable production, vertical farms
- Square Roots (Brooklyn, USA) – Indoor farming. Modular operation in enclosed spaces – shipping containers
- Bionetics (Yorktown, USA) – Since 1969. Certification/payload verification/ biological life science support/ test facilities in support of ISS operations.

5.9.3. Potential Suppliers: Mature Phase

It is anticipated that the same duality of supply options will persist into the Mature Phase, with the added perspective that lunar space tourists will be living in lunar surface hotels, serviced by the private sector suppliers, and all essential food supplies required for sustainability and life support for both governmental and commercial lunar inhabitants will be produced from lunar surface agricultural activities. There will probably be a change in the way revenues are collected with the inclusion of active lunar tourism hotels and restaurants on the surface.

The above tabulation would be continued into the Mature Phase.

6. Value Chains



6.1 Transportation To and From the Moon

The Transportation to/from the Moon and Lunar Vicinity value chain begins with the customer and extends to companies that enable provider operations. These include system providers, infrastructure operators, commodity providers and support equipment suppliers.

6.1.1.Early Phase

The Early Phase extends from the current time to 2030.

6.1.1.1. Value Chain

Customers wanting to send materiel (people, hardware, consumables) to the Moon are the driving force behind cislunar transportation value chain (Figure 6.1.). Transportation providers use Earth launch systems, orbit transfer systems and landers to serve their customers. Transportation providers buy propellant, use spaceports and order systems from prime contractors. Propellant providers support propellant producers. Prime contractors feed second and third tier suppliers and they all buy from material suppliers. Spaceports use A&E contractors to develop their spaceports, which in turn hire construction firms and support equipment providers to build and outfit the spaceports. Finally, spaceports may use cargo handlers to prepare payloads for transportation to the Moon.

The Moon to Earth value chain is very limited during the Early Phase. It is primarily a subset of the Earth to Moon value chain, limited to roundtrip personnel and sample return missions (Figure 6.2.). All customers and providers are Earth-based.

6.1.1.2. Market Interdependencies

The Transportation to/from the Moon and Lunar Vicinity market is divided into Tier 1 and Tier 2 customers. Tier 1 customers are Earth-based space agencies, research insti-

Figure 6.1. The Transportation to the Moon and Lunar Vicinity Value Chain during the Early Phase extends from the transportation providers to their suppliers, spaceports and their suppliers and payload handlers. (note: direction of arrow indicates flow of payments)

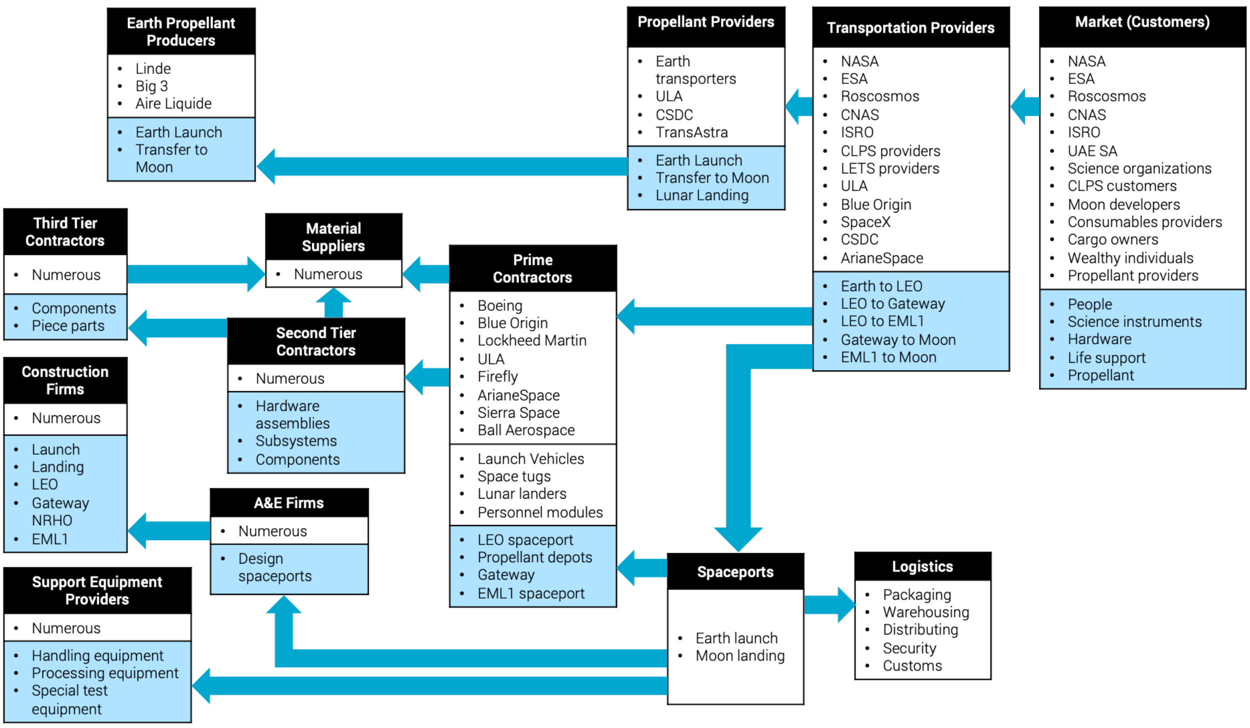
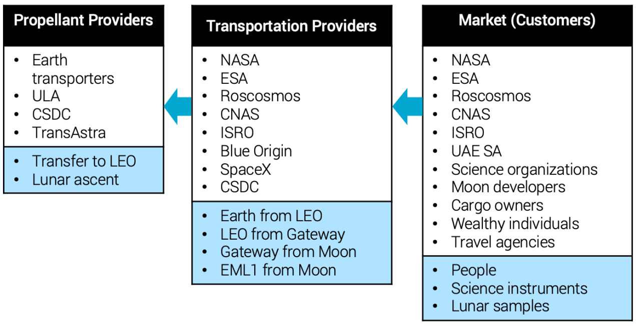


Figure 6.2. The Transportation from the Moon and Lunar Vicinity Value Chain during the Early Phase is limited to transportation providers and their Earth-based suppliers.



tutions, and commercial enterprises. Tier 2 customers are the other nine Market teams defined for this study: Lunar Surface Transportation (2); Communications & Navigation (3); Energy & Power (4); Lunar Products & Services (5); Infrastructure, Construction & Manufacturing (6); Mining & Resource Extraction (7); Habitation & Storage (8) and Agriculture (9). There are some interdependencies during the Early Phase.

Outbound: Outbound markets are from Earth to the Moon and lunar vicinity. Primary market drivers in the Early Phase are the Tier 1 customers, with space agencies being the largest percentage. There will be some market pull from Market Teams 2, 3, 4 and 8 as NASA, and perhaps other space agencies, move to a purchased services procurement model. Additional market pull may come from Market Teams 6 and 7 as companies move to prototype and demonstrate their technologies before full-scale deployment. Outbound customers will largely be hardware deployments with some personnel beyond space agency astronauts such as high net worth individuals and technicians supporting robotic equipment testing.

Inbound: Personnel from Tier 1 customers, high net worth individuals and Market Teams 6 and 8 will be the primary inbound market during the Early Phase. Return missions will also include lunar material samples.

6.1.2. Mature Phase

The Mature Phase will see new players in the outbound and inbound transportation Value Chain as additional Tier 2 Markets emerge on the Moon and companies exploit near Earth objects (NEO) to supply the cislunar economy.

6.1.2.1. Value Chain

The Mature Phase Outbound Value Chain has one additional player relative to the Early Phase value chain. Namely, Space Propellant Providers. This new entrant exploits near Earth objects (NEO) for volatiles and other resources providing them to the cislunar economy. Providers process NEO material, extract volatiles, produce propellants and sell them to companies operating propellant depots or transportation systems in the lunar vicinity and low Earth orbit.

The Mature Phase Inbound Value Chain includes elements based and operating in interplanetary space and on the Moon. These include Market Team 1 Tier 2 customers, NEO resource extraction companies producing propellant, lunar propellant producers, lunar spaceport operators and their suppliers, and cargo handlers (Figure 6.4.).

6.1.2.2. Market Interdependencies

The Transportation to/from the Moon and Lunar Vicinity market is divided into Tier 1 and Tier 2 customers. Tier 1 customers are Earth-based space agencies, research institutions, and commercial enterprises. Tier 2 customers are the other nine Market teams defined for this study: Lunar Surface Transportation (2); Communications & Navigation (3); Energy & Power (4); Lunar Products & Services (5); Infrastructure, Construction & Manufacturing (6); Mining & Resource Extraction (7); Habitation & Storage (8) and Agriculture (9). There are some multiple interdependencies during the Mature Phase.

Outbound: Outbound markets are from Earth to the Moon and lunar vicinity. Market drivers in the Mature Phase are the Tier 2 customers, with Tier 1 customers being a small contributor. There will be market pull from all Market Teams as they import products and people needed to support the lunar community population and growing econ-

Figure 6.3. The Outbound Transportation to the Moon and Lunar Vicinity Value Chain during the Mature Phase includes space-based propellant providers supplying cislunar propellant depots.

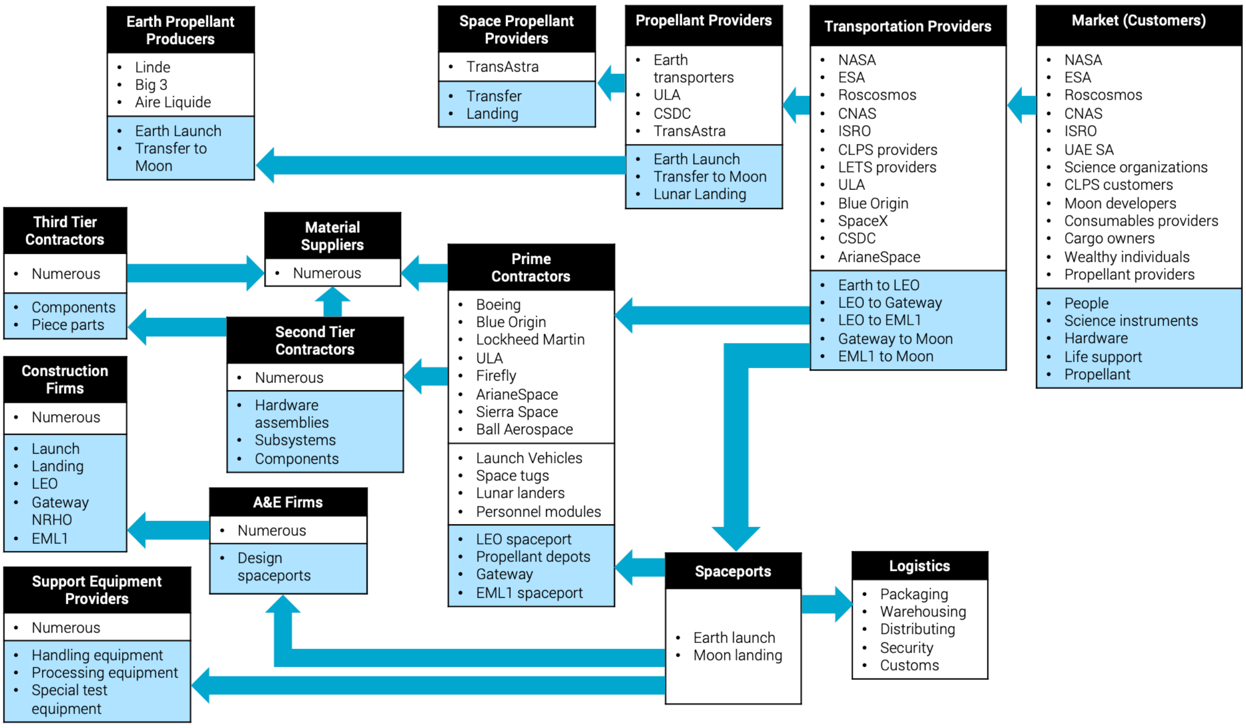
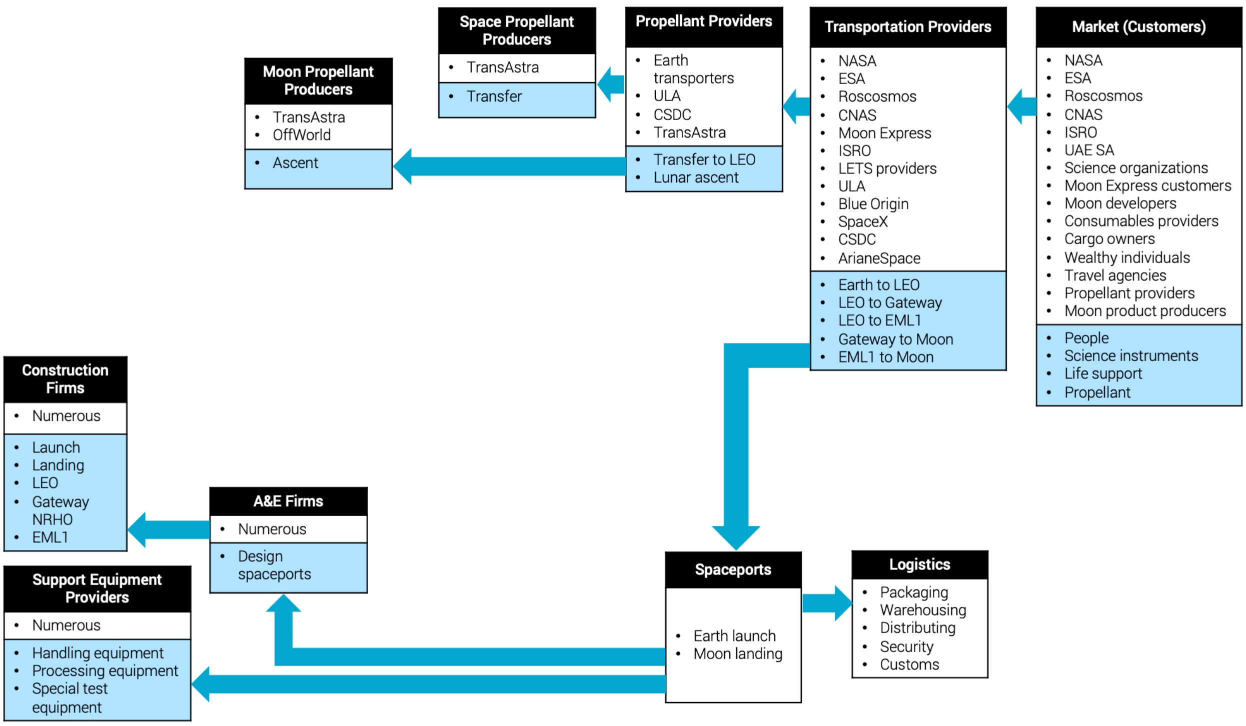


Figure 6.4. The inbound Transportation from the Moon and Lunar Vicinity Value Chain during the Mature Phase includes lunar and space-based propellant providers, spaceports and their developers plus cargo handlers.



omy. Additional market pull will come from high-net-worth individuals and adventure travelers for excursions to the lunar vicinity and lunar surface.

Inbound: Mature Phase inbound customers will include rotating surface personnel, returning adventure travelers, and high-value lunar products from Market Team 4 and possibly Market Team 6. There may also be limited scientific equipment returned to Earth to assess lunar environment impact and continued lunar sample returns for scientific studies.

6.2 Transportation On the Lunar Surface

Value chains in the transportation market are not expected to change significantly across the Early and Mature Phase. Therefore, the below provides generic descriptions of value chains that are valid across both phases.

6.2.1. Robotic Surface Transportation

The value chain for robotic surface transportation is outlined below. Suppliers of end-user transportation services may exhibit various degrees of vertical integration along the value chain. The payload subsystem may either be supplied by the service customer or the transportation provider in cases where the standard offering of sensors is sufficient for user needs. Particularly in cases where the payload is user-provided, transport providers will typically work closely with customers to integrate and test payload performance using the platform.

Value chain dependencies: The primary value chain dependency for robotic surface transportation is with M1 for transportation to the Moon, though many suppliers will also operate their own lunar landers, and offer an integrated services package including surface delivery. While most rovers in the Early Phase will carry their own power supply or recharge using their lander, it is possible that in the Mature Phase, suppliers may become dependent on M4 for power provision, or M7 for hydrogen if rovers are developed that utilize hydrogen fuel cells.

6.2.2. Crewed Surface Transportation

The value chain for crewed surface transportation is outlined below. While it is superficially similar to that of robotic surface transportation, crewed systems will be inherently more complex, particular in the case of vehicles that require a pressurized module and mobile Environmental Control and Life Support System (ECLSS). While crewed rovers will almost certainly be capable of autonomous and teleoperated mobility, it is likely that any vehicle intended for use by lunar tourists will also require an operator/host for the duration of any surface trip.

Value chain dependencies: Again, value chain interdependencies for crewed transportation will be similar to those for robotic transportation. However, the dependence on M7 for resources, particular water (for astronaut use) and hydrogen (for vehicles using hydrogen fuel cells) will be more widespread.

Figure 6.5. Robotic surface transportation value chain

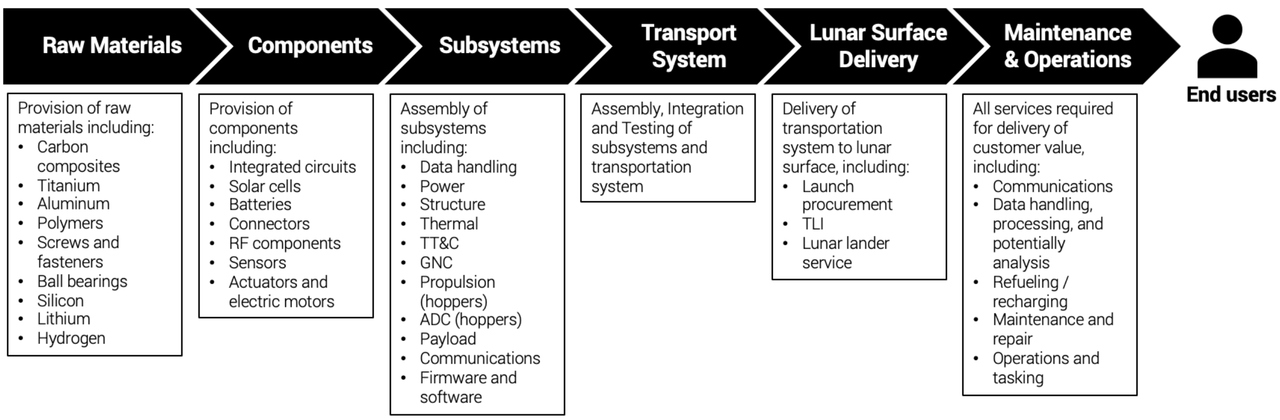


Figure 6.6. Crewed surface transportation value chain

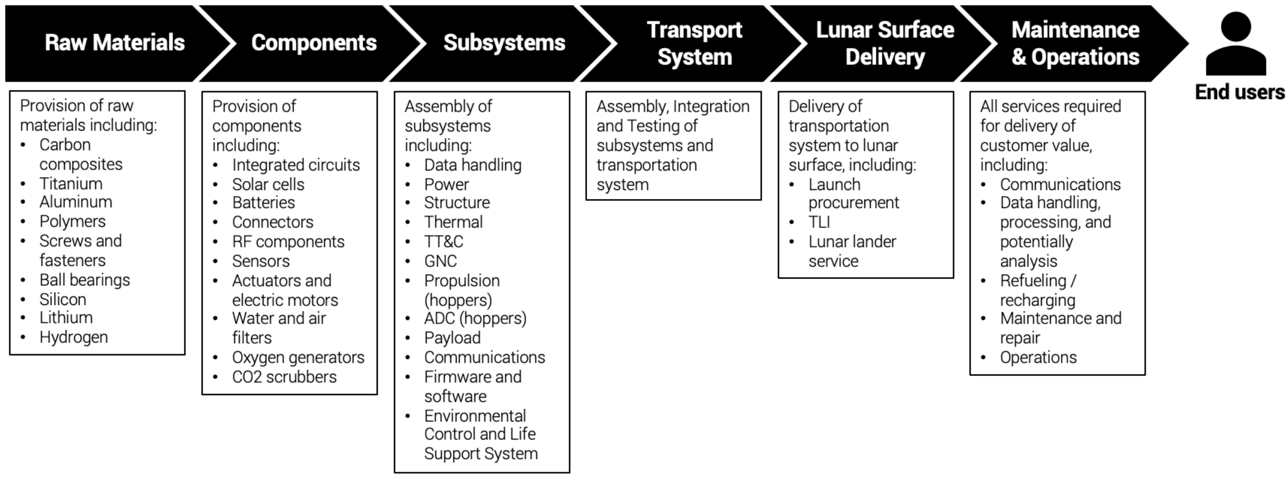
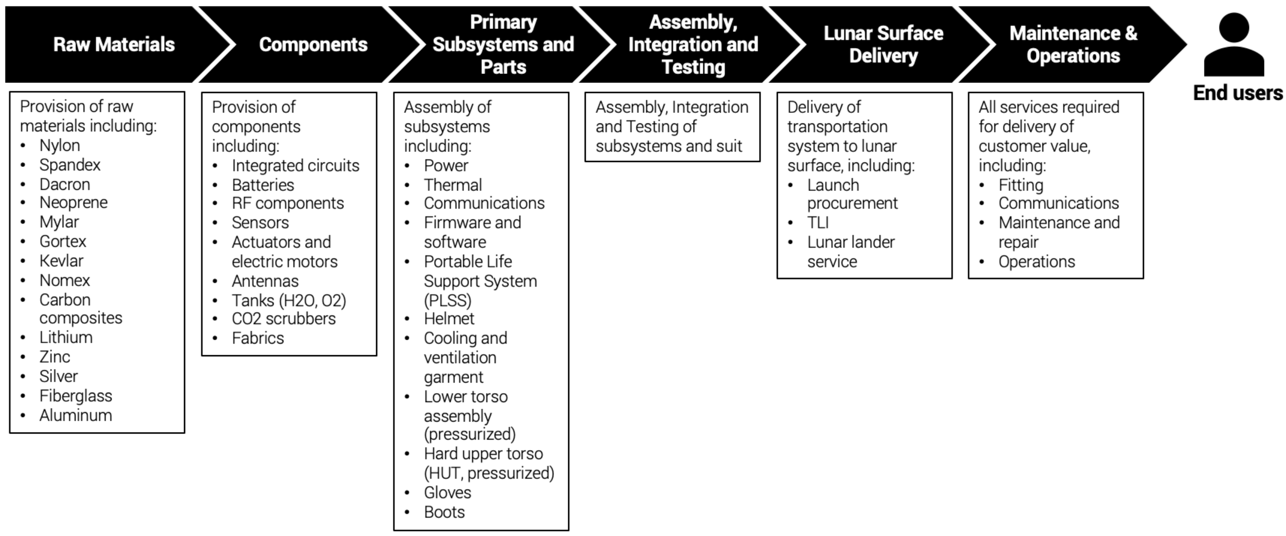


Figure 6.7. Spacesuit value chain



6.2.3.Spacesuits

The value chain for spacesuits is outlined below. As is indicated within the value chain, primary subsystems and parts may differ according to the spacesuit design utilized, with MCP suits likely not requiring a HUT. The maintenance and operations phase will also likely see varying degrees of supplier involvement, with government astronauts potentially taking up more of the workload involved, whilst lunar tourists will require more support.

Value chain dependencies: Like other forms of transportation, spacesuit providers will depend on M1 suppliers for transport to the Moon, though fewer spacesuit providers will also be providers of transport services to the Moon. As with crewed surface transportation providers, a likely dependency on M7 for water and oxygen will likely exist in the Mature Phase.

6.3 Communications and Navigation

6.3.1. Introduction and Overview

This section shows the value chain required to bring value to the customer segments identified in previous sections of the report. Its primary purpose is to outline the business model of suppliers in the market and to highlight any dependencies with other markets.

An overview of the high-level communications and navigation value chain is shown in Figure 6.8. This figure shows a generalized breakdown of the connections that the system has internally, to other market teams, to public organizations, to private organizations, and in terms of the Earth, Space, and lunar services, equipment, and systems that are connected to the core navigation and communication system.

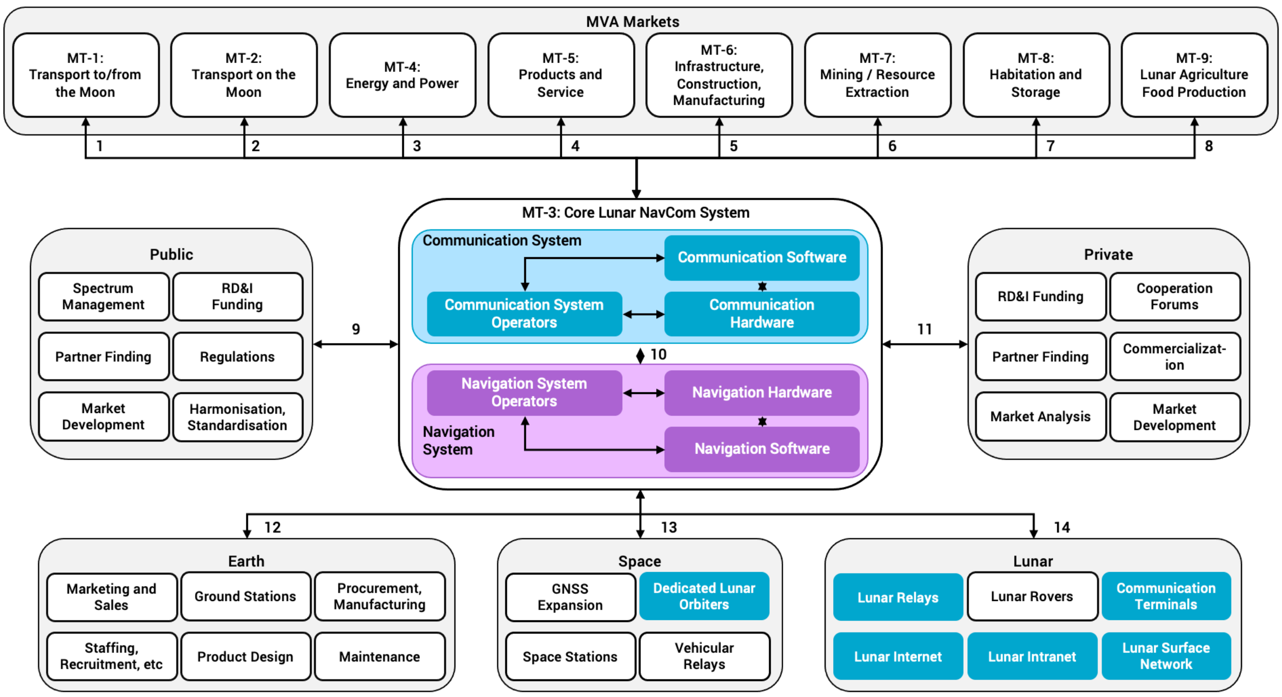
It should be noted that the top, middle, and bottom sections of the diagram have significant overlaps. As an example, a public or private organization (middle) might operate the ground stations (bottom left) or MT-1 (top) might launch the dedicated lunar orbiters (bottom right).

Each of the generalized links in the value chain is represented with an arrow, with a link to a larger box with a pale background implying that this is a link to all boxes within this. To keep this at a high level the links between items outside of the core system are not listed and the included links are simplified.

Due to the generalized nature of the value chain seen in Figure 6.8, this value chain is valid for both the Early and the Mature phases. The main differences between the two value chains would be that the activities would be scaled up across the entire chain, with the largest increases being seen in the lunar-based sections of the value chain and the increase in private funding.

An example of this is seen when looking at

Figure 6.8. A high-level overview of the connections in the communication and navigation value chain



research, development, and innovation funding (RD&I Funding) - in the Early Phase this funding would primarily come from the public sector, either wholly in the public sector or just funded by the public sector due to overall market trends where the public sector can conduct research that is 'for the good of the people' or in other words, research that would not have a return on its investment for many years.

Despite this, the RD&I funding still also belongs to the private sector of the chain during the Early Phase for a few reasons. Firstly, there exists a number of private companies that have historically performed this style of research such as Bell Labs, a company famous for being the largest private organization by the number of Nobel prizes awarded. Secondly, there exists some dual-use research topics, ones that would be used in the lunar systems but also exist in other applications so they are more likely to generate a return on the investment in an acceptable time frame. Finally, but not conclusively, the government-funded research is often including clauses for match-funding.

This would be solved by displaying a lower-level breakdown of the dependencies and connections, but such a quantification would belong in a later stage of this report, instead this section is to be used to comment on interdependencies, connections, and to only provide a high-level overview.

6.3.2. Value Chain and Description

A first analysis has been conducted using the Porter's value chain strategic framework and is seen in Figure 6.9. This analysis shows both the primary and secondary activities related to the services covered by this market team.

Figure 6.10. shows an alternative view of the value chain, this time constructed working backwards from the end users of PNT information backwards through the chain to the original manufacturers and regulators.

6.3.3. Market Interdependencies

This section of the report is intended to present market team interdependencies with a focus primarily on the outbound goods or services provided to other teams, but it does include a limited number of inbound links for connections to external organizations that are separate in the diagram.

Figure 6.9. The communication and navigation porter's value chain

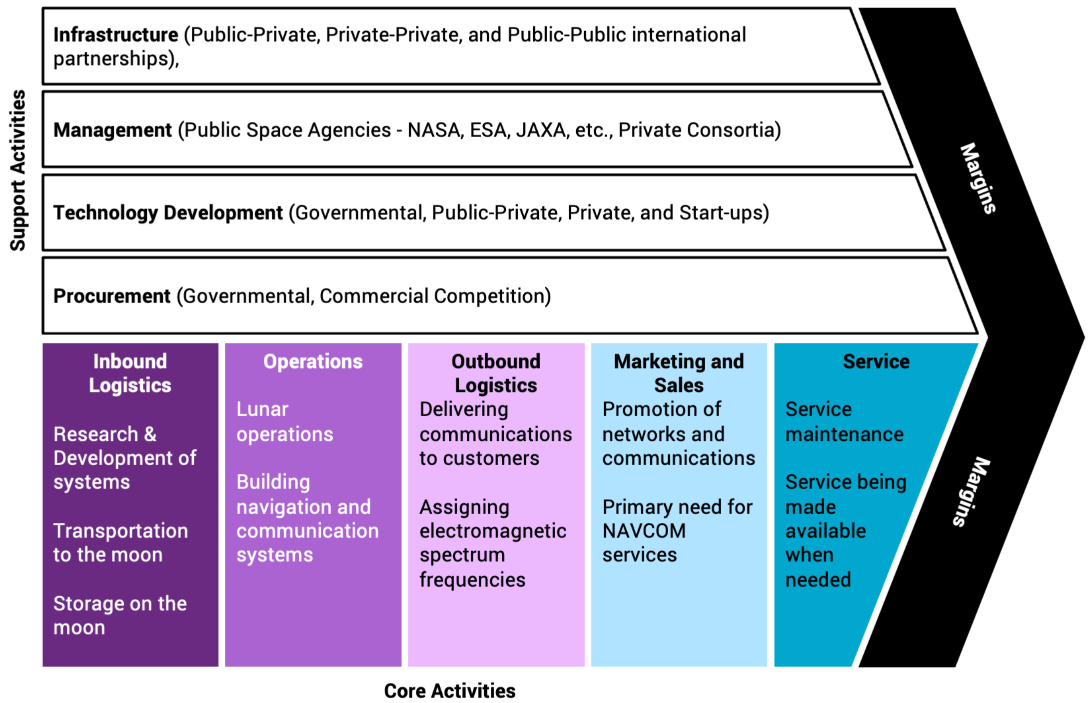


Figure 6.10. An alternative view of the communication and navigation value chain

Organizations / Standardizations	Manufacturers	System Integrators	System Operators	Added-Value Service Providers	End Users	Users of PNT Information
NASA EUSPA ESA JAXA International agencies Corporates Industry working groups NGOs Regulators Anyone not directly providing components or services, but who regulate, legislate, or are otherwise involved	OHB Systems SSTL Thales Alenia Space Airbus Boeing INVAP Lockheed Martin Maxar SAIT Honeywell IMT Safran ANYWAVES NanoAvionics SatLab GOM Space SpacePNT GMV NSL Broadcom Mediatek Trimble Qualcomm STMicroelectronics Samsung Anyone who makes components	Samsung Huawei Trimble Hexagon ICEYE Planet Inmarsat Iridium Hitachi ABB EAton Ericsson Siemens IBM Anyone who puts components together	SES Intelsat S.A. Eutelsat Inmarsat SSC KSAT NASA ESA Goonhilly AWS SpaceX Maxar Orange Anyone who operates the components once they're together	Hexagon Trimble Garmin Global Associations Universities Research Non-profits Anyone who provides additional services using this data but is not an end users themselves	Stakeholders from M1-9 who directly use the services and products	Research institutes Space Agencies Private companies Anyone who uses the information but does not get it direct from the system operator

The following tables provide the descriptions of the goods and services between the stakeholders in relation to the navigation and communication systems. It should be noted that this is not strictly mutually exclusive as there exists a significant amount of overlap between the requirements of the stakeholders. As an example, it is expected that a singular communication system is to provide almost the exact same service to all market teams as there is an inherent need for the market teams to coordinate with each other which by its very nature requires a method to do so.

In addition to this, another consideration to take in mind is that there exist overlaps between the different market teams and the external stakeholders. A prime example is that M1 covers transport to the Moon which would have an overlap with the 'Piggybacked Vehicular Relays' noted in Figure 6.8. This is because the ideal transportation to the Moon would include these relays as standard, but at the same time there is also a number of potential relays that are functionally identical but that wouldn't be covered by M1's analysis. An example of this is a passing research mission using the Moon as a slingshot, but that isn't intended to be a lunar mission. This lunar mission would be both an inbound link (providing relay services) and an outbound link (using our data to verify location or to coordinate with a lunar station to avoid collisions or interference.

Table 6.1. M3's outbound goods and services to other markets

Source	Destination	Good / Service
M3, 1	M1	• Communication service to allow vehicle to Moon to vehicle communication • Communication service to allow vehicle to space to vehicle communication • Communication service to allow vehicle to earth to vehicle communication • Location data to identify vehicle position respective to lunar assets, including landing site • Location data to identify vehicle position respective to space assets • Timing data to allow vehicle to follow mission schedule • Timing data to allow vehicle to be automated • Internet/Intranet to host the required systems for the operation of the services
M3, 2	M2	• Communication system to allow vehicle to communicate with lunar assets • Communication system to allow vehicle to communicate with space assets • Communication system to allow vehicle to request emergency assistance • Location data to identify vehicle position respective to lunar assets (guided navigation) • Timing data to allow vehicle to follow transport schedule • Timing data to allow vehicle to be automated • Internet/Intranet to host the required systems for the operation of the services
M3, 3	M4	• Communication system to communication inside the energy systems • Communication system to allow energy requirements to be transmitted to the systems • Timing data to provide resilience against interference • Timing data to act as a backup time reference source • Internet/Intranet to host the required systems for the operation of the services
M3, 4	M5	M5-a, M5-b, M5-c, M5-d-1, M5-d-2, M5-d-3, M5-d-4, M5-e-1, and M5-e-2 are all purchasing communication, navigation, positioning, and timing services from M3 for a wide range of purposes including but not limited to monitoring plants, patients, providing comms facilities for the emergency services, and other services as listed in M1-3. The demand for M3 services is split between activities on the lunar surface and in orbit, with the Early Phase favoring orbital services and the Mature Phase favoring lunar services.
M3, 5	M6	Communication and navigation services to be provided for both the construction and operation of any lunar surface asset
M3, 6	M7	Communication, navigation, and internet services to be provided to M7. Material moves through in-situ transport, meaning that all the supply chain would need to be tracked and tagged and communication between all assets is to be allowed.
M3, 7	M8	Communication and navigation services expected between all facilities.
M3, 8	M9	Communication and navigation services to be provided to M9.

Table 6.2. M3's outbound goods and services to external stakeholders

Source	Destination	Good / Service
M3, 9	Public	Provide services to governments, such as communicating with their astronauts
M3, 10	M3	The system is interlinked, meaning that it consumes its own services - the communication system uses time information to synchronize communication
M3, 11	Private	Provide services to companies, such as communicating with their astronauts
M3, 12	Earth	Provide requirements to ground stations and operational parts of the system
M3, 13	Space	Provide PNT data to orbiting and passing vessels

Source	Destination	Good / Service
M3, 14	Lunar	This is technically considered part of M3 itself, but in general the system will be providing PNT information to every single lunar asset, with assets such as relays, rovers, terminals, etc., being technically shared with other markets and stakeholders. An example could be that a lunar rover is part of M2, but the lunar rover itself is acting as a communication relay which is a core part of M3. To resolve this confusion, these assets are listed separately and are considered to be consuming the services of M3.

Table 6.3. M3's inbound goods and services from external stakeholders

Source	Destination	Good / Service
Public	M3, 9	• Manage the electromagnetic spectrum allocation • Provide funding and run RD&I activities • Act as a broker for collaboration between M3 stakeholders • Provide guidance and regulations on the M3 systems • Develop the market for the services offered by the M3 systems • Act to harmonize and standardize the systems used, ensuring compatibility
Private	M3, 11	• Procure hardware • Operate and coordinate systems • Provide funding for RD&I activities • Perform RD&I activities • Actively form collaboration partnerships related to M3 • Engage in cooperation forums, including with director competitors • Perform market analyses on the activities of M3 (i.e. Euroconsult's market studies) • Engage in (downstream) market development activities
Earth	M3, 12	• Communication link to allow for messages to be sent to and received by the Moon • Location and timing data to verify and calibrate on-Moon data • Operational support tasks such as requirement, staffing, HR, etc. • Design of the products - could also belong in private or public • Supply the system with the required products • Perform aftersales, manufacturing, and some maintenance activities required by M3
Space	M3, 13	• Provide initial and backup PNT data to the system through GNSS and other space assets • Host the lunar orbiters needed to act as core parts of the system • Act as an out of system communication link, for example, by either piggybacking unrelated missions or space stations to supplement communication capabilities
Lunar	MT-3, 14	Host lunar assets (Relays, Rovers, Terminals, Warehouses, etc) - this is also technically included in other MT's (e.g. M2), but has been included for completeness

6.4 Energy and Power

The value chain for energy and power intends to provide power to the end-user. The overall value chain begins with power generation, followed by transmission and distribution. Depending upon power requirements, and to add redundancy within the supply chain, power storage also forms an essential part of the value chain.

Based on the previously identified interdependencies with different markets, power should be provided to the end-user through a highly redundant distribution network. Like existing power distribution on the Earth, it is envisioned that a utility model shall be replicated on the Moon as well.

Power value chain operations may rely on both autonomous and humans-in-the-loop systems. For each category of power generation, transmission, distribution, and storage, it also becomes necessary to conduct environmental monitoring. The power generation category also requires decommissioning, long term storage, and recycling. In addition, deep repository storage may be considered in the case of nuclear power generation.

6.4.1. Mature Phase Value Chain Characteristics

6.4.1.1. Mature Phase Power Generation

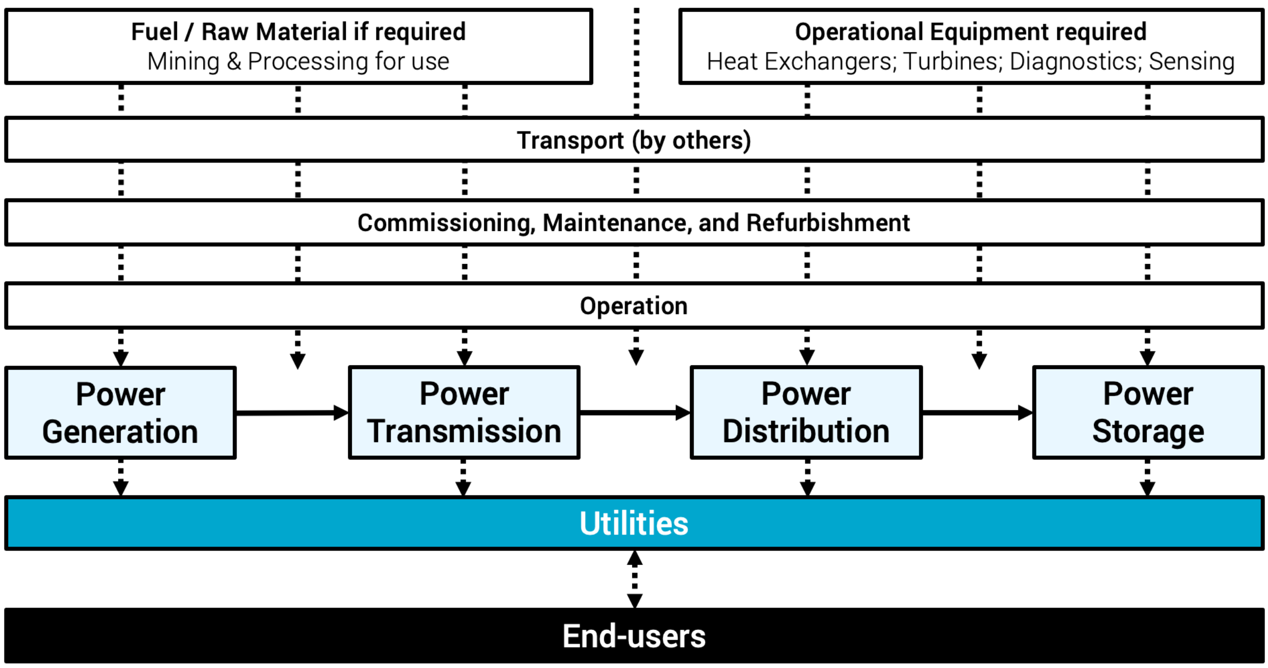
For nuclear, solar, and fuel cell supplies, equipment technology and specifications are likely too complex to be manufactured in Earth orbit or on the Moon by the mid-21st century. They may require near 100% dependence on imports from Earth for decades. In order to mitigate that dependence, it becomes necessary to store enough spare parts and maintenance equipment in order to cope for possible disruption of Earth supplies over a timeline of several years of self-sustenance.

In each of the below categories (nuclear, solar, fuel cells), the following services may be performed: environmental monitoring, decommissioning, long term storage, recycling, and, in some cases, deep repository storage.

6.4.1.2. Mature Phase Nuclear Power Generation

Nuclear power generation may depart from

Figure 6.11. Energy and power value chain



the Earth-based massive nuclear plant paradigm, to follow a miniaturization model. To avoid a single point of failure, at least 2 or 3 such nuclear power units may be installed in sufficiently secured facilities. All equipment necessary for construction, operation, and maintenance would be imported from Earth and rely on M1 for transportation. Construction relies on M6 services.

M5 supplies to M4 services for environmental monitoring, and of nuclear facilities decommissioning, long term storage, nuclear waste recycling, and deep repository storage.

Political and techno-economic decisions of which recycling method to follow may be complex and controversial if a facility is Moon-based. It may be that waste would have to be shipped back to Earth. An assumption that may be taken is that the Low Enrichment Uranium (LEU) option, currently considered and developed by NASA with commercial partners, may ultimately prevail against the High Enrichment Uranium (HEU) option for reasons including but not limited to complexity, costs, and security.

6.4.1.3. Mature Phase Solar Power Generation

Solar power generation may consist of both lunar orbiting units and lunar surface units. All equipment necessary for construction, operation, and maintenance, is imported from Earth. Construction is linked to M6 services. M5 may supply M4 with services of environmental monitoring and waste recycling.

6.4.1.4. Mature Phase Hydrogen Fuel Cells Energy Storage

Hydrogen fuel cell energy storage consists of multiple units of various sizes that are fit-for-purpose for either habitat, life support systems, transportation, agricultural, and industrial uses. All equipment necessary for construction, operation, and maintenance, are imported from Earth, though some degree of maintenance may be required on the Moon. Hydrogen may be supplied by M7 services. The water output may be recycled by M5. Integration in construction units relies on M6 services.

M5 may supply services of environmental monitoring, as well as hydrogen fuel cell maintenance and repair services: even though e.g., PEM proton exchange membrane technology can operate at low temperature, it's not entirely clear to what extent autonomous Moon-based maintenance and repair is affordable.

6.4.1.5. Mature Phase Power Transmission

Transmission will occur via:

- Cables for nuclear and surface solar, and potentially via wireless transmission
- Transmission via wireless device for orbiting solar power, dust permitting

Transmission may rely on M5 for storage and supplies of transmission-related equipment

6.4.1.6. Mature Phase Power Distribution

Grid management will depend on political and economic arrangements. The grid distribution architecture will depend on M5 facilities, M6, M7, M8 and M9

6.4.1.7. Mature Phase Power Storage

Storage units may be distributed in a decentralized fashion among user groups. A hierarchy of needs may well be followed with applications such as life support systems coming first.

6.4.2. Mature Phase Interdependencies

Power storage: All equipment being moved depends on M1 for outbound transportation from Earth to the lunar surface as well as supplementary transportation between the lunar surface and orbit. M5 provides M4 with environmental monitoring services for all power categories.

Mature Phase Nuclear Power Generation: Construction relies on M6 services. M5 supplies to M4 services of nuclear facilities decommissioning, long-term storage, nuclear waste recycling, and deep repository storage.

Mature Phase Solar Power Generation: Construction demand is linked to M6 services. M5 may supply services of solar panels and miscellaneous devices waste recycling to M4. M1 may supply services for back-and-forth transportation services to future solar waste recycling facilities in Earth orbit.

Mature Phase Hydrogen Fuel Cells Power Generation: Hydrogen is supplied by M7. The water output is recycled by M5. Integration in construction units relies on M6 services. Demand for anything that isn't being supplied by either nuclear or solar, is determined by M2, M3, M5, M8 and M9. Hydrogen fuel cells maintenance and repair services may be supplied by M5.

Mature Phase Power Transmission: Relies on M5 for storage and supplies of such transmission-related equipment.

Mature Phase Power Distribution: For a distributed grid architecture, this depends on M6, M7, M8, and M9

Mature Phase Power Storage: Power storage units depend on M2, M5 and M8

6.5 Supplies and Services

As noted earlier, for the special case of MT5, more detail is provided than is currently capable of being quantified.

6.5.1. Segment 5-a: Launchpads Operations and Maintenance

Pads are a stem and a component of a fully regulated Moon Port infrastructure, they are part and parcel of lunar outbound and inbound transportation value chains. There is no fundamental difference of the value chain structure itself between the Early Phase and Mature Phase. What changes is the nature of the pads as they evolve over time. This said, it is unlikely an operational landing pad will be built in the Early Phase, and therefore operation of pads is likely restricted to the Mature Phase

All sections in the value chain in Figure 6.12. may fall under the purview of a Moon Port Authority as a central structure which provides landing pad services to paying customers and contracts various suppliers. A final element of the value chain is the decommissioning and potential recycling of previous generation pads made obsolete and/or non-compliant.

6.5.2. Segment 5-b: Roadways Operations and Maintenance

The value chain for the operation and maintenance of roadways is very similar to that of landing pads. As with landing pads, it is considered unlikely that operational roadways will be present in the Early Phase. As with landing pads, an additional element of the value chain is decommissioning and recycling of previous generation routes made obsolete and/or non-compliant.

6.5.3. Segment 5-c: Operation of Depot for Supply of Water, Oxygen, Hydrogen, and Nitrogen

Suppliers within M5 of depot operation services are essentially end-user delivery-facilitators within the ISRU value chain. Therefore, for the sub-segments of propellant, suppliers within M5 can be seen as delivering to the end user within the value chains shown in Figure 6.19 of M7 and Figure 6.3. and Figure 6.4. of M1. For the life support sub-segment, a similar principle applies, and again, Figure 6.18. and Figure 6.19. of M7 can be referenced, as well as Figure 6.26. of M9.

Figure 6.12. Launchpad operations and maintenance value chain

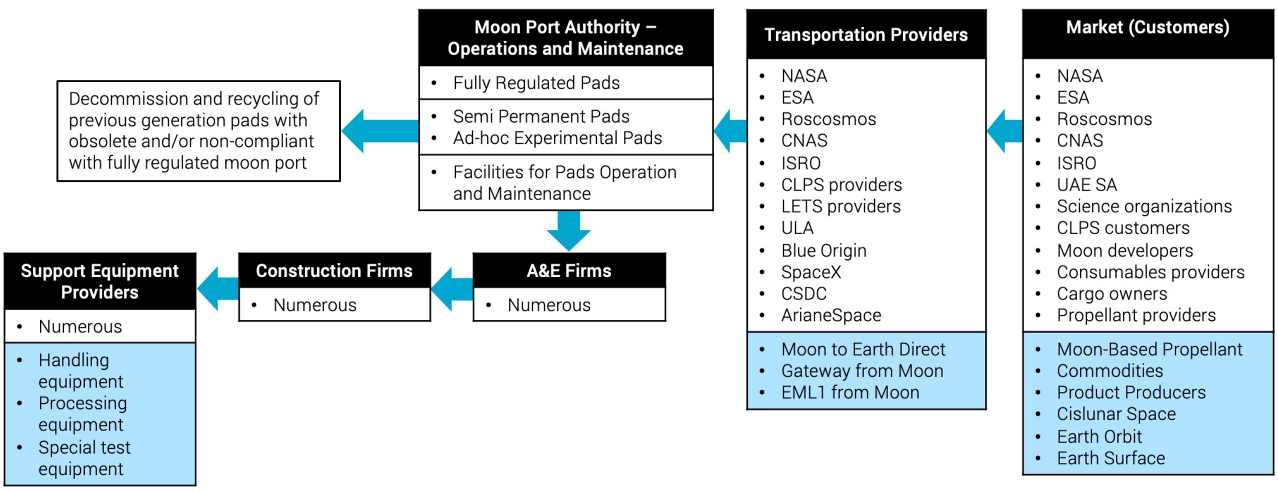
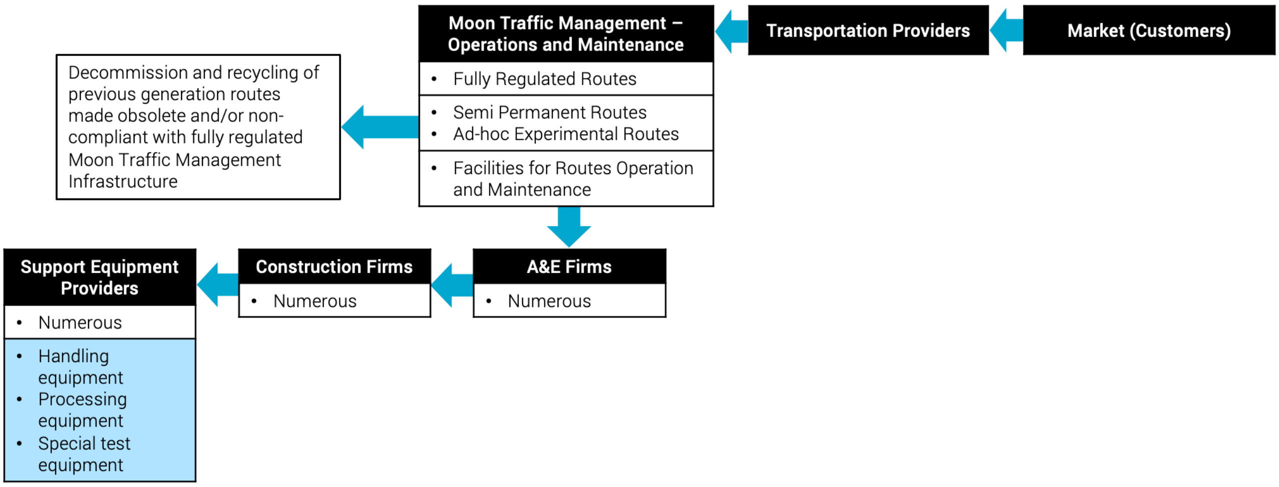


Figure 6.13. Roadway operations and maintenance value chain



6.5.4. Segments 5-d and 5-e

For the following two segments, a generic service/hardware delivery value chain can be visualized which generally holds true for both segments and their respective sub-segments.

- Segment 5-d: Miscellaneous Emergency, Medical, Recycling and Provisions
  - Sub-segment 5-d-1: Emergency/Fire/Rescue Services
  - Sub-segment 5-d-2: Medical/Health/Hyperbaric/Centrifuge facilities
  - Sub-segment 5-d-3: Non-Nuclear Waste Processing/Recycling
  - Sub-segment 5-d-4: General Provision Stores, Maintenance, and Repair
- Segment 5-e: Data, Fintech, Governance includes 3 sub-segments:
  - Sub-segment 5-e-1: Data
  - Sub-segment 5-e-2: Fintech
  - Sub-segment 5-e-3: Governance

6.6 Infrastructure, Construction, Manufacturing

Michael Porter defines "Value Chain" as a representation of a firm's value-adding activities.[69] Value chains encompass the full range of activities and services required to bring products or services from its conception to sale in its final market. Value chain includes producers, inputs suppliers, operation, processors, retailers and buyers.[70]

According to Porter, most organizations engage in hundreds, even thousands, of activities in the process of converting inputs to outputs. These activities can be classified generally as either primary or support activities that all businesses must undertake in some form. The primary activities are:

1. Inbound Logistics - involve relationships with suppliers and include all the activities required to receive, store, and disseminate inputs
2. Operations - are all the activities required to transform inputs into outputs (products and services)
3. Outbound Logistics - include all the activities required to collect, store, and distribute the output
4. Marketing and Sales - activities inform buyers about products and services, induce buyers to purchase them, and facilitate their purchase
5. Service - includes all the activities required to keep the product or service working effectively for the buyer after it is sold and delivered

The secondary activities are:

- Procurement - is the acquisition of inputs, or resources, for the firm
- Human Resource management - consists of all activities involved in recruiting, hiring, training, compensation and laying off personnel
- Technological Development - the equipment, hardware, software, procedures, and knowledge in the firm's transformation of inputs into outputs
- Infrastructure - serves the company's needs and ties its various parts together, it consists of accounting, legal, finance, planning, public affairs, government relations, quality assurance and general management

Value chains for "Infrastructure, Construc-

Figure 6.14. Infrastructure value chain on the Moon

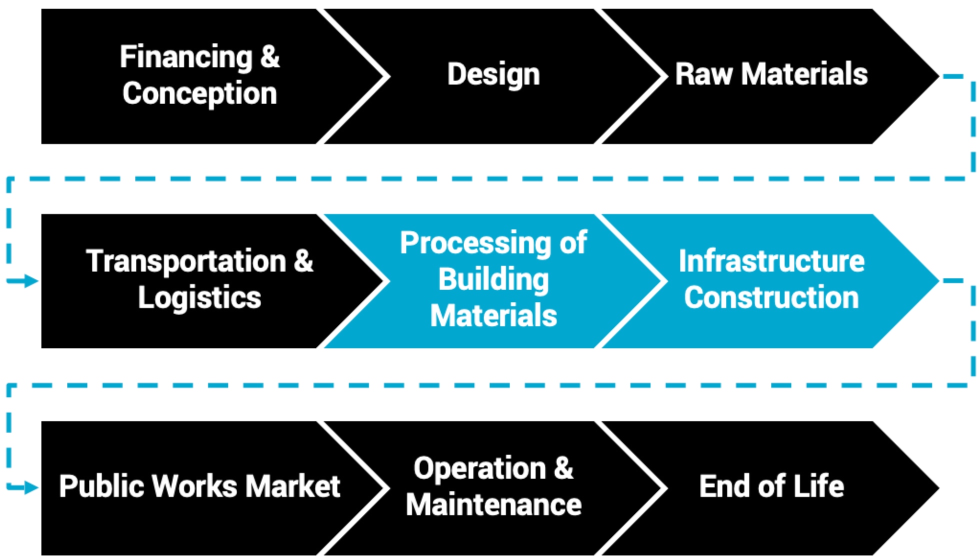
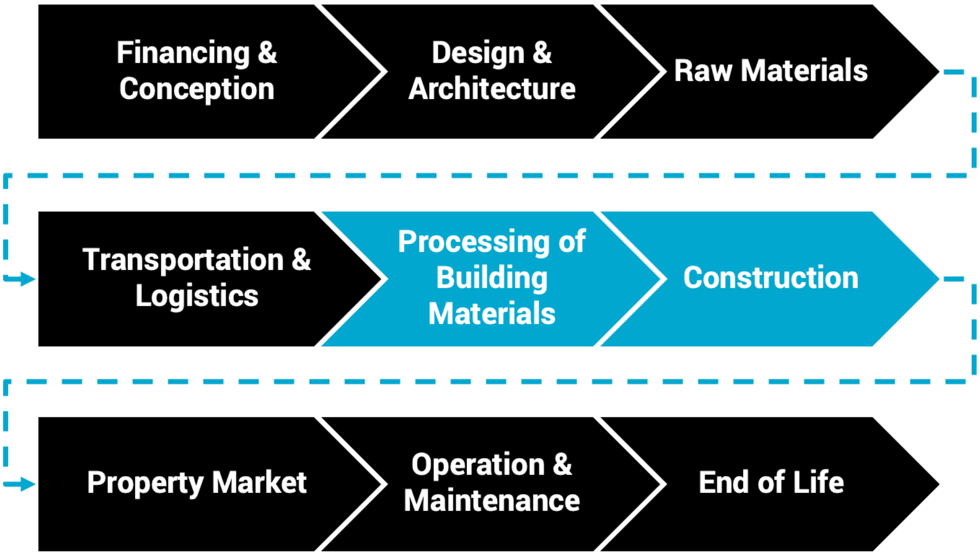


Figure 6.15. Construction value chain on the Moon



tion and Manufacturing on the Moon" have been organized by the 3 main themes of infrastructure, construction and manufacturing. The work has been inspired by Bahn-Walkowiak, 2012[71]; One Planet Network, 2020[72]; Tritschler, 2018[73].

6.6.1. Infrastructure Value Chain

Infrastructure, Construction and Manufacturing is responsible for building the physical infrastructure on the Moon including making the construction materials. Value chain with our activities in blue are in Figure 6.14. Responsibilities for other activities fall elsewhere.

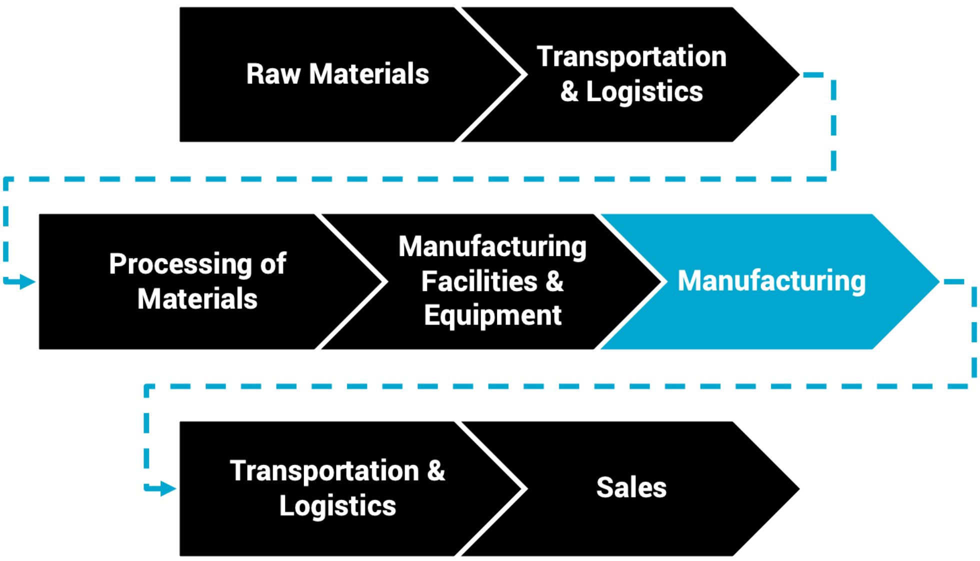
6.6.2. Construction Value Chain

Infrastructure, Construction and Manufacturing is responsible for building the physical infrastructure on the Moon including making the construction materials. Value chain with our activities in blue are in Figure 6.15.

6.6.3. Manufacturing Value Chain

Infrastructure, Construction and Manufacturing is responsible for building the physical infrastructure on the Moon including making the construction materials. Value chain with our activities in blue are in Figure 6.16.

Figure 6.16. Manufacturing value chain on the Moon



6.7 Lunar Resource Extraction

6.7.1. Methodology

We combine Moon Environment First Principles with Earth Mining Value Chain Analogues, more specifically a model formalized by the Canadian (Saskatchewan) potash and uranium industry since 2012. Coincidentally, an excerpt of this model was also used during Space Resources Week 2021.

6.7.2. Moon Environment First Principles

Resources extraction on the Moon is primarily linked to surface mining such as shoveling and superficial drilling. The lunar physio-chemical environment has a direct impact on the Value Chain: The low gravity (1/6 of Earth) environment implies specific hardware and maintenance. Regolith dust issues necessitate measures such as material corrosion mitigation, safety distances and other safe operational practices, as well as specific maintenance. Thermal vacuum and temperature variations have a direct impact on the mining hardware and process. There is no possibility of outdoor activity that implies the use of oil, water, or any physio-chemical process: every process must happen internally, which also implies transportation to specially designed ISRU facilities. In addition, there are legal and regulatory constraints along frameworks that are inherited from space law, the Outer Space Treaty, its accompanying body of Conventions, and any other relevant national and international laws, regulations, and treaties. In particular, various legal and regulatory considerations around space resources and utilization frameworks, mining property and use rights, data property and use rights, codes of conducts, zoning, non-interference, due regard, safety distances, deconfliction and dispute resolution processes, may impact the value chain. This may all remain work-in-progress in this decade and the next ones in accordance with the mechanisms of adaptive governance.

6.7.3. Earth Mining Value Chain Analogues

Mining development on Earth broadly follows 4 steps in time: Exploration (7-10 years), Development (5-10 years), Exploitation (2-20 years), Closure (2-10 years). This Exploration phase is particularly critical as it must make sure to determine the exact location, accessibility, and quantity of exploitable resources from their initial 'inferred resources' status, and, last but not least, the economic viability of their development and exploitation phases.

However, what is critical to understand for the value chain, is that mining companies are essentially general logistics and administrative management companies that fully rely on an ecosystem of contractors. What mining companies do generally comprises:

- Managing cash flow
- Managing legal and regulatory factors
- Developing their own technological 'secret sauce'
- In some Earth locations, managing security (itself sub-contracted)

6.7.4. Implications for Moon Mining Value Chain

The broader Lunar Commerce and Economics timeline, split along an Early Phase (until 2030) and a Mature Phase (from 2040 or later) with a Transition Phase in between, may be somewhat synchronized along the successive stages of the Moon Mining Value Chain as they unfold, from exploration and development to exploitation and closure.

However, a technically and economically

critical stage is needed to happen ahead of exploration, development, exploitation, and closure: it is the transportation of the required equipment to the Moon, and its storage. The Moon mapping stage may include access, sampling, testing, inventory, data exploitation. The Moon mining process may be defined by an outdoor phase (shoveling, surface drilling, transportation) and an indoor facilities phase (sintering, beneficiation, resource extraction).

Each phase of exploration, development, exploitation, and closure may include steps such as waste treatment, data exploitation, and legal and regulatory compliance and enforcement. However, overall, we may want to assume that a lunar (and space) mining company may be organized in a fashion similar to an Earth mining company, with a few nuances.

A Moon Mining company may act as a general logistics and administrative management company that fully relies on an ecosystem of contractors. What it would do itself is:

- Managing cash flow
- Managing its proprietary data (if water is the Moon oil, data is the gas)
- Developing its own technological 'secret sauce'
- Managing legal and regulatory, of which compliance and security (some sub-contracted) are an essential feature of safe, peaceful, and sustainable Moon activities.

For the rest, a lunar mining company would also have to establish its own flow chart of procurement and contractual processes. It would initially have to concentrate on exploration, then establishing and building surface infrastructure.

1. The procurement segmentation could be broadly split along 3 groups:
2. Electricity, comms, computing, electronics
3. Logistics, handling, storage
4. Waste management at all stages, cleaning, and decommissioning

Mining suppliers are (traditionally) split between top tier established firms, a second tier of parts and services suppliers, and a third tier of raw material suppliers, who are expected to pass qualification flow charts and codes of conduct.

Data services, which are geared toward adaptive governance, may include (and not be limited to) commercial, legal, tech, safety, security and sustainability uses, etc.

Most companies active in the 'Lunar Mining' sector today are potential suppliers of products and services along the lunar mining value chain, but not 'Moon Mining' companies per se.

6.7.5. Specific complexities of ISRU Value Chain

The ISRU cycle may be conceived of as follows[74]:

1. Exploration and planning
2. Site preparation
3. Excavation (schedule of quantified 'ore' reserve mixed in regolith)
4. Beneficiation (ratio of grade recovery enrichment, and waste treatment/storage stage)
5. Extraction (yield of chemical conversion process, and waste treatment/storage stage)
6. Final product storage or consumption

At each stage 1 to 6, data exploitation, repair/maintenance, regulatory actions are involved.

6.7.6. Specific role of Data in the Moon Mining Value Chain

Data has a value chain of its own at all stages of the Moon Mining cycle[75]:

- For mission planning: data relevant to landing zones and exploration missions.
- For geological modelling on the Moon: data relevant to science activities and resources.

- For resource estimation: data relevant to volumes, grades, distribution, and structure, on surface and below.
- For reserves quantification: data relevant to the economic value and size of lunar resources deposits: data for volumes, grades, and accessibility of extractable resources, that have technical and economic viability, including the optimum sequence of extraction

For modelling and optimization of the ISRU/SRU Value Chain: data relevant to estimation of optimum capacities and productivity based on parameters for extraction (mass extracted over time and number of units needed), beneficiation (throughput/mass recovered over time and recovery percentage), refining (throughput/mass refined over time and refining percentage), optimum method of extraction, optimum technologies for beneficiation, etc. is required

Data is directly relevant to all subsequent stages of development, exploitation, and closure, including waste treatment/storage and regulatory measures. Data is essential at all steps for other aspects such as safety, security, sustainability and governance of the Moon Mining operations, and compliance with various codes of conducts, within an international context.

Data will play a critical role also due to necessary human-machine interaction, since a number of tasks in the SRU and ISRU cycles will be performed by robots and autonomous systems under various degrees of human-in-the-loop supervision. This is also dependent on communications and navigation, computing infrastructure and portable power supply.

6.7.7. Lunar Mining Value Chain in the Early Phase

As a reminder, there are no independent permanent Moon facilities in the Early Phase. Each mission brings their own power supply and hardware for autonomous use by each mission. Toward the end of Early Phase, some storage facilities may be built to store equipment.

There is a common Value Chain for the below 5 market segments in Early Phase:

- Transportation providers bring the mission to the Moon then back to Earth
- Earth-based scientific and process equipment providers supply the hardware
- Each mission carries its own independent power supply
- Mission results including data are supplied to the customer who paid for the mission

Activity differentiation for each market segment doesn’t change this Value Chain pattern.

It is expected that purely experimental activities may occur in the Early Phase in the following areas. While the flight of these experiments represents demand for M1 and M2, they are likely not in themselves revenue generating materials within the lunar resource extraction market, unless the data generated by them is commercialized and sold.

- Extraction of water for propellant use in in-space servicing
- Extraction of water, oxygen and nitrogen for life support
- Extraction of raw material for future infrastructure and parts construction; Hydrogen for fuel cells; Nitrogen-based fertilizer
- Extraction and production of: PMGs (Platinum Metal Group elements); REE (Rare Earth Elements); K and P (potassium / potash and phosphorus / phosphate mostly for use as fertilizer)
- Extraction and production of Helium-3 for (still highly speculative) utilization as nuclear fusion fuel

6.7.8. Moon Mining Value Chain in Mature Phase

In the Mature Phase, there are independent facilities, and the market is fully developing for ISRU on the lunar surface and in orbit, in cislunar space, and in Earth orbit. The value chain in the Mature Phase is shown in Figure 6.17., which is informed by the information in the previous sections, and draws from value chain and operational chain concepts put forward by ispace (2021)[76] and Alves (2021)[77]. Figure 6.18. (adapted and distilled from Alves, 2021), puts forward a high-level view of the ISRU functional flow, with M7-related activities highlighted blue. Finally, Figure 6.19. summarizes the addressable markets served by the M7 value chain.

Figure 6.17. The Market 7 Mature Phase value chain

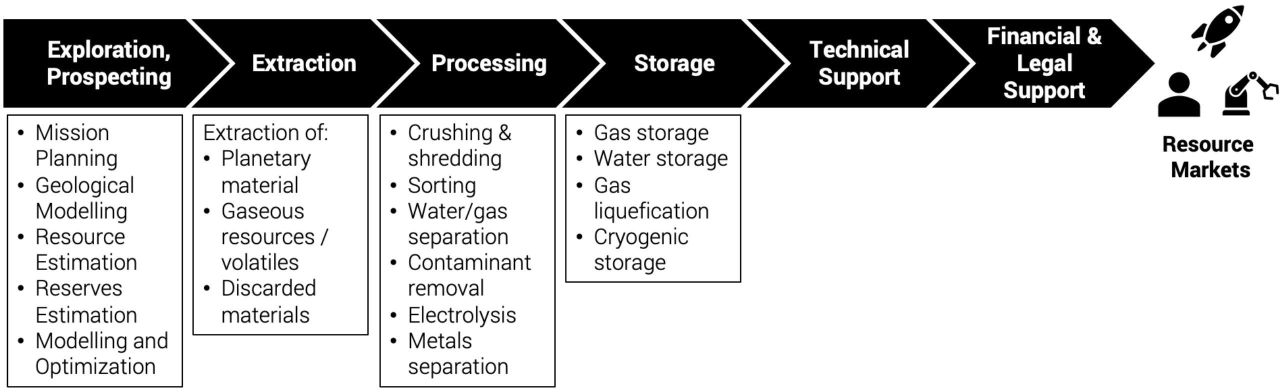


Figure 6.18. The Market 7 operational chain

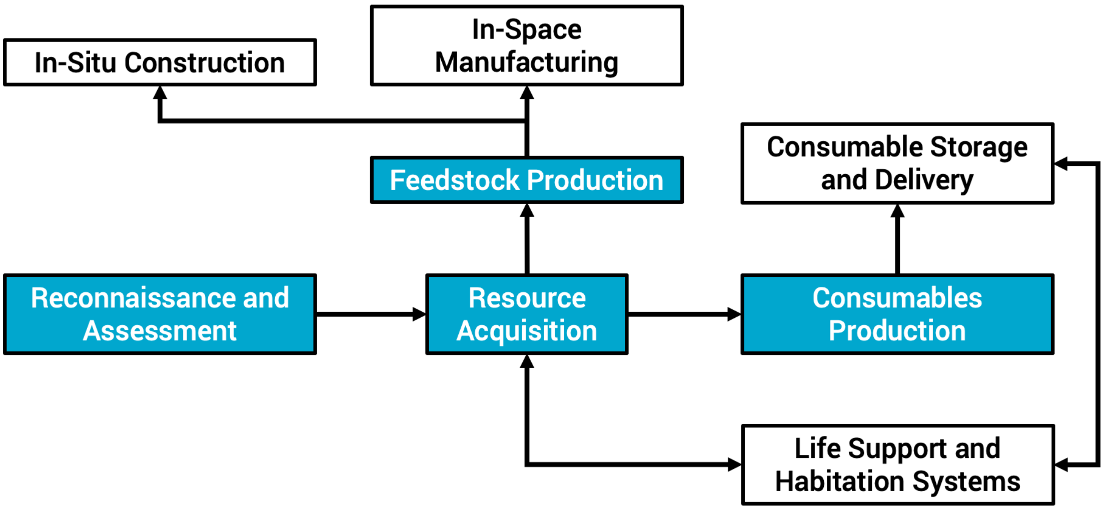
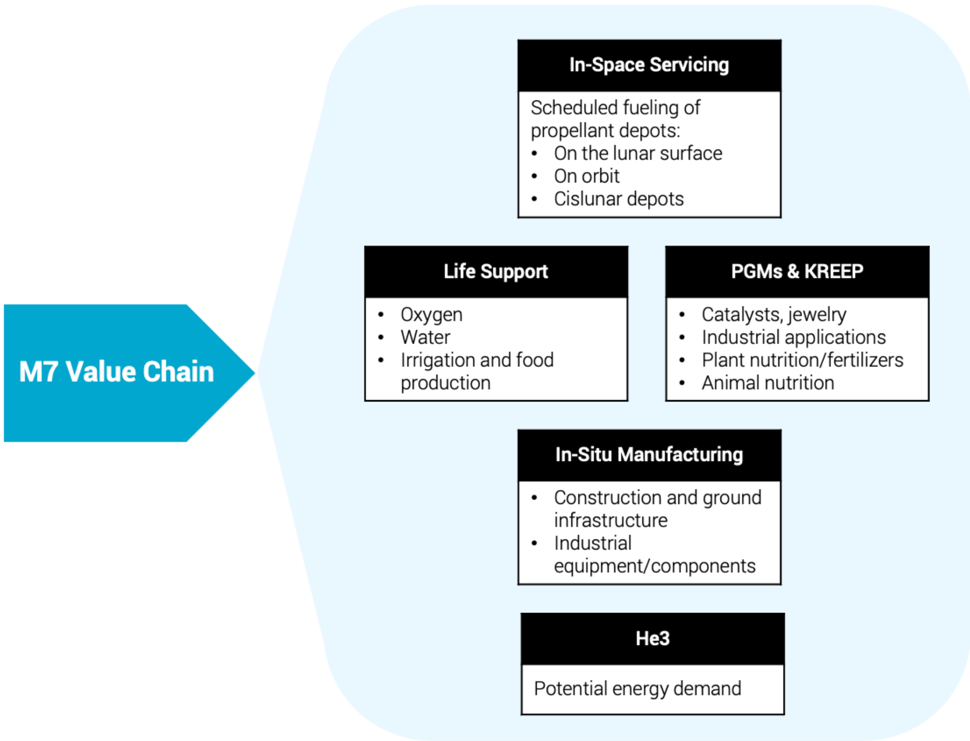


Figure 6.19. The demand side of the Market 7 value chain



6.7.9. Moon Mining Value Chain Interdependencies

By the Mature Phase, value chain interdependencies are clearly identifiable.

6.7.9.1. In-Space Servicing

The Interdependencies for In-Space Servicing Value Chain are:

- M1 for scheduled and emergency refueling of propellant depots, spacecraft and miscellaneous facilities from lunar orbit to Earth orbit
- M2 for scheduled and emergency refueling of propellant depots on the lunar surface
- M4 for power supply on the lunar surface
- M8 for construction of propellant depots on the Moon
- M5 for ISRU waste recycling stages, for pre-consumption removal of toxic elements and molecules in lunar water; for recycling of water, of multiple origins, post human, vegetal, animal, and industrial use; and for data management and exploitation
- M6 for all components manufacturing that might be sub-contracted to it

6.7.9.2. Life Support

The interdependencies for the Life Support Value Chain are:

- M1 for transportation of life support material (breathing, drinking, irrigation and food production) to locations in lunar orbit, cislunar space, and Earth orbit
- M2 for transportation of life support material (breathing, drinking, irrigation and food production) on the lunar surface, which implies comms and nav (M3).
- M4 for power supply on the Moon and in orbit.
- M5 for ISRU waste recycling stages, and for data management and exploitation
- M8 for storage of life support finished product and equipment on the Moon
- M6 for all components manufacturing that might be sub-contracted to it
- M9 for irrigation and food production on the lunar surface and elsewhere

6.7.9.3. In-Situ Manufacturing

The interdependencies for the In-Situ Manufacturing Value Chain are:

- M1 for transportation from the Earth's surface, Earth orbit, cislunar space, or lunar orbit, of any equipment and parts that can't be produced on the lunar surface
- M2 for moving equipment, machines, tools, parts and components for construction, infrastructure etc. on the lunar surface, which implies comms and nav (MT3)
- M4 for power supply on the Moon and in orbit
- M5 for ISRU waste recycling stages, and for data management and exploitation
- M8 for storage of in-situ manufacturing products and equipment on the Moon
- M6 for all components manufacturing that might be sub-contracted to it

6.7.9.4. PGMs & KREEP

The interdependencies for the PGMs & KREEP Value Chain are:

- M1 for transportation from the Earth's surface, Earth orbit, cislunar space, or lunar orbit, any equipment and parts that can't be produced on the Moon surface, and for transporting PGMs (Pd, Pt, Rh, Ru) and REE to manufacturing facilities in lunar orbit, cislunar space, Earth orbit, or the Earth's surface (if added value economy allows)
- M2 for moving, on the lunar surface, equipment, machines, tools, parts, components for construction, infrastructure etc., and for transporting PGMs (Pd, Pt, Rh, Ru) and REE to lunar surface manufacturing facilities, which implies comms and nav (M3)
- M4 for power supply on the Moon and in orbit
- M5 for ISRU waste recycling stages, and for data management and exploitation
- M8 for storage of In-Situ manufacturing products and equipment on the Moon
- M6 for all components manufacturing that might be sub-contracted to it
- M9 for use of phosphate/potash in plant nutrition and phosphate in animal feed

6.7.9.5. Energy (Helium-3)

The interdependencies for Energy (Helium-3) Value Chain are:

- M1 for transportation from the Earth's surface, Earth orbit, cislunar space, or lunar orbit, any equipment and parts that can't be produced on the lunar surface, and for transporting Helium-3 supplies to relevant nuclear fusion locations in lunar orbit, cislunar space, Earth orbit, or on the Earth's surface
- M2 for moving, on the lunar surface, equipment, machines, tools, parts, components for Helium-3 production, and for transporting Helium-3 supplies to lunar surface nuclear fusion facilities, which implies comms and nav (M3)
- M4 for conventional (not Helium-3) power supply on the Moon and in orbit
- M5 for ISRU waste recycling stages, and for data management and exploitation
- M8 for storage of in-situ manufacturing equipment and Helium-3 supplies on Moon
- M6 for all components manufacturing that might be sub-contracted to it

6.8 Habitation and Storage

6.8.1. Early Phase Value Chain

The value chain of our market in this phase includes the following activities:

- Material mining and refining. This also includes pre-finished steel products (sheets, pipes, etc.,), chips, wires, electrical components manufacturing, and other similar base-level components.
- Inbound logistics, meaning all the activities involved in transporting the output of the previous phase to the next phase.
- Complex components and subsystems manufacturing. This includes assembling pumps, light fittings, CO2 scrubbers, solar panels, radiators, and other subsystems.
- Prime contractors collect the output of the previous phase from multiple separate suppliers and assemble this in a final product, which could be a space station, a lunar base, or a lunar lander.
- Outbound logistics, sending the final product to its location of use. This could be a launcher sending the space station from the Earth's surface to its operational orbit, or a pressurized module to the Moon's surface to be covered by regolith for radiation protection.
- Operations and Maintenance - This comprises all the activities of MT8, which include a lease, rent, and sales of facilities, as described in section A.

An example of such a chain can be done for the Lunar Gateway station, where there is already a well-defined value chain. The customer base described here merely represents the possibility for commercial use of the station, as no contracts have been signed yet for commercial entities to use the Lunar Gateway.

The main difference with the Mature Phase is that some phases will be done on Earth, in contrast to being done on the lunar surface or orbit, in particular the sourcing of materials and the construction phases. In fact, construction will actually be manufacturing, defining manufacturing as assembling of a lander, module, or other pressurized vessels done inside a warehouse, in opposition to construction as an operation that is performed predominantly "in-situ".

Figure 6.20. Value chain Early Phase

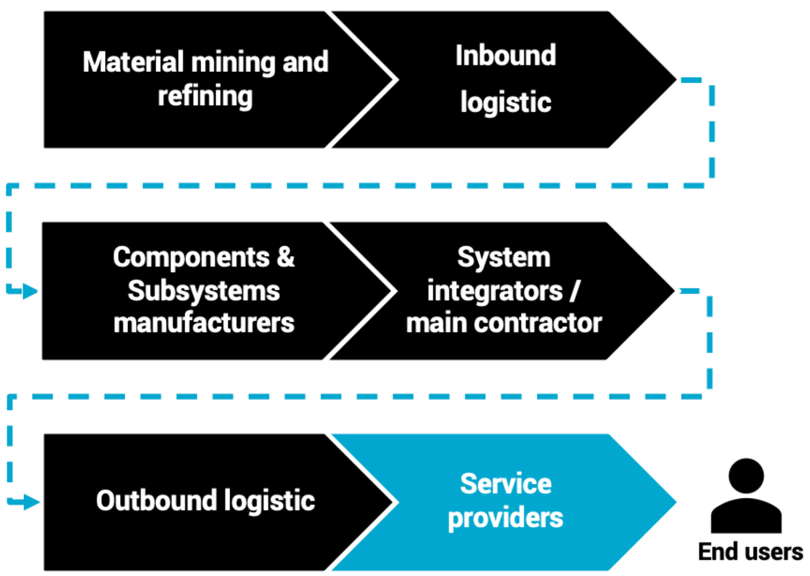
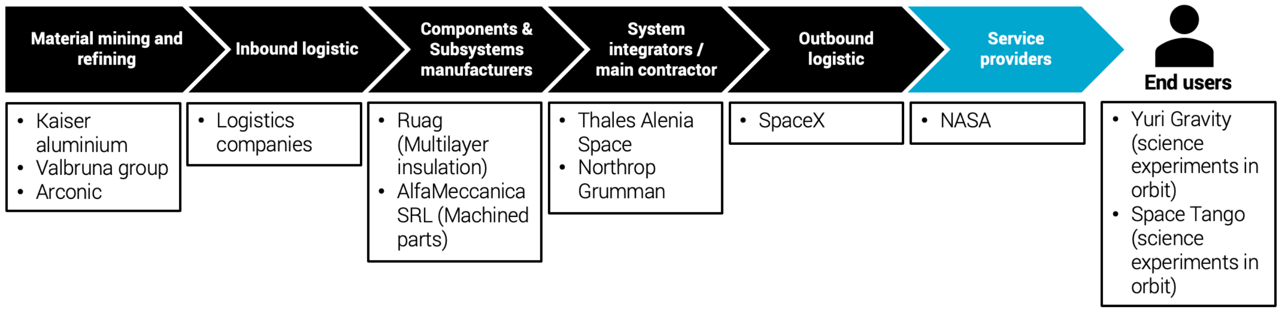


Figure 6.21. Lunar Gateway value chain.



6.8.2. Early Phase Market Dependencies

6.8.2.1. Inbound Interdependencies

In the initial phase of Moon settlements, the main supplier of services and products enabling the Housing and Storage lease, rent and sale market segment will be:

- M1 - Earth/ Moon Transportation will supply inbound and outbound travel service to/from the properties. As mentioned in the market definition, this service can be incorporated in the M8 service provided, where the entity includes the transport from Earth to the Moon, and then rent a space in the Lunar Gateway station orbiting the Moon in Halo orbit for example. At the moment of writing such an agreement has not been made public yet, but it is a possible business case for the Gateway.

The following market segments will not be represented by commercial entities in the Early Phase,

- M2 - Moon Surface Transportation Services will supply services similar to M1, but on Moon's surface. It is unlikely that such services will be available for commercial use in the Early Phase.

The following market segment services will be integrated into the Early Phase of habitation and storage management, and there will not be a commercial entity providing them, as the customer segment would be very limited if not non-existent in this phase.

- M3 - Comms and navigation: Known contracts from commercial entities supplying comms services and products to the M8 Market are:
  - o Communication & Power Industries "CPI" (to provide hardware to aid communication, telemetry, and data functions during the docking and berthing of the Lunar Gateway modules in orbit)
- M4 - Energy & Power: habitation and storage facilities will have integrated power generation systems, like solar energy panels for orbital stations like the Lunar Gateway, as well as power storage systems like batteries. Power transmission and distribution will be integrated in the power generation and storage assembly hardware. Known commercial suppliers for the Early Phase are:
  - o Deployable Space Systems (DSS) / Redwire (deployable solar panels to the Lunar Gateway)

The product provided can also be considered within the scope of the M6, as it could be seen as a tier 1 supplier to the construction company building the Lunar Gateway.

- M5 - Lunar products and Services: Water supply and management, waste management, Oxygen (atmosphere likely O2/N2) supply and management will be part of the ECLSS systems, and each product is managed by a particular subsystem, similar to the ISS ECLSS system configuration.

The Emergency & Fire rescue and Medical services will be implemented by the crew using the habitation and storage system. At this early stage, there would be no commercial case for a separate commercial entity to provide such services.

Manufacturing and Goods production will be limited in scope, 3d printed for internal use of the habitation complex. However, there is a business case to be made, where some selected commercial entities provide blueprints and files for the 3d printer, in particular for spare parts. These commercial entities may provide a maintenance service pay-as-you-go to the crew using the facility. Possible candidates are:

- Thales Alenia Space (Halo module, ESPRIT Module, I-Hab, Lunar Gateway)
- Northrop Grumman (Halo module, Lunar Gateway)
- Maxar (Power and Propulsion Element PPE, Lunar Gateway)
- Made in Space / Redwire (3d printing technology, already used in ISS)
- Paragon Space Development Corp. (ECLSS to Lunar Gateway)

Finally, the Fuel production and management will be a product and service that again the supplier of Habitation and Storage service will include in its own scope.

- M6 - Infrastructure, construction, and manufacturing: in this Early Phase there will be mostly government agencies providing this product to the M8 market. Possible commercial entities, providing habitation and storage facilities are:
    - SpaceX (Starship used as a camp base in the Early Phase after landing)
    - Blue Origin (Blue Moon Lander, storage and potentially habitation)
    - Firefly (the Blue Ghost lander offer storage/payload capacity to the commercial user up to 50kg)
- M9 - food production: This will be integrated by the facility managing entity as a service (food supply from Earth via cargo) or in situ crop production. No known commercial entity has been awarded a contract for this so far.

6.8.2.2. Outbound Interdependencies

The services of M8 of Storage can be used by

- M2 - storage of Moon surface transport vehicles
- M5 - storage for lunar products
- M6 - Storage for construction materials and tools
- M7 - storage of extracted resources and tools.

The services of MT8 Habitation (residential, hospitality and commercial-like offices) can basically be used by all other market segments to host their workforce, external contractors, executive team internal movements.

Nasa in particular can create a business case using the Lunar Gateway for private scientific research, tourism, and logistic operations.

6.8.3. Mature Phase Value Chain

The value chain of our market in this phase includes the following activities

- Extraction of raw materials: this can include prospecting, all the financing activities that a mining company may require, the actual extraction of the materials through different processes.
- Refinement and manufacturing of materials for construction: This can be done by a company that is already doing the previous activity, depending on the size, financial capacity of the company.
- Design and engineering of the facility (orbital, surface). This activity can be performed by companies doing the construction, in a “Design & Build ” contract, or variation of the same with some portion of the design done by external consultants.
- Financing of the project.
- Construction/Manufacturing phase.
- Operations and Maintenance - This includes all the activities of M8, which in-

clude a lease, rent, and sales of facilities, as described in section A.

- The loop can be closed if, at the end of the life of the product (the building), the material is recycled, entering the Extraction / Refinement initial phase.

The value chain can assume different configurations depending on the customer base (private and government) and the kind of contracts that are put in place to deal with the suppliers. This can be conceptualized three main configurations.

6.8.3.1. Customer base > Commercial service provider > Developer (1 tier)

The customer base can be either private or government, while the supplier of the service is a commercial entity (Figure 6.22.). The 1st tier supplier can be a developer that coordinates its own construction company, designers, and raises financing for the project. The finance for the project can be raised from the developer from Tier 2 suppliers, which could be either institutional funds (like a sovereign fund) or private equity. A small variation of this configuration can be in the developer team, where the supplier of design and construction services is one entity working with a Design & Build procurement.

6.8.3.2. Customer base+ Service provider (Government) > Developer (1 tier)

In this case, a government is its own customer and manages the facilities (Figure 6.23.). The state then becomes the customer of a private developer that provides the 1 tier service like in the previous configuration A. In this configuration, the government can decide to finance the entire development, or it can set up a private/public partnership with the developer, that will participate with private funds and will have some form of income from the government.

6.8.3.3. Customer base commercial and private + Service provider (Government) > Developer (1 tier)

In the third option, the government provides the M8 service and fund for the development, but it allows commercial and private customers to use its facilities, as well as other governments (Figure 6.24.).

Again, the financing can be entirely government funds or a private/public partnership with the suppliers of tier 1.

Figure 6.22. Visualization of the value chain: Customer base > Commercial service provider > Developer (1 tier)

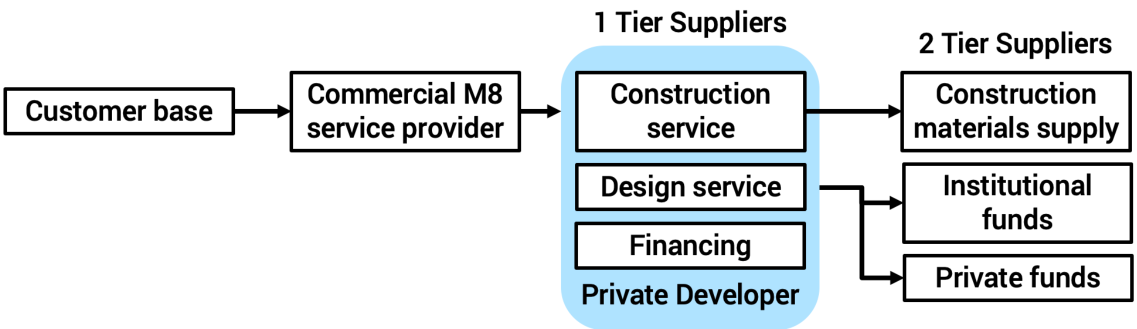


Figure 6.23. Visualization of the value chain: Customer base+ Service provider (Government) > Developer (1 tier)

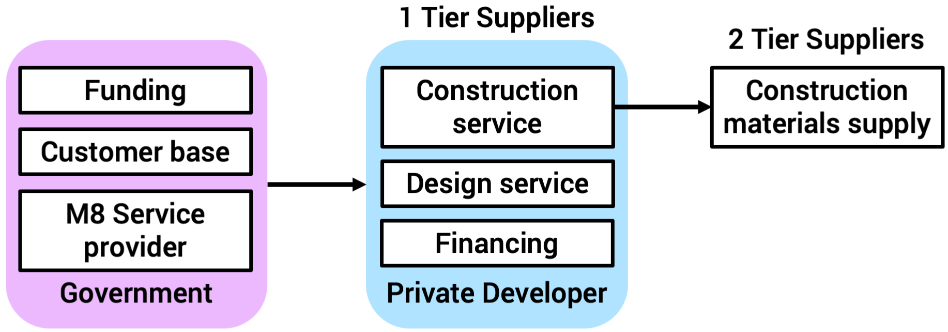
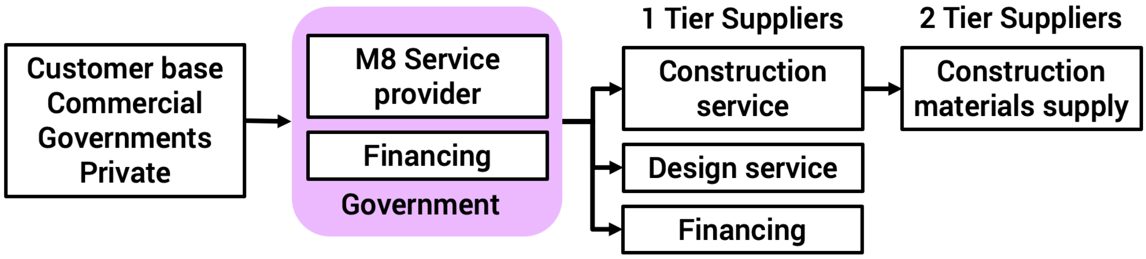


Figure 6.24. Visualization of the value chain: Customer base commercial and private + Service provider (Government) > Developer (1 tier)



6.9 Lunar Agriculture

In this section, we outline in effect the business model of the suppliers in this market, and identify the way in which they evolve over time from Early to Mature phase. Each value chain is represented by a tree graphic, which portrays the explanation of what is happening at each link in the chain.

6.9.1. Early Phase Value Chain

For the Early Phase, the following key steps are involved:

- Importing Food – packaged, freeze-dried vegetables, fruit, initial supplies of seedstock.
- Preparation and Processing – importing cooking utensils, microwave ovens, etc.
- Distribution – including intermediate low temp storage
- Consumption – by international government astronauts and lunar orbit space tourists.
- Food waste recycling – as with the experience of space stations, including the ISS.

6.9.2. Early Phase Market Interdependencies

In this part of the portfolio, we describe the relationships with other market teams assumed to be relevant during the Early Phase.

Several teams provide goods and services as input to this lunar Agriculture and Food production market: M1, aided by M2, provides initial terrestrial supplies; M4 provides energy to grow the food products, M7 provides the necessary water and Oxygen. Then, in turn, this market team provides inputs to the general provision stores of M5 (which also receives the food waste for onwards recycling), and to the hotels and restaurants of M8, and in general supplies all food to the occupants of the Moon and the lunar orbit facilities.

6.9.3. Mature Phase Value Chain

For the Mature Phase, the following modified key steps are involved:

- Importing Food – as in 6.9.1, but limited to only premium items not available locally.
- Production of Food
  - Vegetables, from seedlings and pollination (pinto beans, tomatoes, rice, potatoes, arugula)
  - Fish, from fish eggs (tilapia, shrimp, silver carp)
  - Animals, eggs (from chickens), rodents, maybe goats for milk/cheese.
  - Insects
- Preparation and Processing
  - Facilities and Infrastructure – garden zone, hydroponics, aquaponics, ovens, automated farming machinery, tanks, etc.
  - Storage
- Distribution – low temperature facilities (4° C and sub -20° C), general store out-

Figure 6.25. Early Phase value chain

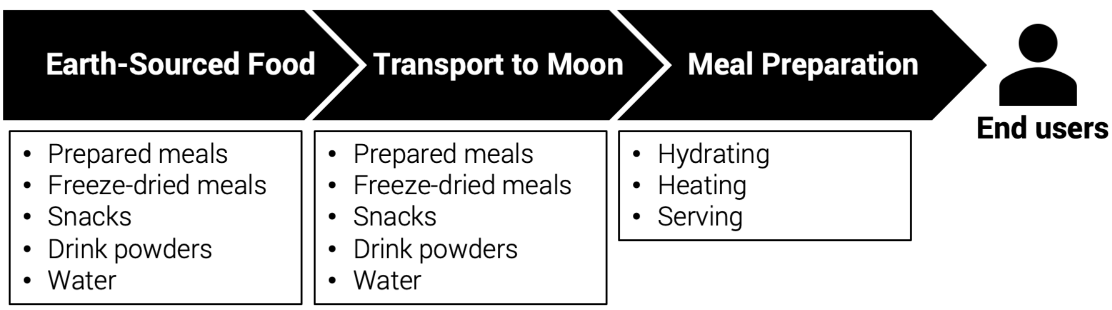
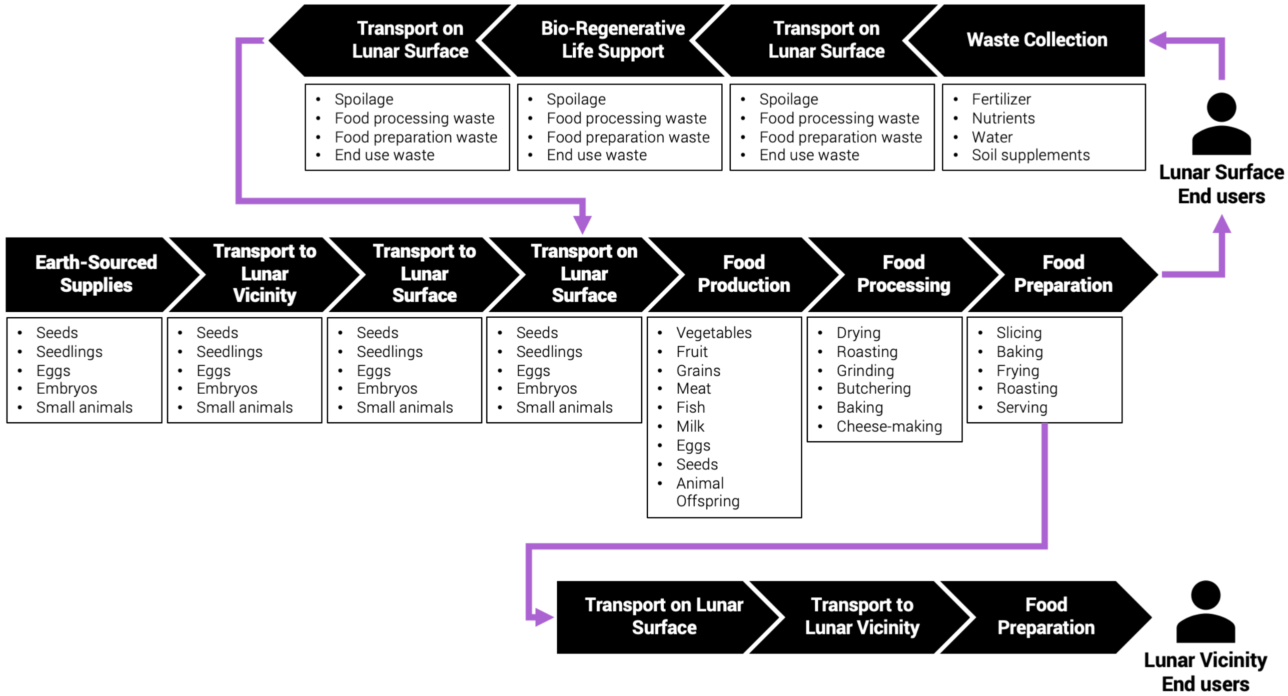


Figure 6.26. Mature Phase value chain



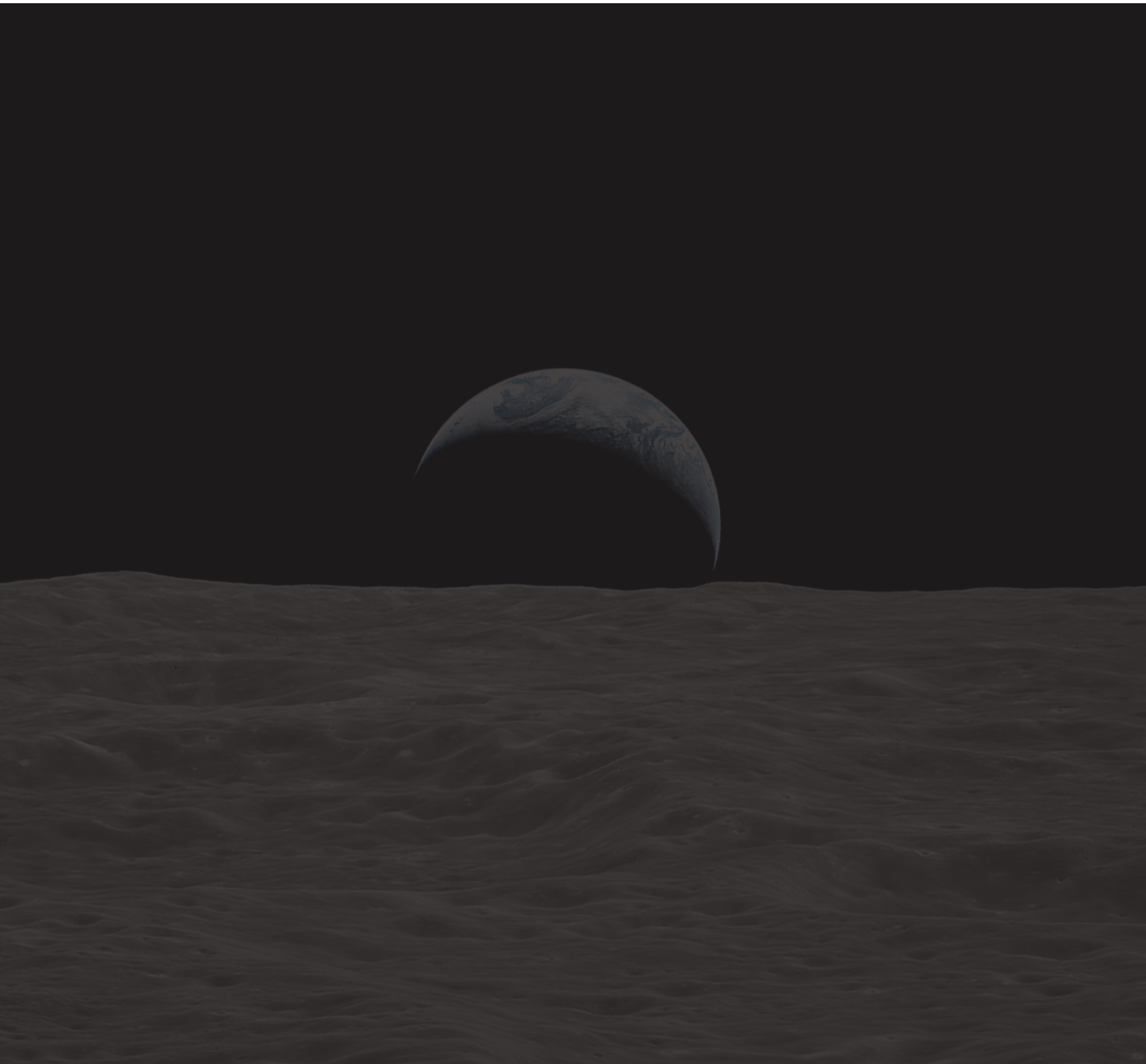
lets, transport to lunar orbit, etc.

- Consumption – multiple government facilities, tourism hotels and restaurants (on surface and in orbit)
- Food waste recycling – bio-regenerative closed cycle for sustainability

6.9.4. Mature Phase Market Interdependencies

In general, this section mirrors the contents of section 6.9.2 above.

7. Market Quantification



This exercise has been the beginning of a process. If humankind is going to eventually embrace the idea of using the resources of the solar system to improve and sustain life on Earth, then the Moon is a logical space to attempt to start. Traditionally, space exploration has been the preserve of state entities, but there has been a realization that in order to make further progress, there is a need to harness the engine of commercial motivation for the next phase. National and regional space agencies have begun the process for the return to the Moon, but there is a new emphasis on sustainability for the endeavor as we return to the Lunar surface. And an assumption that commercial entities will be able to contribute significantly to the viability of the operation.

However, commercial entities have a different set of criteria to undertake an operation from those of, say, a state entity. They have to be convinced in advance that there is a money-making business proposition. They have to be able to assess the likelihood and timeframe of profits for their shareholders. The work of this Lunar Commerce Portfolio activity has been aimed at beginning to provide the necessary answers in order for potential commercial operators to make the investments. At this stage, it has not been possible to investigate profitability, but a set of revenue projections have been possible, which vary significantly with changes in assumptions of external political and regulatory parameters. All of the assumptions have been documented, together with the models which capture the revenue generation and interaction between market segments. It will therefore be possible to continue to improve the results with successive versions of the Lunar Commerce Portfolio beyond this first issue. In particular, it should be possible to reduce the wide ranges of uncertainty, as successive iterations are able to use more robust values for constituent market data, when new market research and experimental results become available. It must be underlined, therefore, that comments and feedback on the methodologies and assumptions from users are welcome, and arguably necessary, as the community begins to use successive versions of the Lunar Commerce Portfolio as a trusted resource for their future planning. Please respond with suggestions and any more robust data sources to **gidon.gautel@moonvillageassociation.org**

One of the most valuable outputs from the Lunar Commerce Portfolio process has been the creation, within each market sector, of the value chain information, including data on potential suppliers and customers. It is hoped that various entities considering involvement in the effort to commercially develop the Moon will be able to use these information sources as they proceed with their due diligence. The Portfolio therefore contains within these sections an implicit invitation to participate in the future of Lunar commerce, by finding the best place for your entity to contribute. Within the value chains are a complete array of potential business opportunities, several of them not requiring any prior knowledge of space operations. There can be room for everyone, both in terms of commercial operators and developing countries, to be involved in developing the Moon, once the uncertainties can be reduced to manageable levels.

The previous sections of the Portfolio have recorded the findings for each successive market segment. The overall results, when interactions between segments are fully taken into account for the entire anticipated Lunar economy, are presented in this section. Also presented are the implicit uncertainties, and thereby commercial risks. We stress that the uncertainties in the findings are a consequence of the real unknowns at this stage of the Lunar development process. We have used the best available public domain data in reaching these findings. And so, the range of values is a realistic assessment of the range of possible outcomes. It can only be reduced, in subsequent iterations of the Lunar Commerce Portfolio, by substituting more robust assumptions when they become available.

In order to manage the immense amount of commercial forecast data that has been pro-

Figure 7.1. Lunar economic revenue by market, Sustainable Community scenario ($M)

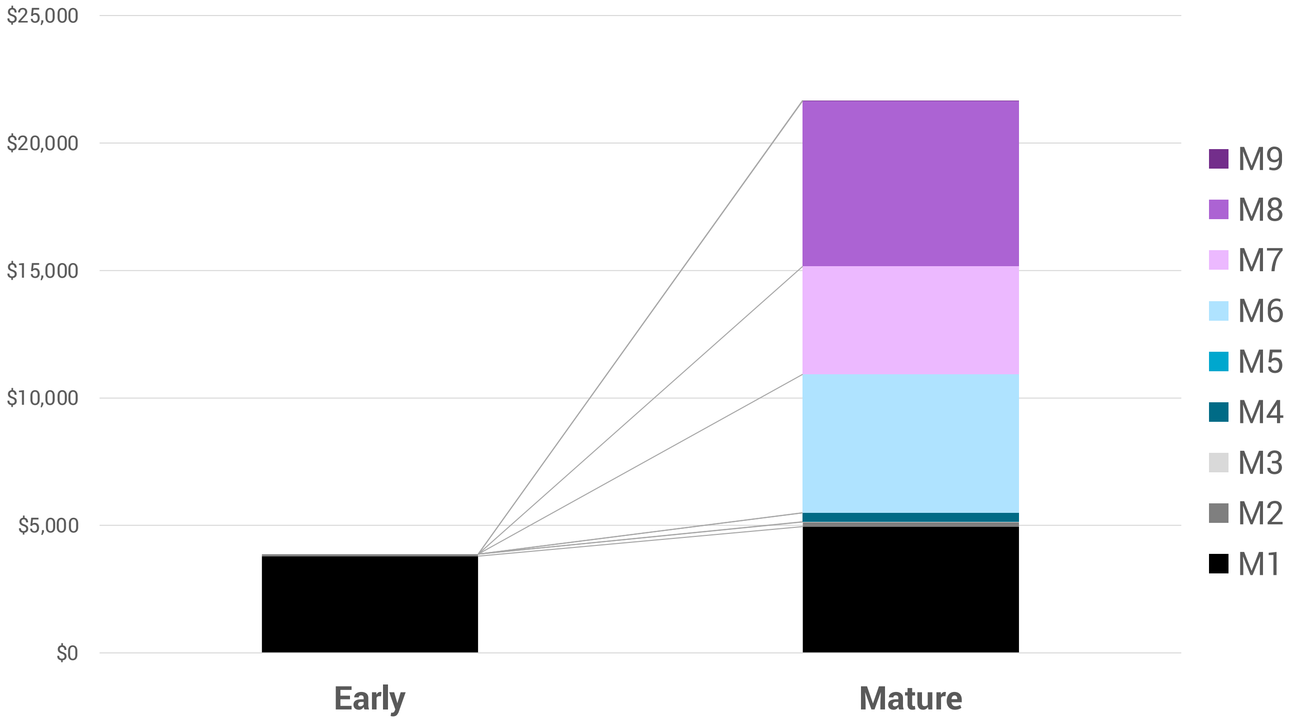
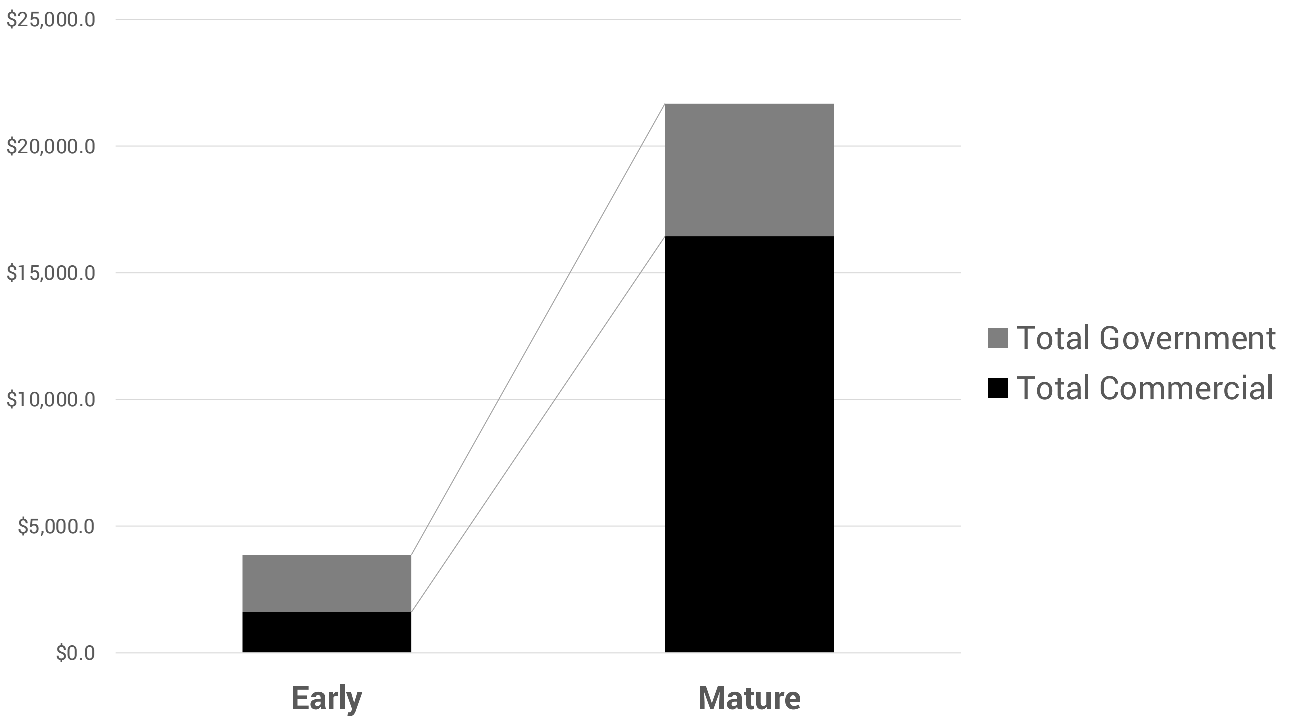


Figure 7.2. Lunar economic revenue by commercial and government source, Sustainable Community scenario ($M)



duced in this exercise, four scenarios were decided at the outset as a means of providing a consistent external framework for the analysis. They were described in the Methodology section of this report. For presentation purposes, we shall therefore first give a full account of the scenario named "Sustainable Community" (Figure 7.1, Figure 7.2, which demonstrate the relative sizes of commercial and governmental contributions). Thereafter, we shall provide a comparison showing the lower projected outcomes for the "Sorties" and "Research Stations" scenarios, and the greater potential of the "Resources for Earth" scenario (Figure 7.3, Figure 7.4, Figure 7.5, which present the findings for the

Figure 7.3. Lunar economic revenue by market, Sorties scenario ($M)

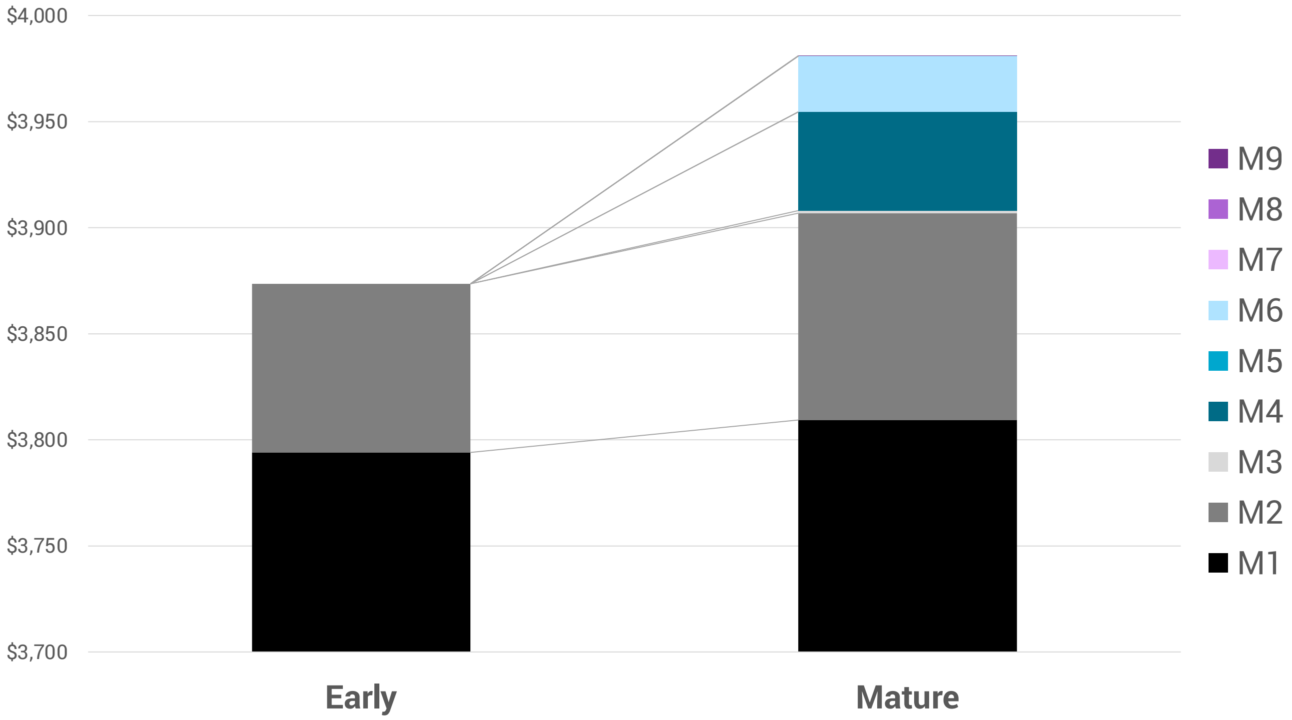
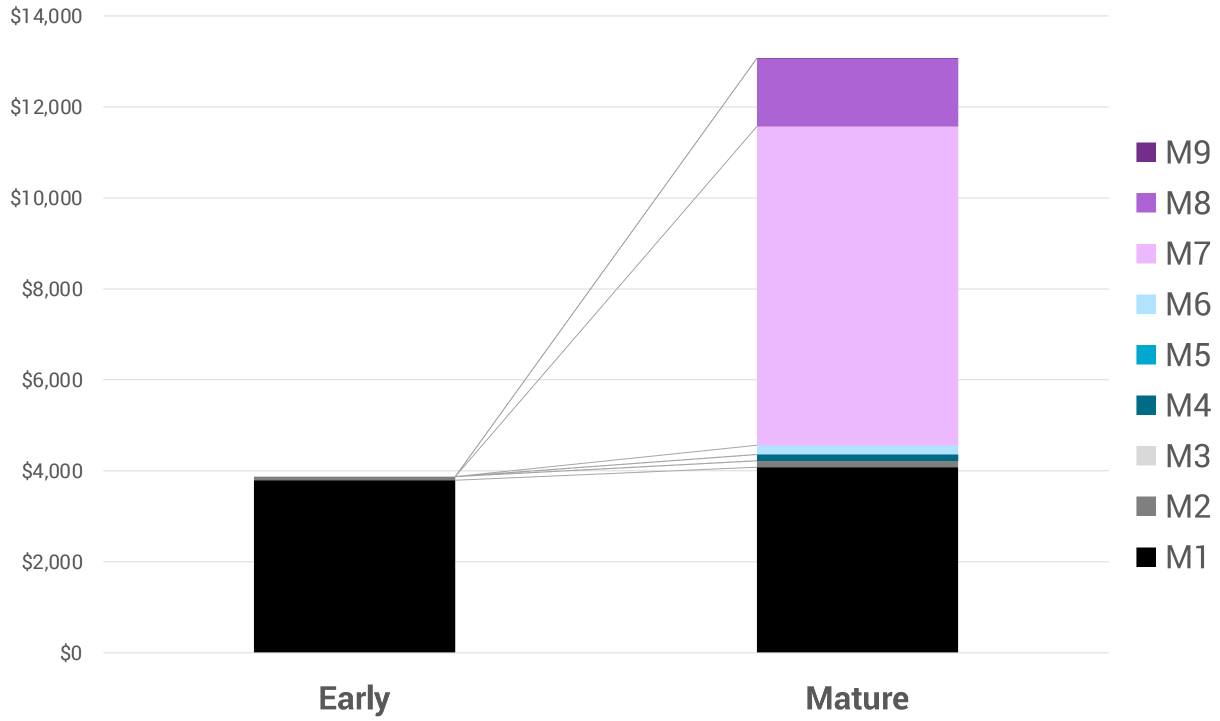


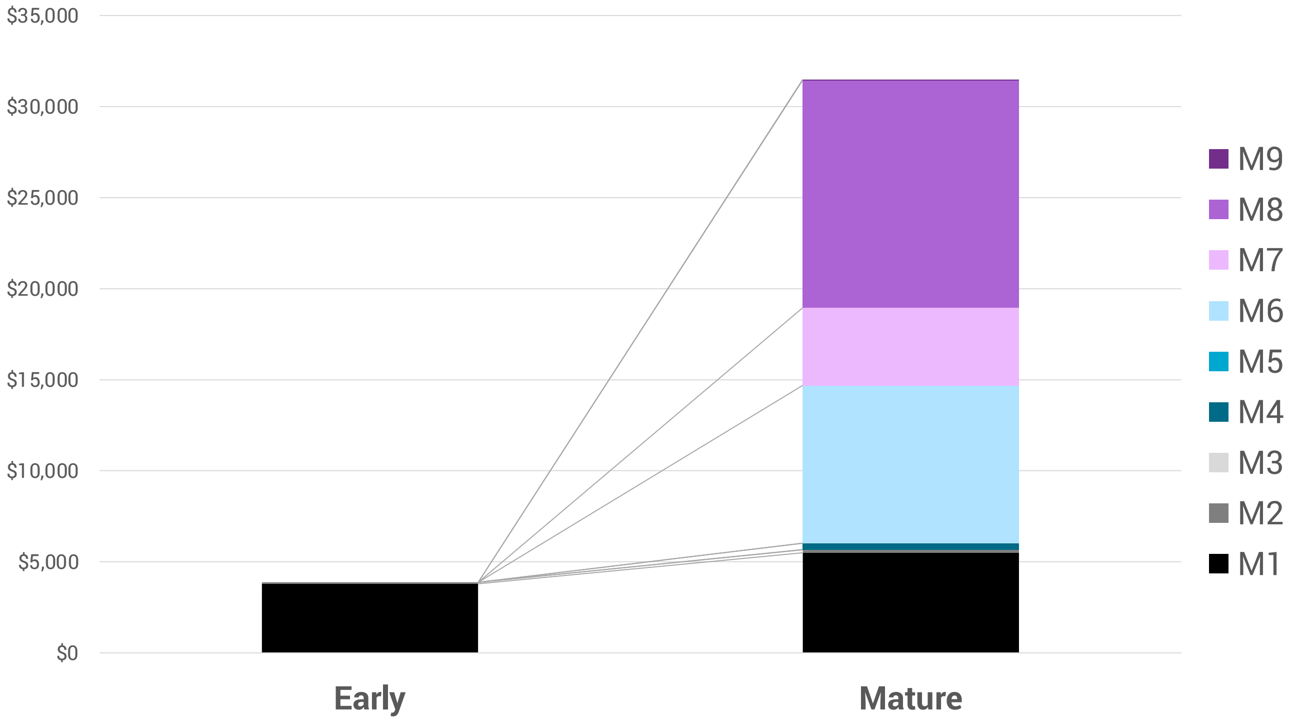
Figure 7.4. Lunar economic revenue by market, Research Stations scenario ($M)



combined commercial and government markets in each case). We then show how the purely commercial market opportunities will differ across the four scenarios (Figure 7.6, Figure 7.7, Figure 7.8, Figure 7.9). In all these cases, we are showing the combined results of Lunar surface and Lunar orbit revenue opportunities.

So, in the case of the "Sustainable Community" scenario, we begin with the assessment of revenue opportunity in both the "Early Phase" and in the "Mature Phase", and the implied growth between this current phase (the period up to 2030) and a potential subsequent period, probably beyond 2045, when "there is assumed to be a permanent human presence on the Moon self-sustainable with

Figure 7.5. Lunar economic revenue by market, Resources for Earth scenario ($M)



the necessities of life, and not dependent for them on a logistical supply chain of deliveries from Earth".

We see from Figure 7.1 and Figure 7.2 that the proportions of governmental and commercial elements change between the current Early Phase and the potential Mature phase, from 60% governmental at the outset to 30% by the time of the Mature phase. And, furthermore, the relative proportions of the different market segments change from eg., a negligible Market Sector 7 (Lunar Resource Extraction) in the Early Phase moving to a 20% proportion in the Mature phase. The overall revenues (in this "Sustainable Community" scenario) grow from $3.8B in the Early Phase to $21B in the Mature phase.

We now look at the different outcomes using different scenarios to define the external factors which can influence the outcome. The comparison between these next charts is with Figure 7.1 above, viz we are comparing the impact on the combined governmental and commercial revenue opportunities of a change in scenario. Figure 7.1 presents the baseline "Sustainable Community" outcome, show what happens when these external factors are changed.

Thus, we observe that in the "Sorties" scenario, only 20% of the potential revenues emerge, compared with the baseline, and "Research Stations" fares a little better as a scenario, with total revenues representing 60% of the baseline. If we are able to entertain the assumptions of the "Resources for Earth" scenario, then the total revenue outcome is greater than the baseline, by a factor of 45%.

The next charts (Figure 7.6 through Figure 7.9) demonstrate how the potential commercial revenue opportunities vary depending on variations of the external parameters, and this therefore underlines the implicit uncertainties involved in assessing revenue potential.

We find that the potential total commercial revenue opportunity in the Mature case varies from a lowest value of $1.6B in the "Sorties" case, to a maximum of $22B for the "Resources for Earth" scenario. This, therefore, indicates the implications of choices in emerging political/regulatory scenario possibilities. Uncertainty itself can be a major disincentive to commercial investment, and so there would be advantages in terms of reducing risk in clarifying the likely scenario parameters for future developments.

Figure 7.6. Purely commercial lunar economic revenue, Sorties scenario ($M)

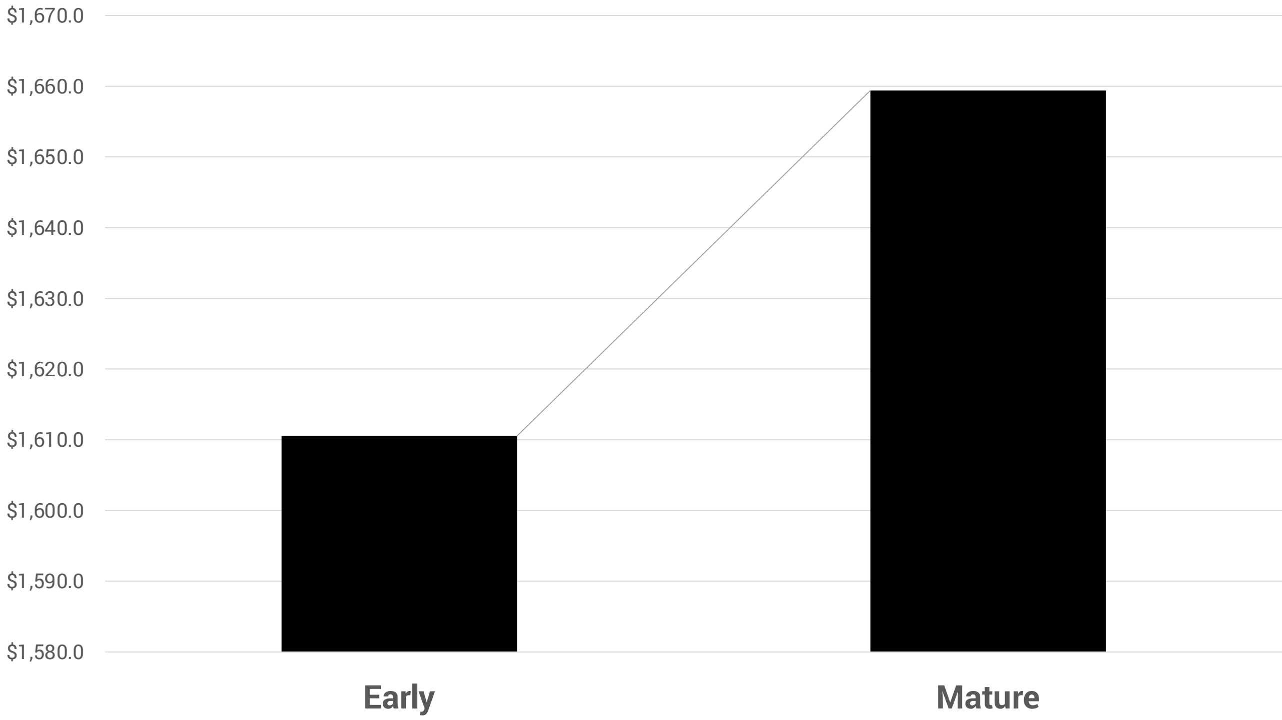
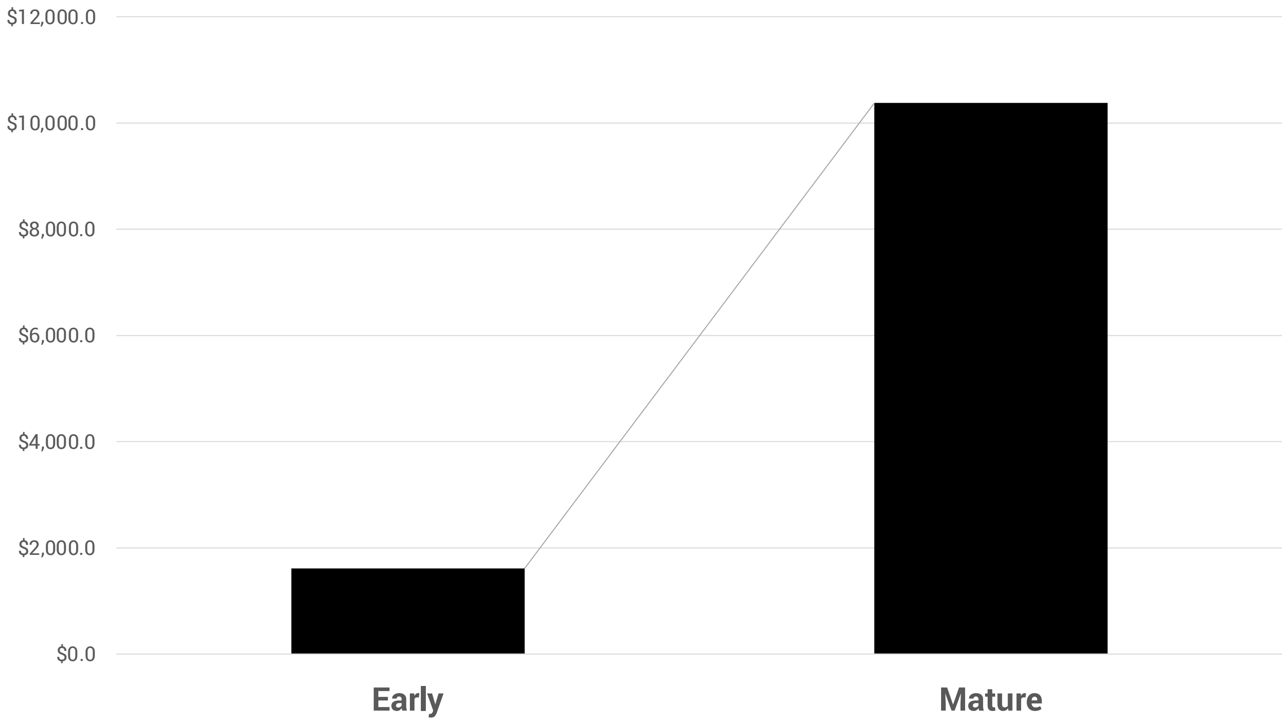


Figure 7.7. Purely commercial lunar economic revenue, Research Stations scenario ($M)



There are also insights via these findings into the meaning of "sustainability", and the implied assessment of when the Mature Phase might become possible. Clearly, there is always going to have to be a sizable government contribution, even after commercial revenues make possible a viable space economy, and it will be necessary to establish for taxpayers the extent of these ongoing commitments.

One further set of comparisons involves the relative proportion of lunar surface versus lunar orbit revenues (Figure 7.10).

A key outcome of this exercise has been the identification of key risk areas in the analysis. This therefore points the way where more research is needed to reduce the size of the

Figure 7.8. Purely commercial lunar economic revenue, Sustainable Community scenario ($M)

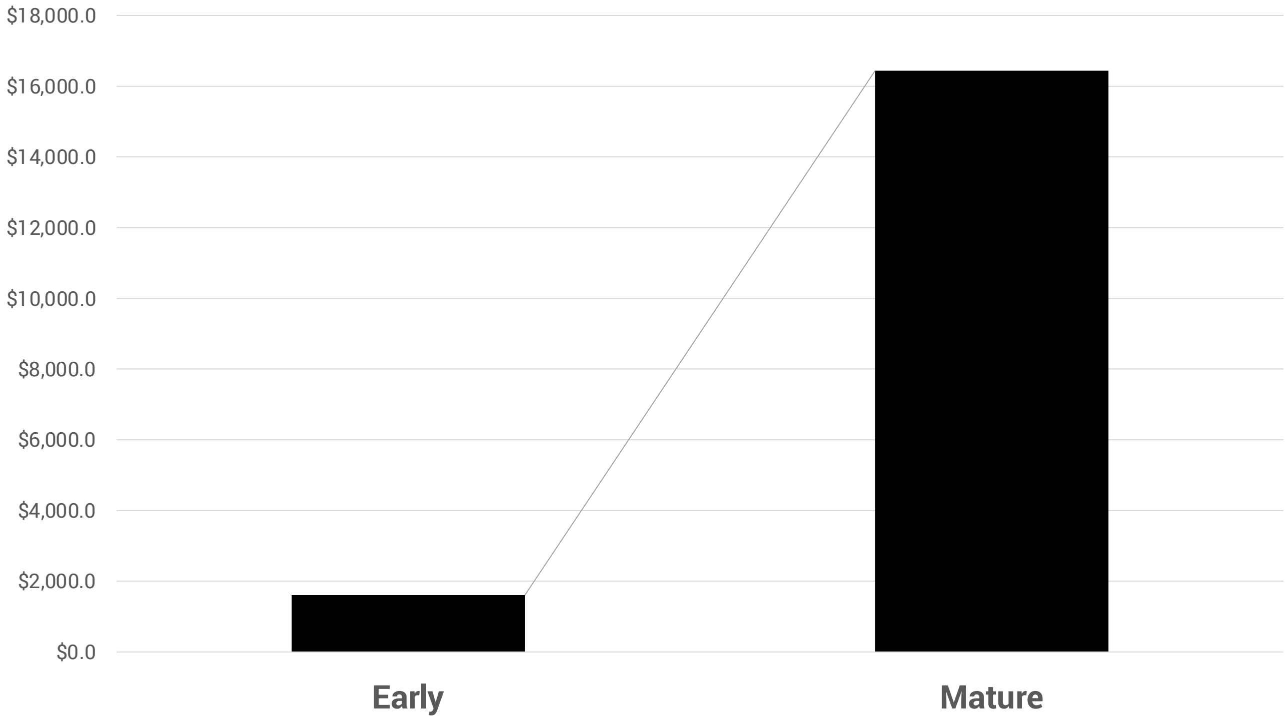
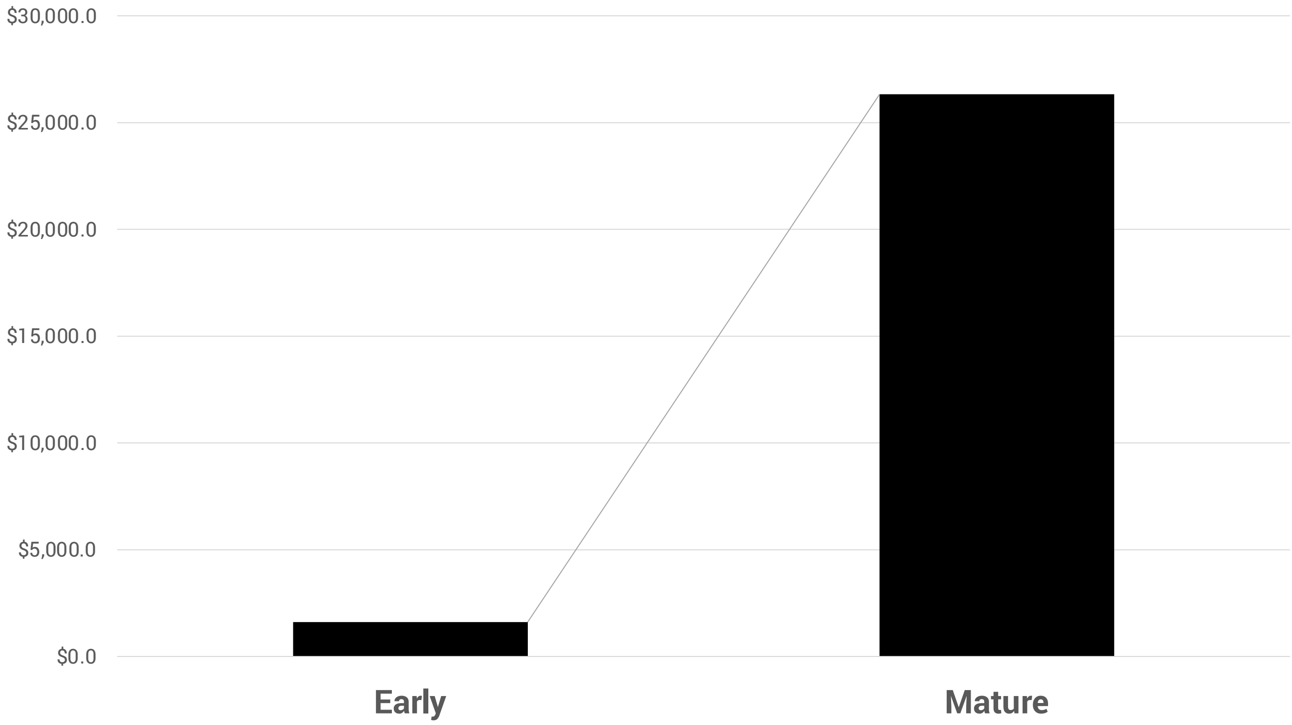


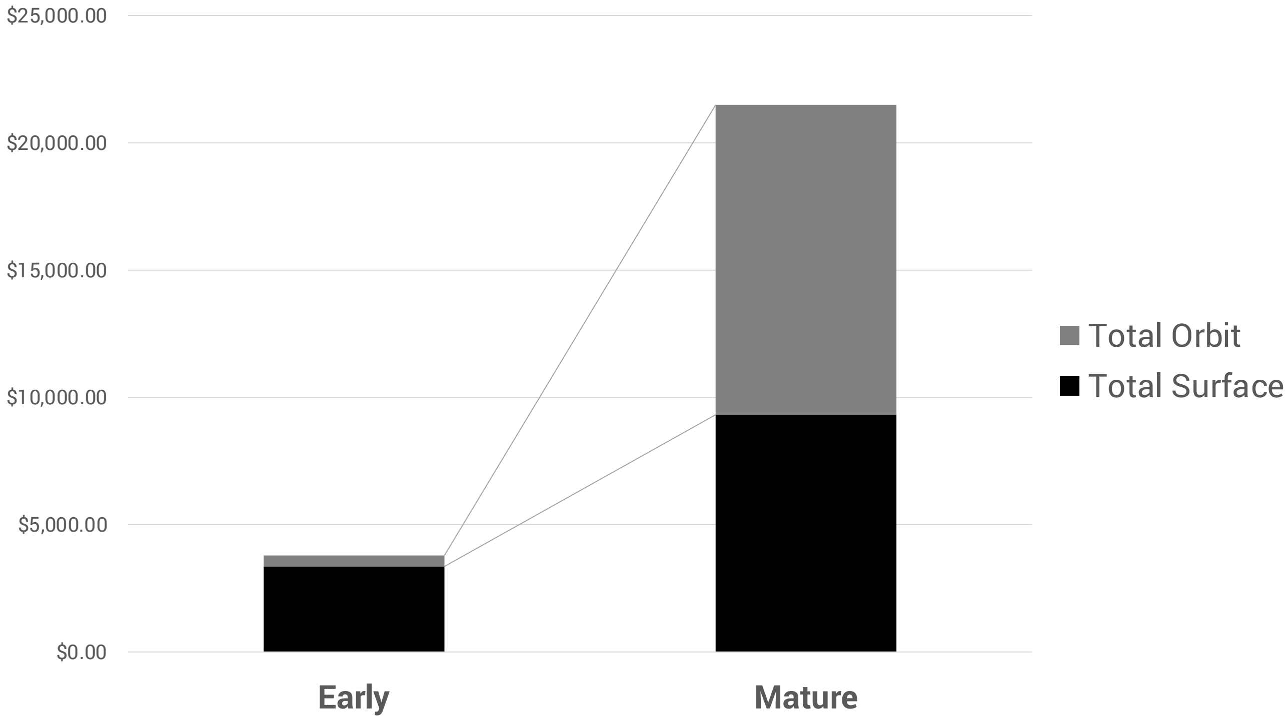
Figure 7.9. Purely commercial lunar economic revenue, Resources for Earth scenario ($M)



range of the unknowns. By focusing on the sectors representing the largest parts of the revenue potential, and within those sectors drilling down to the least known quantities in the data and assumptions, it becomes a useful indicator for entities capable of helping reduce the uncertainties. For example, the following areas would be worthy of a focused effort to pin down the values of the working assumptions, and iterate on methodology, in the Lunar Commerce Portfolio in subsequent iterations:

- Pricing information across all markets, however, especially for M3, M4, M5, and M6
- Mass estimates to provide a clearer picture of cargo flown with M1

Figure 7.10. Lunar economic revenue by surface and orbit, Sustainable Community scenario ($M)



- Quantification of data generation to improve M3 market estimates
- Further quantification of lunar manufacturing
- Estimates of habitat costs and mass, particularly for potentially large orbital structures in the case of high lunar tourism demand
- Power requirements for various activities to greater specificity
- Greater sophistication in the modelling of propellant demand and production

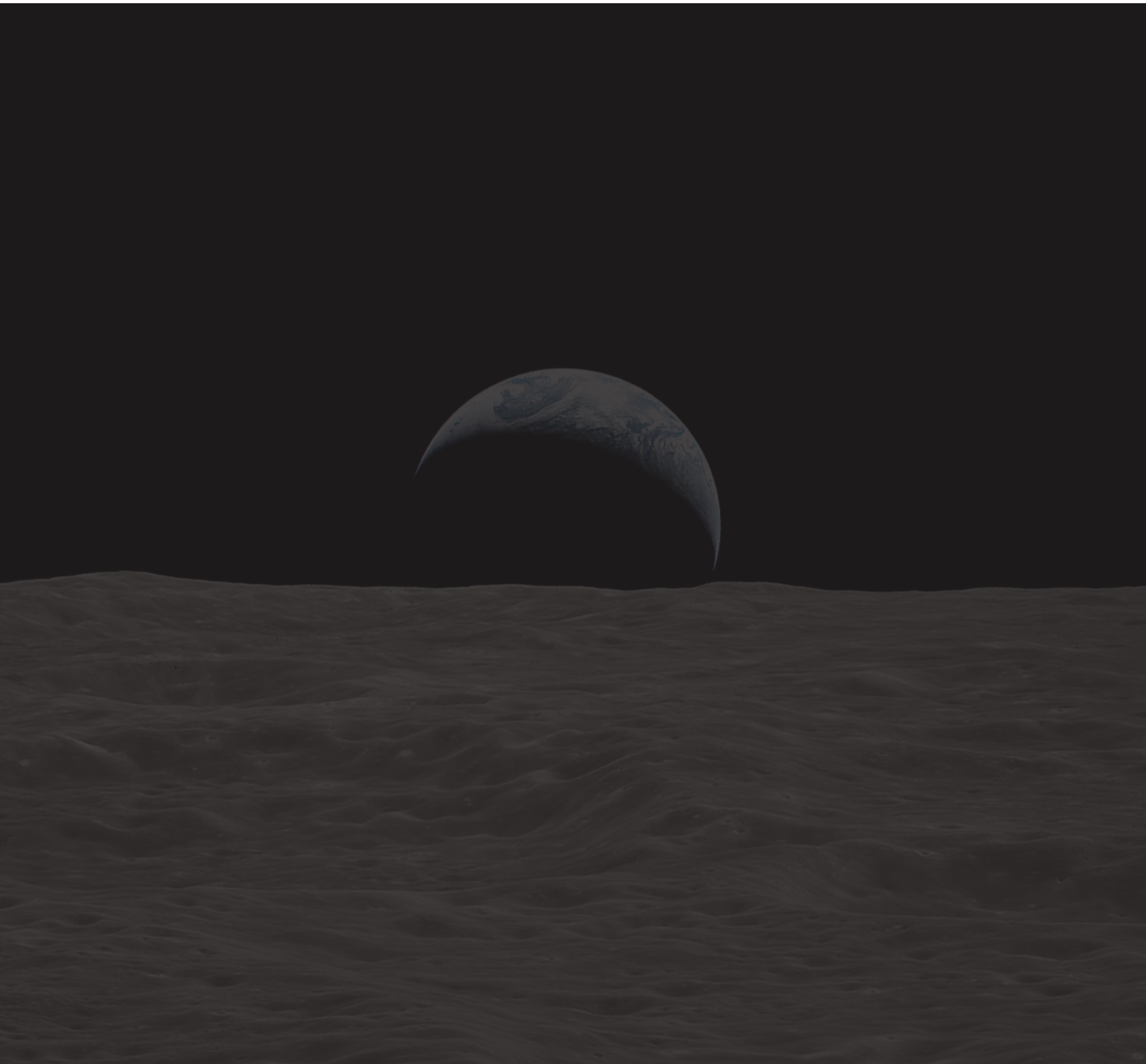
We can also begin to identify the likely focus for future work and use of the models and data. The following are some potential new areas of exploration which can be evaluated using the foundational work in preparing this Lunar Commerce Portfolio:

- Different scenario descriptions:
- Adding scenarios which meet the specific needs of certain users
  - o Refining the assumptions used in the existing four scenarios based on feedback from potential users
  - o Adding newer data to reduce the uncertainties and risks of the analysis?
- Considering Mars missions and their associated role of the Moon?
- Economic modelling to account for price sensitivity and closing of business cases

This could have a significant effect on revenue outcomes. Now that this first version of the LCP has established a baseline, we can refine each market's methodology, improve inputs, and add in the commercial opportunities associated with using the Moon as a gateway for Martian travels, and again make careful distinctions between governmental and true commercial endeavors.

It has yet to be determined how this ongoing work will be undertaken, but it will involve close association between the MVA Working Group on Lunar Commerce and Economics and the potential users of the findings. It is expected that some arrangement will be made whereby the MVA operates the model and users present requests for particular scenarios or data configurations.

8. Conclusion and Future Work



This document and its associated models represent 2 years of work by volunteer members of the Lunar Commerce and Economics Working Group of the Moon Village Association. The volunteer analysts were sustained in making their contributions by a belief that the end result would prove to be a significant contribution to humankind's next steps into space and the economic development of the solar system, starting with the Moon. Some of the analysts worked throughout the whole 2-year period; others volunteered their services for a shorter period. All, however, agreed to work together – via Zoom in this era of COVID-19 when international travel was curtailed, preventing face-to-face working arrangements – and collectively produced this work. The international and multidisciplinary nature of the Working Group has enhanced the final work product. The main "glue" that kept this team together was agreement on a set of common assumptions, and an agreed format for assembling the data from publicly available sources. So, the mere reporting of these common assumptions, and the consensus agreements on such matters as the list of extraneous factors which will inevitably impact revenue forecasts, have merit in themselves. Indeed, it can be said that one merit of the assembled work is its very completeness. All major potential lunar markets have been considered, including their mutual interactions, and value chains, and have been recorded in an open and systematic way, which it is hoped will be particularly beneficial to the users. More generally, we can say that the work consists of two types of information – both qualitative and quantitative – and in each part there is material which brings added value to the potential users of the Lunar Commerce Portfolio.

Can the Moon become a source of future economic growth, rather than a financial drain on resources? And if we cannot make it on the Moon, what are the chances for economic development on Mars and the rest of the solar system? The work has been completed, the assumptions made transparent, and the results published - and offered freely to the user community by the Moon Village Association. What have we concluded?

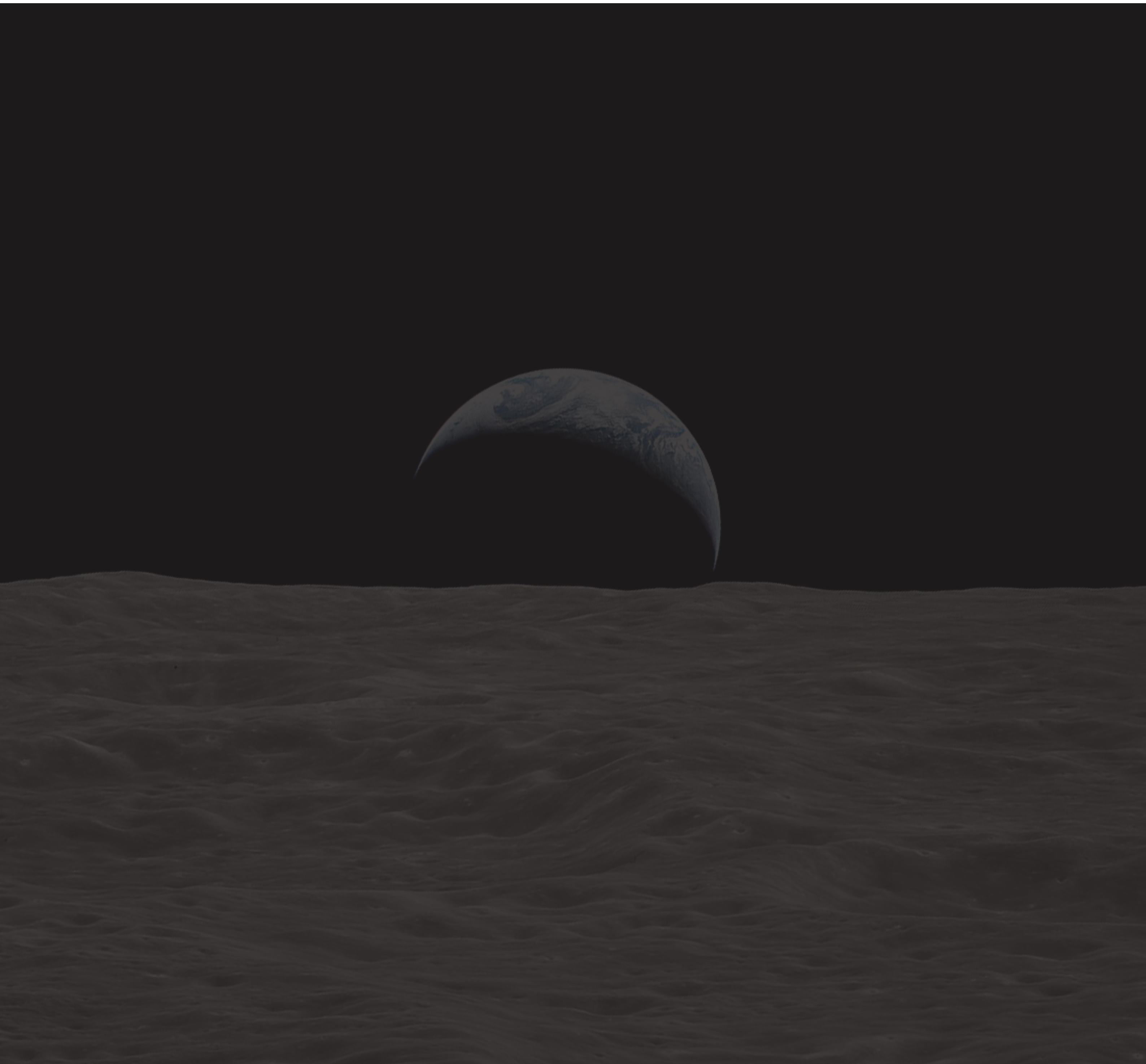
Regarding the qualitative work, the results speak for themselves, in their very completeness. This is a resource that we hope will prove helpful especially to countries and companies who have not yet been involved in space activities, but who see the potential of lunar commerce as a way to become part of the next phase of space developments. In regulatory terminology, this document in its qualitative sections makes a contribution towards "benefit sharing", which is a concept that is fundamental to international space law such as is represented by the Outer Space Treaty of 1967. Newly entrepreneurial businesses can seek the appropriate place to enter the value chains. Existing commercial space businesses can see to what degree their business success depends upon the actions of other businesses, sometimes not even competing in their own sector. On the Moon, everyone is dependent on everyone else. Even if the data is thus far not complete in every respect, The Lunar Commerce Portfolio, since it is being offered freely to the user community by the MVA, establishes a structure and even a language for talking about lunar business, which will encourage further developments.

Regarding the quantitative work, we must re-iterate that this is only the First Edition of the Lunar Commerce Portfolio, and one of its main purposes has been to highlight those areas where quantitative data is lacking. In subsequent editions, with the benefit of feedback from the user community, it is expected that the constituent data will improve, and consequently uncertainties will be narrowed. At present, we have identified a whole range of unknowns where data is badly needed before a realistic forecast of lunar commercial revenues will be possible. Some of the unknowns will begin to be known once the early Artemis-related robotic missions begin to bring back data about resources on the Moon and their likely accessibility. Other ranges of uncertainty could be reduced by judicious statistically valid market research into such areas as the market demand for lunar space tourism at various price points. Of course, we must remind users that these issues about lack of certainty in data and assumptions is inherent to lunar commerce projections. Any alternative sources of lunar commercial outlooks which do not report wide ranges of uncertainty are therefore not presenting the full picture. We do, however, have with this model a mechanism for exploring the degree to which various external factors can influence the revenue outcome, or the range of revenue outcomes. In subsequent runs of the model, we can refine these estimates.

We therefore have identified a number of key future steps in further developing the Lunar Commerce Portfolio. And perhaps the most important is to ensure some mechanism for getting reliable feedback and assumptions from the lunar commerce community. By working together with users, having a common purpose in reducing uncertainties, subsequent versions of the LCP will produce improved quantitative outcomes. Subsequent versions of the LCP might also include operations deliberately excluded from this first version - including those resulting from the potential use of the Moon and its resources as part of an architecture for Mars missions. Eventually, as data begins to firm up with the results of real exploratory missions on the Moon, and possibly by incorporating some statistically valid market research results, it may become possible to produce a string of annual revenues, rather than the simplified two-time-phase approach used here (i.e., the "Early" and "Mature" phases).

The Moon Village Association's Working Group on Lunar Commerce and Economics (LCE) intends to continue its work in refining the LCP, its assumptions, data, and modeling algorithms. It intends to be able to offer the possibilities to users in the future Lunar Commerce User Group of exploring changes of assumptions in their own specific market areas to help them plan their future work, and to understand where they are likely to be impacted by external factors.

Addendum



Lunar Tourism Analysis

Introduction

Since it may have a significant impact on demand for various commercial services in a future lunar economy, we need to have an estimate of the likely scale of the potential steady state future lunar space tourism business, as applicable for the Mature Phase (i.e., the assumed steady state period beyond 2040 at the earliest). A fairly comprehensive search of the literature discovers that there has been not much in the public domain to address this question. There have been a series of market surveys carried out to assess the revenue potential of terrestrial space tourism – both of the orbital and sub-orbital kind. But not so much regarding lunar space tourism opportunities and demand. For the Early Phase – the period up to 2030 – we can assume zero lunar surface space tourism opportunities, and only a few isolated trips into lunar orbit (with those tourists being serviced entirely with their needs by provisions brought from Earth).

This short note has therefore been assembled from what little data does exist, and uses that data to develop lunar space tourism market forecasts which can be used as part of the quantification effort of the Moon Village Association's Working Group on Lunar Commerce and Economics. Indeed, it is likely that lunar space tourism will be among the first truly commercial revenues generated at the beginning of lunar economic development.[78] This document thus records the basis for the assumptions used in generating the lunar space tourism aspects of the Lunar Commerce Portfolio. It does so in a transparent way which will make the calculations comprehensible and repeatable, and furthermore capable of being updated in the future when better data points emerge.

Space tourism in general has proven to be of great interest and both sub-orbital and Earth-orbital missions have been oversubscribed. Recent sub-orbital space tourism flights (July 2021), by both Blue Origin and Virgin Galactic, are reported to have been priced at over $200,000 or more per passenger, whilst the Earth-orbital missions, using Russian Soyuz spacecraft arranged by Space Adventures between 2001 and 2009, cost between $20M and $70M each, at the time. A recent Dragon flight to the ISS, arranged by Axiom Space, had ticket prices of $55M per seat. A recent report from investment bank UBS[79] puts a value of $3B a year on currently estimated space tourism markets. The Industry Arc analytics company anticipates a compound growth rate in space tourism revenues of 12.4% during 2020-2025, and they record that more than 500 people signed up with Virgin Galactic at a price of $250,000 per ticket for rides on the Virgin Galactic sub-orbital spaceship from Spaceport America in New Mexico.[80]

Lunar space tourism is therefore merely the latest stage in the development of the space tourism business, which is valuable in its own right as the latest stage in the development of the terrestrial based tourism sector (which is a major economic engine in the terrestrial economy), and furthermore is destined to possibly become a major driver of the commercial development of the Moon. In this document, we consider in sequence two distinct types of lunar space tourism: lunar orbit space tourism (which, as we shall see, already has some customers signed up), and lunar surface space tourism, which is assumed to come on the scene later, as the associated technologies develop during the Mature Phase. First, we look at lunar orbit space tourism.

Lunar Orbit Space Tourism

Apollo 8 was the first (in December, 1968) crewed mission to make the journey to the Moon, go into lunar orbit, and return to Earth.[81] Since then, there have been a few plans put forward to send space tourists into lunar orbit. In 2007, Space Adventures offered the DSE-Alpha mission using the Russian Soyuz governmental spacecraft, linked with a specially built mission module, for two tourists accompanied by a trained cosmonaut, at a price of $150M per tourist. Subsequently, in 2017, SpaceX offered a mission using a private Dragon capsule launched on a Falcon Heavy launcher, to also be offered at $150M per person. However, before this SpaceX mission could become established, SpaceX changed the parameters of the offering. Elon Musk announced that the Falcon Heavy would not be used for these crewed missions. It became the plan to instead conduct the lunar orbit mission using the Starship vehicle. The target date is currently still set at 2023, and a contract was signed in September 2018 with a customer for the mission. Yusaku Maezawa, a Japanese billionaire, will take with him up to 6 to 8 of his artist friends. The ticket price for this "DearMoon" Project has not been announced.

There have not yet been any statistically valid published forecasts of lunar orbital space tourism demand. Mihalic and Gartner (2013) indicate maybe only 2 passengers per year at a price of $150M each from The Space Tourist's Handbook by Anderson and Piven, published back in 2005.[82] Some survey data on lunar space tourism aspirations was acquired as part of the Adventurers' Survey.[83] This information was, furthermore, included in the Space Tourism Business Book (Webber 2021).[84] For the purposes of that survey (which canvassed 1,000 people on the website of Incredible Adventures), the "Round the Moon" trip was defined as: "This adventure takes you away from Earth on a 3-day journey to the Moon. After going around the Moon six times (ie 12 hours) you will fly the 3-day return journey back to Earth. This will be an experience just like the early Apollo missions, but will not include a landing on the Moon". At a gross level of demand, where pricing does not matter, 47% of respondents "wanted to experience" the "round the Moon" mission. When asked about a "fair price" for such a mission, respondents suggested a range between $1M and $100M. At the low end of $1M ticket pricing, 19% say they "would and could" go. These quantified responses were supported by a great many free-form comments amongst the respondents, such as "Around the Moon? – beyond my wildest dreams!", "If you are going to take the time to train ---why not go for the Gold", and "I want to feel the exhilaration of seeing the Earth rise over the Moon".

It should be noted, however, that the respondents to this survey were self-selected to be adventurers, though were not necessarily wealthy individuals, and therefore the results cannot be assumed to be statistically valid for the population at large, or for those wealthy enough to afford the ticket price. By comparison, the statistically valid Futron/Zogby millionaires survey of space tourism intentions recorded "willingness" factors of 12% for suborbital flights and 10% for Earth orbit experiences at their associated price levels, when the 450 wealthy respondents had been fully informed of the risks, by identifying as "definitely likely" to the survey questionnaire. These results were designed to be valid within a margin of error of +/- 4.7% at the time. So, it would be more prudent and conservative to half these values, and therefore assume a value of about 5% for our purposes, as a combined "willingness factor" for the more expensive lunar space tourism experience as applicable to the general millionaire population, which would take into account not just wishes, but other factors such as health limitations which could limit the options of some potential lunar space tourists. This assumption would be in line with our stated intention to involve "no hype" in our projections.

Lunar Surface Space Tourism

No humans since the Apollo governmental astronauts have landed on the Moon, the last mission being Apollo 17 with Cernan and Schmitt, returning to Earth on Dec 19th 1972. However, there has been progress in terms of private access to the Moon's surface. The Google Lunar XPRIZE offered $40M in prizes for non-governmental teams able to conduct a mission to the lunar surface, drive 500 meters and send back HiDef images. Team SpaceIL, from Israel, made an attempt, launched in 21st February 2019, slowly making its way to the Moon over the succeeding weeks until 11 April, 2019, when it hard-landed. The Team was awarded $1M for the achievement by the competition organizers, even though the formal Google Lunar XPRIZE competition had by then ended, and the soft-landing was not achieved. NASA has subsequently awarded contracts to a number of former Google Lunar XPRIZE teams to conduct robotic landings under the CLPS program, as precursors for the eventual crewed governmental landings envisioned under the Artemis program.

NASA has also awarded a contract of $2.9B to SpaceX to use its Starship as the Human Landing System of the Artemis program, with a scheduled first crewed landing now announced as "not before the end of 2025".

Although there were no specific quantified questions in the Adventurers' Survey, there was an abundance of circumstantial free-form commentary about the wish to be part of a lunar surface space tourism adventure, eg "Would really like a surface stay on the Moon", "I'd rather land on the Moon", "Want to walk and stay on the Moon", "I want an eight- or nine-day Moon adventure, orbiting, landing, and walking. Maybe staying two or three days at a Moon base", "A Moon landing would be even better!", "A lunar landing with a one-week stay is my ultimate goal, assuming that I can be successful enough to afford the trip, or that it is part of my job to welcome space tourists to a lunar outpost", "Lunar surface exploration is the thing", and "Would prefer a lunar landing rather than just a circumlunar loop". For these reasons, a "willingness factor" of 5%, amongst those wealthy enough to afford the trip, is also assumed to apply to the surface lunar space tourism variant.

There has been to date just one proposed commercial lunar landing space tourism mission, proposed by the Golden Spike Company, in 2010, with a charge of $750M per seat, but that company went out of business and the website closed down in 2015.

Demand Calculations

Given the data as reported above, how can we assess the likely steady state Mature Stage market demand for lunar space tourism, both for lunar orbital and lunar surface experiences? The following procedure follows the rationale which was used for the Futron/Zogby space tourism demand forecasts. It is based on, first of all, calculating that proportion of individuals who would be wealthy enough at a given ticket price, and then, amongst that select group, finding by carefully conducted market survey who would be wanting the experience. It is a combination of an affordability analysis and a statistically valid market survey of intentions.

So, the approach starts with an assessment of numbers of high-net-worth individuals.[85][86] In summary, there are 2,700 billionaires and 56 million millionaires in the world today. We need to have a distribution profile of different wealth ranges from $1M net worth and upwards. The number of millionaires represents globally the top 1.1% of the adult population (and in the U.S., that percentage rises to 8.4%). So, we are trying to understand the breakdown of that small percentage, and it is notoriously difficult to obtain reliable wealth data for high-net-worth individuals (probably for tax-related reasons). Referencing Credit Suisse, however, we find the following breakdown of the numbers of the 56 million wealthy individuals with net worth above $1M:

$1-5M	49.0 million
$5-10M	4.5 million
$10-50M	2.3 million
$50-100M	0.1 million
$100-500M	0.06 million
$500M +	0.005 million

And to break down the numbers even further, we find from Forbes that, breaking down the 5,332 people with wealth greater than $500M, there are 2,755 billionaires (with 724 of them being in the U.S.).

Then, we need to estimate the likely range of price levels for both the lunar orbit and lunar lander missions. This will depend on the likely architectures – and in particular, lower prices would be the result of Starship, rather than SLS missions. We need therefore to make the calculations at both ends of the price level range. We are guided in this by comments made by Elon Musk.[87][88] Thus "similar to ISS" is about $55M now, and so we can use that price in our range estimates below for the Mature Phase time period:

Prices for lunar orbit mission – assume range from $55M to $150M per passenger.

Prices for lunar lander mission – assume range from $290M ($2.9B divided by 10 passengers, ignoring at this stage the eventual $1/2M Elon Musk announced Mars target indicator price) to $750M per passenger. Note that it is assumed for the purposes of this exercise that the proposed price ranges include space transportation, provision of space suits, and the accommodation and food and life support at the destination.

Then we proceed to derive demand forecasts. We know from the millionaire preference data,[89] that high-net-worth individuals will typically not spend more than 10% of their net worth on an individual discretionary purchase leisure project (as was the case for the first few orbital space tourists, back in the early years of the 2000's). So, we can apply this percentage in reverse to calculate how many of the population would be able to even afford the prices of tickets for both lunar orbit and lunar surface missions, if they should want to do it.

For the lunar orbit missions, at the stated ticket prices assumed to represent 10% of net worth,

this implies the wealth needed at each ticket price would be either $550M or $1.5B. From the wealth population statistics, this implies a potential pool of 2,000 to 62,000 sufficiently wealthy people globally. If we apply the "willingness" factor of 5%, this results in a potential annual steady state market for lunar orbit space tourism of approximately 3,200 persons (at $55M per ticket) down to 100 persons (at $150M per ticket). The associated revenue potential range is $175B down to $15B.

For the lunar surface space tourism missions, at the stated prices assumed to represent 10% of net worth, this implies the wealth needed at each ticket price would be either $2.9B or $7.5B.

From the wealth population statistics, we find that we are down to very small numbers as a potential pool of sufficiently wealthy candidates. The resulting range is from 200 to 2,500 at the appropriate price levels. If we then apply the "willingness" factor - also assumed to be at 5%, then this results in a potential annual steady state market for lunar surface space tourism of approximately 125 persons (at $290M per ticket) down to 10 persons (at $750M per ticket). The associated annual revenue potential is $35B down to $8B.

We also make this assumption for the record, without at this time any data to back it up (could be a subject for future market research survey), that these two forecasts (ie lunar orbit and lunar surface space tourism demand) are independent of each other, and are therefore additive with respect to revenue stream contributions.

Thus, what we have derived is based upon a series of conservative assumptions:

1. Assessing the likely price ranges for the offerings;
2. Multiplying the prices by ten to arrive at the wealth level needed to even consider the experience;
3. Finding out from wealth statistics how many people have that much wealth; and then
4. Taking 5% of these numbers as the potential revenue generating lunar space tourist projections.

Thus, for the record, we note that the numbers are conservative, and do not take into account any potential tourists coming from wealth categories lower than the assumed cut-offs, even the lowest level of which is a net worth of $550M.

Lunar Commerce Portfolio Impacts

As we noted early in the process of developing the Lunar Commerce Portfolio, and created the nine teams to analyze the commercial market demand potential, activities related to Lunar Space Tourism would have impacts which could potentially have implications across all the nine sectors. We noted the need to record these specific impacts, whilst making sure that we were not double-counting the revenue opportunities. So, in this section, we proceed to track the meaning of the forecast range developed under Section 4, and allocate the impacts across the various market teams, to ensure internal consistency within the overall quantification process.

But first, we need to make some further assumptions about the way in which the forecasted space tourists are likely to arrive in the lunar environment. Specifically, how frequently should we assume the arrivals and departures, and how many folks at a time are likely to be staying in lunar orbit tourism hotels and on the lunar surface? The best data source for this is The Adventurers' Survey (Webber, D and Reifert, J, 2006), and Futron's Space Tourism Market Study (Webber, D, et al. 2002), where we learn that millionaires in general are busy people, who do not spend long periods on vacation. So, we make the assumption that lunar stays, whether in lunar orbit, or on the surface, will not exceed two weeks (with another week assumed during transit). In the case of the surface hotel guests, we can make the further assumption that they will be in residence there during the period of the lunar day, and that the hotel will be unoccupied each time during the subsequent two Earth weeks each month.

With these assumptions, we derive the following rounded numbers of space tourists at any one time occupying the lunar orbit or lunar surface tourism facilities, during the steady state Mature Phase:

For Lunar Orbit: At the high end, the 3,200 figure translates into 130 Lunar Orbit space tourists, each staying for two weeks, then being replaced by a similar contingent. At the low end, the 100 figure translates into just 5 Lunar Orbit space tourists, each staying for two weeks, and then being replaced by a similar contingent, and so on throughout the year.

For Lunar Surface: At the high end, the 125 figure translates into 10 Lunar Surface space tourists, each staying for two weeks, then being replaced after a 2-week gap by another 10. At the low end, the 10 figure may be translated into only 1 Lunar Surface space tourist, staying for about 2 weeks and then being replaced by the next customer, again, following a 2-week gap, with this process continuing throughout the year.

Now, we can lay out the impact assumptions of lunar space tourism in round numbers for each of the nine Market Teams during the Mature Phase of operations. In doing this, we make the assumption that the supply for the various lunar support services in the steady state grows to achieve a match with the expressed demand for lunar space tourism experiences:

Market 1 – Transport to/from Moon and Lunar Orbit

This market team needs to provide for the arrival of between 5 and 130 tourists into Lunar Orbit, every two weeks throughout the year, with associated cargo, and returning them to Earth at the same frequency, depending on the price levels. They will also need to deliver associated Oxygen and water from the lunar surface to lunar orbit to support these lunar orbit tourists.

Furthermore, the team needs to be able to deliver to the surface between 1 and 10 tourists, depending on price level, each month, with associated cargo, and return them to Earth at the same frequency. They will depart after their 2-week stay, and will not be replaced until after the lunar night, when the next group will arrive for their two-week stay.

Market 2 – Transportation on the Moon

This team may need to include some surface transport missions to tourism sites for between 1 and 10 tourists, depending on price level, on a monthly basis, during the lunar day. It is assumed for our purposes that the price for such surface trips is included in the overall lunar surface space tourism pricing developed in Section 4.

Market 3 – Communication and Navigation on the Moon

This team may not need to make any special arrangements, except to ensure that the lunar surface space tourism hotel has adequate IT and Internet capability for its customers, during the lunar day.

Market 4 – Energy and Power on the Moon

This team will need to be able to provide enough power to sustain the needs (lighting, heating, etc.) for between 1 and 10 tourists at a time, for 2-week periods each month in lunar surface hotel accommodation during the lunar day, and between 5 and 130 tourists at any time in lunar orbit, depending on price levels.

Market 5 – Products and Services on the Moon

This team will need to be able to provide enough general provisions for between 1 and 10 tourists at a time on the lunar surface, depending on price level, and for between 5 and 130 tourists in lunar orbit at any one time. Also required for the same numbers of tourists will be the other support services, including waste processing/recycling.

Market 6 – Infrastructure, Construction and Manufacturing on the Moon

This team needs to enable the building and outfitting of a lunar surface space hotel capable of supporting between 1 and 10 tourists for two weeks at a time during the lunar day, depending on price, and manufacturing products for sale to this number of tourists.

Market 7 – Mining and Resource Extraction on the Moon

This team will need to be capable of producing enough Oxygen and water for the needs of between 1 and 10 tourists for two consecutive weeks at a time in any month in the lunar space tourism hotel during the lunar day. The team will also need to be able to provide enough Oxygen and water to supply the needs of between 5 and 130 lunar orbit tourists at the same two-week intervals, throughout the year.

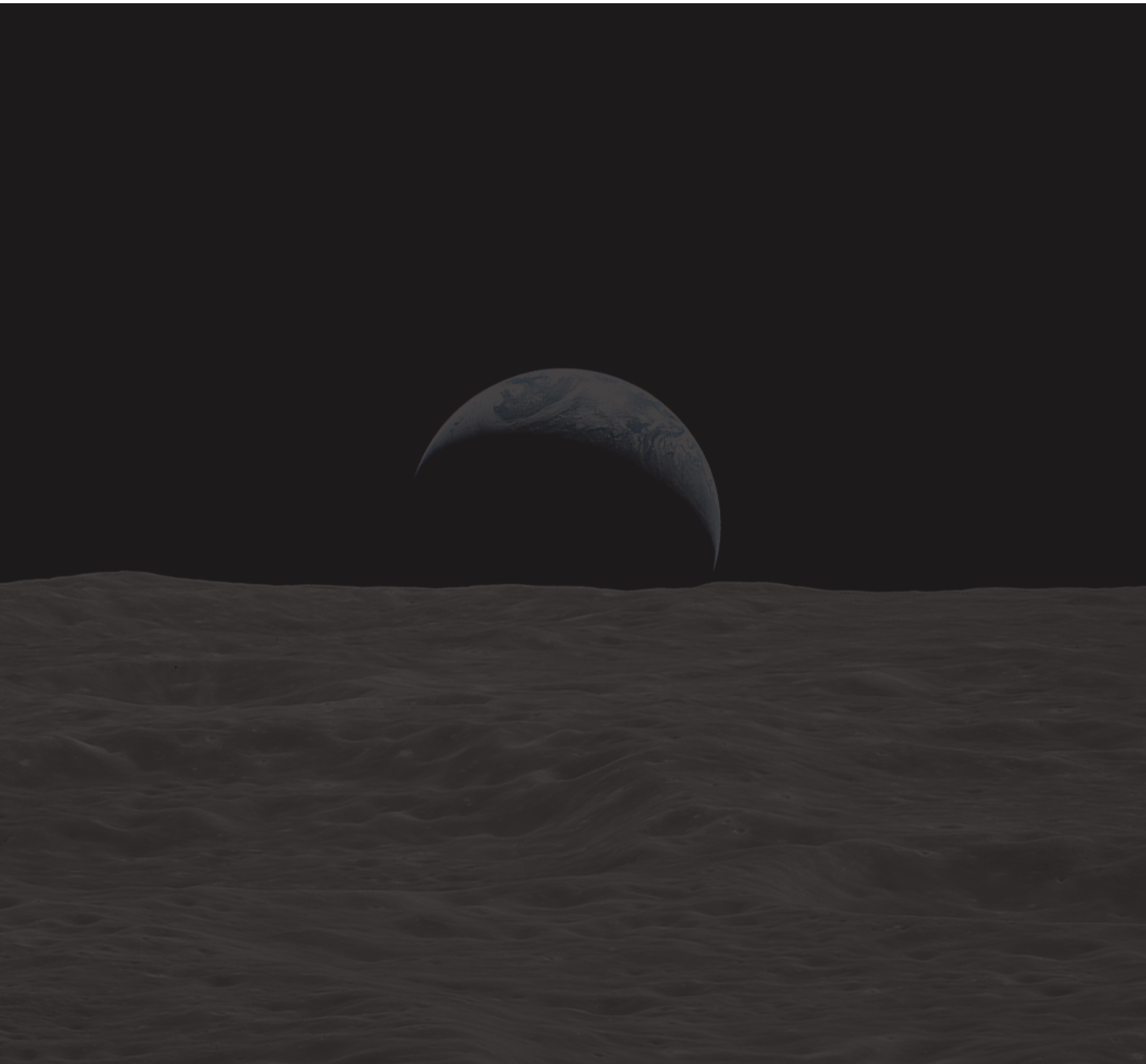
Market 8 – Habitation and Storage on the Moon

This team will need to be able to provide the leases of enough habitable space for the lunar space tourism hotel, for restaurants, bars, casinos, entertainment and leisure facilities for between 1 and 10 tourists on the lunar surface for two weeks at a time, during the lunar day, depending on price levels.

Market 9 – Lunar Agriculture and Food Production

This team will need to be able to grow and supply enough food (meat/fish/vegetables) to provide enough calorific intake for between 1 and 10 tourists on the lunar surface for two weeks at a time, during the lunar day, depending on price levels. We could also assume that this team might provide the food for the orbiting tourists (i.e., between 5 and 130 at two-week intervals). However, at this stage, to avoid double-counting, it is assumed that the food for lunar orbit tourists is provided from the Earth rather than from the Moon, although that assumption would be open to review in subsequent iterations of these forecasts.

Endnotes



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