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OASIS 2045: Case Study of the First Human Lunar Settlement – A Progress Report for 2022

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Abstract

During 2019-2022, the Moon Village Association (MVA) Architectural Concepts and Considerations Working Group ('Architecture WG') has conducted a case study of a potential human lunar settlement – to be established by the year 2045. Just during the course of the three-years of the case study, the prospects for lunar missions sponsored by governments, relevant plans for new capabilities, and the context of commercial space markets have all changed dramatically. This paper presents a progress report from the study, including three major topic areas, framed in terms of several high-level commercially-oriented 'use cases.' These three topic areas include first and foremost, transportation to and from the Moon, for logistics, equipment and personnel. The second topic area involves mining and in situ resource utilization (ISRU), including both production of key products such as water, air, propellants, etc. as well a fabrication and construction using local materials (for example, of roads, pressurized volumes, etc.). Finally, the paper examines the requirements and potential for major science activities on the Moon, including observatories on the far-side of the Moon, as well as laboratories in conjunction with lunar settlement operations.

Keywords: *OASIS 2045, Moon Village Association, MVA, Lunar Settlement, Lunar Homestead*

Acronyms/Abbreviations

CONOPS	Concept of Operations
CSA	Canadian Space Agency
EML1	Earth-Moon Libration Point Number 1 (an example)
ESA	European Space Agency
ETO	Earth to orbit
GEO	Geostationary Earth Orbit
GER	Global Exploration Roadmap
IoT	Internet of Things
ISEC-G	International Space Exploration Coordination Group
ISRU	*In situ* resource utilization
JAXA	Japan Aerospace Exploration Agency
kg	kilograms
kWh	kilowatt-hours
LEO	Low Earth Orbit
LH_2	Liquid Hydrogen
LLO	Low lunar orbit
LOX	Liquid Oxygen
LS	Lunar Surface
Maglev	Magnetic levitation (or electro-magnetic levitation)
MT	metric tons
MVA	Moon Village Association
NASA	(US) National Aeronautics and Space Administration
NGO	Non-governmental organization
RLV	Reusable Launch Vehicle
SLS	Space Launch System
TSTO	Two stage to orbit
WG	working group
WPT	wireless power transmission

1 Introduction

During 2019-2022, the Moon Village Association (MVA) Architectural Concepts and Considerations Working Group ('Architecture WG') has conducted a case study of a potential human lunar settlement – to be established by the year 2045. Just during the course of the three-years of the case study, the prospects for lunar missions sponsored by governments, relevant plans for new capabilities, and the context of commercial space markets have all changed dramatically. This paper presents a progress report from the study, including three major topic areas, framed in terms of several high-level commercially-oriented 'use cases.' These three topic areas include first and foremost, transportation to and from the Moon, for logistics, equipment and personnel.

The second topic area involves mining and in situ resource utilization (ISRU), including both production of key products such as water, air, propellants, etc. as well a fabrication and construction using local materials (for example, of roads, pressurized volumes, etc.). Finally, the paper examines the requirements and potential for major science activities on the Moon, including observatories on the far-side of the Moon, as well as laboratories in conjunction with lunar settlement operations.

2. MVA Architecture Working Group Overview

The Moon Village Association (MVA) is a non-governmental organization (NGO), organized in Vienna, Austria for the purpose of promoting future expansion of human activities to Earth's Moon. Within the MVA there are a number of specific working groups and projects that address a variety of topics important to that goal. One of these is the MVA "architectural concepts and considerations working group" – the focus of which is the technical subjects involved in near- to farther- term lunar activities.

During the past several years, MVA 'architecture working group' (WG) activities have been focused on a targeted 'case study' addressing the concept of a permanent human settlement on the Moon to be operationally by the year 2045: "OASIS 2045".

3. OASIS 2045

3.1 Introduction

The great majority of the now-ongoing activities concerning the Moon across many countries and programs focuses on the near-term: what technologies will be demonstrated and which missions will be implemented during the coming decade? However, many of the investments in new space technologies and novel space business opportunities look to the future beyond the 2030s.

During 2017-2019, the MVA Architecture WG defined and circulated several alternate 'scenarios' for how post-2030 lunar activities might unfold. However, in December 2019 at the MVA annual workshop and symposium event in Japan several important changes in likely cis-Lunar space capabilities became evident. First and foremost, the prospects for exceptionally low-cost reusable launch vehicles (RLVs) emerged in the near-term related to the development of the "Starship / Heavy booster" two-stage to orbit (TSTO) RLV by the US company SpaceX. Moreover, additional RLV developments have been announced in the US, Europe, Japan, China and elsewhere (e.g., New Zealand and the UK). As a result, it seems inevitable that the cost of access to low Earth orbit (LEO) and cis-Lunar space – and therefore to the Moon – will drop substantially by not later than the early 2030s. This will be transformational for lunar development and operations.

In response, the MVA Architecture WG decided to target its efforts on a specific 'case study' addressing the first permanent human settlement on Earth's Moon: OASIS 2045.

3.2 Description

The high-level description of the study and of OASIS 2045 that follows includes (1) the process by which the study is being conducted, (2) the requirements for the settlement concept, (3) the selected site(s) that were chosen for settlement operations and activities, and (4) the diverse "building blocks" comprising the system-of-systems involved.

3.2.1 Case Study Process

The process by which the OASIS 2045 case study is being implemented has been updated since the status report presented at the IAC 2022 in Dubai. [1] It now comprises several interrelated steps: (1) the definition of requirements; (2) the selection of a specific site at which the notional lunar settlement would be located; and (3) the initial; framing of a preliminary concept-of-operations (CONOPS). These first three steps were followed by (4) the definition of systems 'building blocks' that might make up the settlement and the identification of various candidate (5) missions and markets that might be served by the OASIS 2045, and various more detailed 'use cases' involving those missions and markets. These have been examined, and the interim results used to update the preliminary CONOPS. Next, (6) selected modelling of the use cases is being conducted. The final stage will involve (7) the identification of preliminary interfaces, opportunities for interoperability and standards for the OASIS 2045 building blocks and CONOPS. Figure 1 presents an overview of this process for the OASIS 2045 case study.

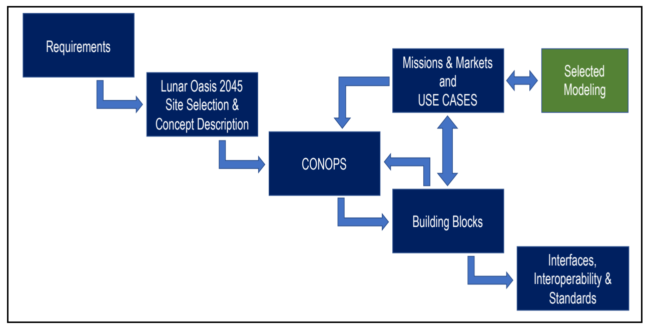

Fig. 1. OASIS 2045 Case Study Process Overview

3.2.2 Requirements

The case study began – naturally enough – with the identification of a set of requirements that a potential lunar settlement must satisfy. The critical drivers for the OASIS 2045 concept involve: (1) the availability of energy at the location; (2) proximity and access to prospective resources (detected in the form of water ices is the permanently shadowed regions (PSR) of the Moon; (3) the thermal environment of the location; (4) 'smoothness' of the surface in the vicinity of the chose location (to allow surface mobility); and, (5) access to/from the Earth by vehicles landing at and returning from the settlement.

In addition, the site was chosen such that a clear line-of-sight exists to the Earth in the lunar sky. This was both for reasons of communications (with requiring an orbiting relay satellites) and also psychology (inhabitants were adjudged to probably be happier if they could from time-to-time actually see the Earth.).

3.2.3 Selected Site(s)

The OASIS 2045 concept comprises systems and operations located at some six distinct locations and/or types of location related to the Moon Village vision. These include: (1) Zone 1 – the targeted location for the human habitation and primary human-robotic operations at the lunar south pole; (2) Zone 2 – lunar resource mining sites at the lunar south pole including the permanently shadowed regions (PSR); (3) Zone 3 – lunar surface science sites, presumed to be primarily located on the far-side of the Moon; (4) Zone 4 – low lunar orbit (LLO) operations and systems; (5) Zone 5 – cis-lunar space located systems and operations (including the Earth-Moon Libration points (such as EML1, etc.); and, (6) Zone 6 – comprising operations in Earth orbit (primarily low Earth orbit (LEO).)

During summer 2022, NASA indicated a 'baker's dozen' (i.e., thirteen) of candidate sites for the planned Artemis 3 human landing missions. The sites identified included the location on the lunar south polar ridge chosen by the MVA Architecture WG case study for the OASIS 2045 settlement.[2]

3.2.3 Building Blocks

The building blocks that have been identified as parts of OASIS 2045 include basic infrastructures, comprising: (1) ***Utilities*** (Communications & Networks, Power Generation & Energy Systems, Position Location and Navigation systems, Imaging & Operational Sensing, and Computing and Data Management); (2) ***Transport & Logistics systems*** (Space Transport Systems including surface-to-space and surface-to-space including Expendable, Reusable, etc., Landing Systems & Vehicle Support Systems, Advanced Launch Concepts, and Surface Transport including Crew, Cargo, Materials); (3) ***Operations Systems and Procedures*** (Dust Mitigation, Construction, Physical Waste Processing & Recycling, Manufacturing); (4) ***Resources Systems*** (Resources Exploration & Characterization, Mining Systems & Resources Extraction, Resources Processing & Handling; and, (5) ***Robotic Systems*** (such as human surrogates / or robotics for augmenting human capabilities) that might operate inside pressurized habitats or outside them, or both – just like humans).

The building blocks also include an array of OASIS 2045 elements necessary for human presence, including: (6) ***Habitation / Self-sustaining 'Biospheres'*** (Habitable Volume including the Pressure Vessel, Air, Water, Lighting, Thermal Management, etc., Radiation Protection, Agricultural Systems, Biological Waste Processing & Recycling, Human Operations & Health); (7) ***EVA Systems*** (Airlocks, EVA Suits, Personal Mobility Systems, EVA Maintenance Systems); (8) ***Medical Care Systems***, such as Urgent Care, Immunology, Surgical Care, etc.); and (9) ***Lunar-Gravity Mitigation systems.***

Finally, the building blocks also involve (10) prospective ***Science Missions / Payloads*** that might be deployed on the lunar surface, include "Science of the Moon" (e.g., geophysics), "Science from the Moon" (such as astrophysics), and "Science on the Moon" (including various laboratory sciences).

Figure 2 illustrates the dynamic interactions among the several building blocks.

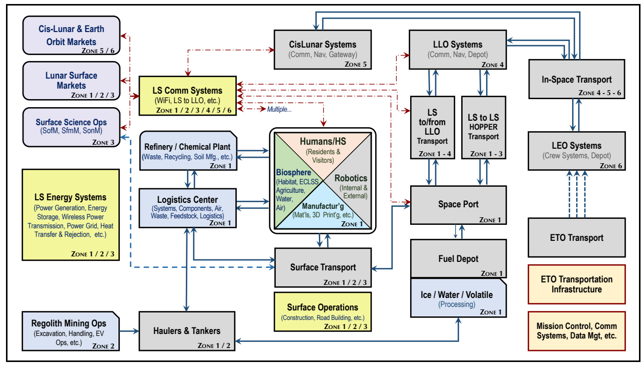

Fig. 2. Integrated Model" of the Interactions Among OASIS 2045 Primary Building Blocks

The section that follows lays out in greater detail a broadly chosen set of activities for OASIS 2045 – the 'use cases' for a settlement on the Moon.

4. OASIS 2045 'Use Cases'

As a way of exploring the operational and economic implications of the OASIS 2045 concept, a series of distinct 'use cases' have been formulated. Figure 3 presents a summary illustration of a cross-section of some twenty (20) use cases. These are discussed in the paragraphs below.

IT / Nav / Comms	Basic Materials / Systems	Transportation	Human Presence Related
1.1: Navigation Services (satellite and LS based)	2: Power Generation & Sales (primarily electricity)	3.2: LS Propellant sales & services at the Space Port (LOX-LH2 basis)	8.1: Visitor Transport to/from the Space Port (from/to a Lunar Orbit Station / Zone 4)
1.2: Communications: Local & Internet Services (satellite and LS based)	3.1: Water Production & Sales (from Ice-bearing Regolith Mining, ice extraction / processing, to water)	3.3: LLO Propellant sales & services at a Lunar Orbit Space Port 3.1 Lunar surface sourced 3.2 Earth sourced	8.2: Visitor Logistics sales at OASIS 2045 (water, air, meals, beverages) 7.2.1 Consumables 7.2.2 Recycling of waste
1.3: Communications: LS to Vehicle, Orbital & Earth (satellite and LS based)	4: Fabrication & Construction services & sales (e.g., ceramics from Regolith – including landing pads, roads, pressure vessels)	6: Surface Mobility Services (incl. personnel or cargo transport between the Space Port and OASIS, vehicle 'moves', etc.)	8.3: Visitor Accommodations rentals at OASIS 2045 (lodgings, share of common spaces, etc.)
1.4: Operational Imaging Services: LS-to-LS, Orbital-to-LS, etc. (LS-based, satellite, etc.)	5: Viable Soil Production & Sales (from Regolith with 'additives', such as water, nematodes, etc.)	7: Pt-to-Pt Mobility Services (including 'hoppers' for crew or cargo transport between the Space Port and other LS locations.)	9: Settler Homesteads "sales" at OASIS 2045 Homesteads (lodgings, farms with soil, power, share of common spaces, etc.)
1.5: Computing Services (LS, orbital and Earth based)	11: SPS Components production & sales (from Regolith, recycled systems, with 'additives')	12: Electromagnetic Launch services to LLO, cis-Lunar, GEO etc. (from EM launcher on LS)	10: Farm Products sales (including recycled air, water, food products, materials (e.g., fibers, etc.)

Note: the color coding in this table indicates closely related use cases (services, products, etc.)

Fig. 3. Cross-Section of OASIS 2045 Use Cases

4.1 IT / Navigation / Communications (Use Cases Group 1)

There are a number of important use cases – beginning with opportunities in the near-term – that related to information technology (IT), navigation and communications services. These cases are summarized below.

4.1.1 Navigation Services (Use Case 1.1)

This market case involves navigation services, which might be provided by a combination of (1) satellite-based position, location and navigation systems

(PLANS), similar to the well-known Global Position System (GPS) and similar systems; (2) lunar surface (LS) based navigation beacons and systems (e.g., similar to the functionality of mobile phone towers, etc.; and (3) markers and imaging involving specific 'targets' and cooperating sensor systems (e.g., tags or bar coding and imaging, RFID systems, etc..

4.1.2 Communications Services, Local & Internet (Use Case 1.2)

This use case (1.2) is fundamental and pertains to communications services that are local (e.g., system to system on or near the lunar surface) or networked (e.g., human internet access, IoT, etc.). Local and internet-type communications services will interact with and affect essentially all of the 'building blocks' identified above.

4.1.3 Communications Services, LS to Vehicle, to Orbital, to Earth (Use Case 1.3)

Use Case 1.3 is closely related to 1.2, but involves communications services from the lunar surface (LS) to various locations and systems at greater distances – for example to vehicles (such as lunar landers), systems in low lunar orbit (LLO or cis-lunar space (e.g., the Lunar Gateway), or from the Moon to/from Earth.

4.1.4 Operational Imaging Services (Use Case 1.4)

Another aspect of IT related services that will likely be provided to lunar settlement activities will be that of operational imaging services. For example, imaging from LLO will likely be needed – both for operations by a given party and for monitoring of those operations by competitors and/or regulators. Such services are likely to involve imaging systems in LLO, cis-lunar space, and selected local systems (e.g., rovers, external and/or internal cameras, etc.). These services may involve both imaging as well as other types of remote sensing (such as laser ranging, radar surveillance, etc.).

4.1.5 Computing Services (Use Case 1.5)

In addition to the various IT related services identified above, it is also likely that there will be 'cloud-type' computing services on or in support of OASIS 2045; these are the subject of Use Case 1.5. There are three options for the delivery of these lunar cloud computing services. First, computing might be Earth-based with high bandwidth communications as the enabler. This option seems unlikely to be acceptable due to the RTLT (round-trip-light-time) lag of approximately 2 seconds.

Second, the computing might be provided by dedicated 'server farms' as is done on Earth. And, finally the cloud computing might be delivered in a distributed fashion by processors and memory distributed across many 'smart systems' on and near the Moon. This final option seems to be the most likely in the nearer term since essentially all lunar systems will require electronics and computing.

4.2 Power (Use Case 2)

Power generation and distribution will be essential to almost all lunar activities, including human habitation operations (life support, agriculture, recycling, etc.), *in situ* resource utilization (including regolith mining, water extraction, fuel production), fabrication & manufacturing, and construction, and most others. "Use Case 2" addresses a primary aspect of this operation: the development and operation a solar power 'wireless grid' generating power on the usually sunlit hilltops and crater rims of the lunar south pole and delivering that power via wireless power transmission (WPT) to locations where it is needed.

4.3 Mining, Process and Propellant Services (Use Cases Group 3)

The following group of use cases are related to the mining, extraction of volatiles and processing of those materials to produce water, propellants and other consumables; the use cases include (1) water, (2) propellants for use on the lunar surface, and (3) propellants for use in low lunar orbit (LLO)

4.3.1 Water Production & Sales (Use Case 3.1)

This 'use case model' involves the end-to-end CONOPS to deliver the following value: *"surface propellant for Reusable Lunar Lander (RLL) operations*." The foundational commercial venture for a lunar surface settlement is the production of propellants for surface-to-orbit transportation refueling – based on resources extracted from the regolith itself.

4.3.2 Lunar Surface Propellants sales and services (Use Case 3.2)

This 'use case model' involves the end-to-end CONOPS to deliver the following value: "Surface Propellant for Reusable Lunar Lander Operations." The foundational commercial venture for a lunar surface settlement is the production of propellants for surface-to-orbit transportation refueling – based on resources extracted from the regolith itself.

4.3.3 Lunar Orbit Propellant sales and services (Use Case 3.3)

There are two options for providing propellant sales and related services in LLO (low Lunar orbit): (1) lunar-sourced propellants, and (2) Earth-sourced propellants. (In the longer-term, propellants from small, near-Earth objects (NEOs) might become an option, but probably not in the timeframe of OASIS 2045.)

LUNAR-Sourced LOX-LH_2. This 'use case model' involves the end-to-end concept of operations to deliver the following value: "Lunar-Derived Propellant in LLO for Reusable Lunar Lander Operations." This is a primary economic justification for the development of lunar-sourced materials – in particular propellants – in transportation operations from (see Section 4.1 above) or to the lunar surface (discussed here).

Earth-Sourced LOX-LH$_2$. A fundamental question is whether it will make economic sense to deliver LOX-LH$_2$ propellants derived from the lunar regolith to a refuelling station in low Lunar orbit (LLO) – or if it will make more economic sense to provide such propellants (for LLO to LS transportation) from the Earth instead. This 'use case model' involves the end-to-end CONOPS to deliver the following value: "Earth-Sourced Propellant in LLO for Reusable Lunar Lander Operations."

4.4 Fabrication & Construction Services (Use Case 4)

Although not critical for short-duration *sortie* missions, the fabrication of objects and the construction of infrastructure on the Moon will be critical for a permanent lunar settlement.[3] This is the subject of Use Case 4.

4.6 Use Case 6: Lunar Agriculture Water

There are many different potential goods and services that will be required to achieve a self-sustaining, biologically-enabled biosphere on Earth's Moon – including atmosphere regenerations, delivery of potable water to inhabitants (human and animal), growing and delivering food, recycling of wastes of various types, etc. This 'use case model' involves the end-to-end CONOPS to deliver the following value: "Water for use in Lunar OASIS Agricultural Operations."

4.5 Viable Soil (Use Case 5)

Use Case 5 relates to the production and sale of 'viable soil' made from regolith to the operators of agricultural parcels and other businesses. In comparing lunar regolith to terrestrial soils, there are both deficiencies (e.g., lack of Carbon and Nitrogen) and excesses (e.g,, Aluminum Oxides). The 'manufacture' of viable soil including various 'additives' – such as water, nitrogen, insects, etc.

4.6 Surface Mobility (Use Case 6)

This 'use case model' involves the end-to-end CONOPS to deliver the following value: "personnel and cargo transport between two points on the lunar surface." This includes the capability to transport logistics, goods, and personnel to-and-from the spaceport, and from-and-to the OASIS 2045 settlement.

In an operational sense, this use case may comprise a number of different 'building blocks' or perhaps only one, with alternative 'plug-ins' depending on how the functionality is implemented. For example, a single reconfigurable vehicle might be able to carry cargos or crews, or there might be two different vehicles (e.g., a truck and a bus).

4.7 Point-to-Point Mobility Services (Use Case 8)

This 'use case model' involves the end-to-end CONOPS to deliver the following value: "point-to-point" mobility services – in particular rocket powered flight from one location on the Moon to another, and (in reusable cases) return flights. This includes the concept of transport of personnel and cargo generally, and especially transport to / from human-tended lunar far-side science station(s). It seems likely that these transportation services would involve LOX-LH$_2$ propulsion – like the RLL's discussed above in Paragraphs 4.3.2 and 4.3.3.

4.8 Visitor Products & Services (Use Cases Group 8)

There are three (3) use cases included in the "Visitor Produces and Services" group as currently defined; these include: (1) visitor transportation; (2) visitor logistics; and, (3) visitor accommodations. The paragraphs below sketch these use cases.

4.8.1 *Visitor Transportation (Use Case 8.1)*

This use case involves the full range of transportation services required to allow visitors to OASIS 2045 from Earth, including transportation to/from LEO to LLO, transport to/from LLO to the LS spaceport near the settlement, transportation to/from the spaceport to the OASIS 2045 habitation complex.

4.8.2 *Visitor Logistics (Use Case 8.2)*

This 'use case model' involves the end-to-end "concept of operations" to deliver the following value: lunar visitor habitation consumables' and waste disposal. The materials involved include air, water, food and waste management and disposal or recycling. There are, of course diverse consumables that will be required by future visitors to a human settlement on Earth's Moon. These visitor-required materials / products might be provided in two different ways: first, they might be imported with each visitor, or they could be produced locally.

4.8.3 *Visitor Accommodations (Use Case 8.3)*

Visitor accommodations include a variety of elements of infrastructure, consumables and services related to individuals who travel to the Moon (to OASIS 2045) for various purposes, including but not limited to (1) government-sponsored astronauts and scientists from various countries; (2) corporate-sponsored engineers, researchers etc.; and, (3) private individuals (perhaps of high-net worth, perhaps sponsored through one means or another). The delivered accommodations would include lodgings (including pressurized volume, a share of common spaces, etc. Consumables for visitors and logistics are addressed in Use Case 8.2.

4.9 Settler Homesteads (Use Case 9)

It is inherent in the concept of a settlement that there will be food production – including the reproduction of various species, including plants, animals, fungi, microbes and human. There must also be air and water recycling, human waste processing and recycling, and other similar functions. Some of these capabilities might be provided in various fashions: factory farms, aquaculture, building-sized 'petri dishes' full of growth media, etc. However, there is only one known 'system-of-systems' in human experience that can accomplish some or all of the needed functions: conventional agriculture. However, for purposes of the OASIS 2045 case study the conceptual approach to achieving these functions has been established as *soil-based agriculture*.

The question then becomes: how should the economics of lunar settlement soil-based agriculture be organized? Here again, there are multiple options to be considered. For example, 'factory farms' owned by a large-conglomerate might be the organizing approach. In this case the residents of the settlement would like be analogous to the employees of a mining town – owning to the 'company store' and working for extended periods to pay-off their debt. Another term for such laborers in a top-down farm economy is 'serf' or 'indentured servant' – best know from the European middle ages. Alternatively, such 'factory farms' might be owned by the governments (either local or remote). The laborers in such an economy might again be described as 'serf' or 'indentured servants' – working to discharge a debt (at least in part). Such systems were well-known in various countries in the 20th century: Soviet communism, for example.

The approach chosen for the OASIS 2045 case study is drawn from the 18th-19th century model of the '***homestead'***: agricultural parcels that would be 'owned' by individuals, where that individual would be responsible for the health and well-being – the productivity of the parcel – in the settlement. This is the basis of Use Case 9, discussed here.

Settler Homesteads – Use Case 9. This 'use case' involves sales and services related to monetization of settler "homesteads" – i.e., lodgings, farms, and related systems, with power, soil, air, water, and an appropriate share of common spaces. The individual parcels would be sized to be approximately consistent with the bio-regenerative life support requirements of an individual, plus some margin (to be determined) to allow 'sales of farm products' as per Use Case 10, described below.

4.10 Farm Products (Use Case 10)

Use Case 10 pertains to material '**farm products'** that might be produced by settlement 'homesteads' and provided for sale to other OASIS 2045 businesses. (See paragraph 4.9 for an explanation of the 'homestead' concept for the lunar settlement.) These would include food of course, but also freshened air, purified water, material products (such as fibers, craft materials such as wood or bamboo, etc.).

4.11 Manufacture and Sale of Structural Systems for SPS repair and maintenance in GEO (Use Case 10)

This 'use case model' involves the end-to-end CONOPS to accomplish the manufacture and sale of modular / robotically deployed structural systems for solar power satellite (SPS) repair and maintenance in GEO. Of course, the diverse issues involve multiple aspects of future lunar surface operations including being a 'customer' in a lunar economy for various of the use cases described previously. Table 1 presents a preliminary listing of the various products that might be produced for sale into an existing SPS market, including (1) bulk materials, (2) simpler finished products, (3) complex products, and (4) highly complex 'systems-of-systems'.

4.12 EM Launch from the Moon (Use Case 12)

This 'use case model' involves the end-to-end concept of operations to transport cargo (including both bulk materials and manufactured items) to low Lunar orbit (LLO), cis-lunar space, Earth orbit (including GEO), and interplanetary trajectories. For purposes of the 'use case' described here, the primary emphasis is on the specific topic of MAGLEV-based (electromagnetic (EM) levitation) transportation of bulk materials from the lunar surface to a destination in space.

Table 1. Prospecting Lunar Products for Sale into a Space Solar Power Marketplace.

Bulk Materials	Simpler Finished Products	Complex Products
• *Propellants*	• *Primary Structural Systems*	• *Heat Engines (e.g., Stirling Cycle)*
• *Oxygen*	• *Electrical Wiring*	• *Rocket Engines*
• *Water*	• *Tethers / Cables*	• *Electronics*
• *Hydrogen*	• *Pressure Vessels*	• *Cryogen Tankage*
• *Reactants (for Heat Engines)*	• *Antennas*	• *"Electron Tubes" (e.g., Magnetron, Gyrotron, etc.)*
• *Glass*	• *Reflectors*	
• *Electronics-Grade Silicon*	• *Optical Systems (e.g., Lenses)*	
• *Steel, Aluminum, etc.*	• *Radiators / Heat Pipes*	
• *Doping Elements (for Electronics)*	• *PV Arr*	
	• *Software*	Systems / Systems of Systems
	• *Electromagnets*	• *MagLev ('magnetic levitation') Launchers*
	• *Electric Motors*	• *Rocket Vehicles*

5. OASIS 2045 Modelling

In order to evaluate the economic viability of the OASIS 2045 concept some level of analytical (i.e., quantitative) modelling is essential. Also, to assess in some cases the differences between one approach and another to accomplishing the same market objective, some internally-consistent evaluation of the options is crucial. However, the overall complexity of the first settlement on the Moon is a daunting prospect.

Nevertheless, preliminary systems analysis modelling has been accomplished using a physics- and terrestrial analogy- based spreadsheet approach. The objective of this modelling is to develop high-level estimates of the types, scales (e.g., masses), numbers and the costs of various "building blocks" (see Section 3), and to so consistently among the various 'use cases' (see Section 4).

Additional modelling is planned during the coming months and into 2023.

6. Preliminary Economics of OASIS 2045

For purposes of the MV Reference Architecture 'Settlement Case Study, it is assumed that in 2045 there will be a diverse set of market customers and providers for a wide range of goods and services. This marketplace comprises:

- Longer-term / mission-level contracting to Government Projects,
- Providing goods and/or services to Government Missions,
- Providing goods and/or services to Commercial Markets,
- Contracting to Commercial Firms,
- Providing goods and/or services to Private Individuals,
- Selling to "Visitors" (e.g., government or commercial sponsored visitors),
- Selling to Public Space Travelers or "Tourists" (e.g., personally financed visitors),
- Selling to "Settlers" (i.e., those who intend to stay), and
- Providing Goods and/or Services to 'the Settlement'.

The market is presumed to be international in character – i.e., various country's space agencies, firms from diverse countries, etc.

7. Discussion

The MVA's "OASIS 2045" first lunar settlement case study has been ongoing since December 2019. A great deal has been accomplished already, and the study is approaching is final phase: development of models and analysis of the building blocks and their interactions in order to evaluate at least some of the various use cases that have been defined.

A more complete set of some twenty (20) 'use cases' have been formulated in a hand-full of diverse areas. These use cases provide a focused framework for more detailed consideration of the underlying economic drivers and limits for a future commercially-viable lunar settlement. Within this framework, a set of 'limits analyses" are now planned that will explore the relationships parameters such as the cost of energy ($ per kWh) to the minimum cost of propellants ($ per kg-LOX and LH_2) and the resulting cost of transportation of visitors to/from the settlement ($ per person).

This paper has introduced an important new concept: the notion of the '*lunar homestead*'. This is both an approach to scaling and organizing essential agricultural activity (enabling bio-regenerative life support) as well establishing a basic organizational principle for governance of the OASIS 2045 society.

8. Conclusion

This paper presented a progress report from the study, including three major topic areas, framed in terms of several high-level commercially-oriented 'use cases.' These three topic areas include first and foremost, transportation to and from the Moon, for logistics, equipment and personnel.

Another topic area involved mining and in situ resource utilization (ISRU), including both production of key products such as water, air, propellants, etc. as well a fabrication and construction using local materials (for example, of roads, pressurized volumes, etc.).

Finally, the paper examined the requirements and potential for major science activities on the Moon, including observatories on the far-side of the Moon, as well as laboratories in conjunction with lunar settlement operations.

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