**INITIAL PLANNING PAPER – JANUARY 2021**

# WORKING GROUP ON LUNAR COMMERCE AND ECONOMICS (LCE)

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This document is designed to provide a framework, some perspective, and guidance for the work of the Lunar Commerce and Economics working group of the Moon Village Association. It also provides links to the MVA Roadmap for Establishing the Moon Market, and efforts being undertaken in other MVA working groups, in order to ensure that there is no overlap and that the work of the differing working groups is complementary.

## AIM OF THE LCE WORKING GROUP

Given the global focus of lunar exploration by the space community, this Working Group has been established to address the commercial dimension associated with this new era. The group will focus on discussing, categorizing, and to the extent possible, quantifying the potential lunar commercial markets in both an early phase and a longer-term mature phase.

The key aims of the LCE working group are as follows:

- Identify future revenue-generating lunar markets
- Gather and create a 'best possible view' database for each future market outlining assumptions, constraints, value chains, market drivers and quantified market sizes where possible (Lunar Commerce Portfolio)
- Provide a forum for international experts to centralize, debate and align on visions for aspects of the future lunar economy

The ultimate product of the LCE working group will be a Lunar Commerce Portfolio, consisting of the best available international information on commercial lunar businesses and resource markets. This database product will be available to support GEGSLA in providing input to UNCOPUOS to support discussions and decision making on such matters as resource sharing and long-term sustainability of outer space activities. There is a direct link between the development of commercial lunar market potential in the abstract, and the ability of the potential commercial operators to raise funds in order to address those markets. Furthermore, the successful results of the efforts of this working group will produce tangible benefits for the MVA itself, by being the means of making this key fundraising information available.

For each market within the Lunar Commerce Portfolio, the end goal will be to have, to the extent possible:

- An outlined market description which is non-overlapping with other defined markets
- A value chain for the market
- A market driver tree for the market
- Quantified market sizes / sub-elements where possible
- Assumptions implicit to the market design outlined above
- Constraints likely to impact the market

- List of top players (public and private, space and non-space) operating within each market

**DEFINITION OF COMMERCIAL LUNAR MARKETS AND INITIAL ASSUMPTIONS**

For the analysis work of the LCE to proceed, there is a need to have a universal understanding of what we mean by commercial activity and an agreed, comprehensive and generic list of market segments for potential commercial development of the Moon.

What do we mean by "commercial development of the Moon"? In a true commercial transaction, we need to be able to clearly identify and differentiate between the customer and the provider of product or services, and for at least one of these to be non-governmental. I.e. if the Government is providing a service to itself (e.g. a crewed launch service for the purposes of human spaceflight) this is strictly not commercial activity.

Having said this, it is imperative that a government-government dynamic within a market is not ignored as there is the potential that this specific demand could someday be met by the commercial sector. For this reason, we will classify 'commercial development of the Moon' as ALL lunar demand for each market, and only then, will we afterwards assess how commercialized each market is expected to be. In addition, there will always be second-order "spinoff benefits", of course, from such a complex endeavor as developing the Moon, but in this working group we consider initially only the prime direct revenues of Moon businesses and operations.

We imagine a time, sometime after 2040, when there will be a permanent human presence on the Moon, which is totally sustained by the Moon's resources, and not dependent on a logistical supply chain of deliveries from the Earth. At such a time, which we shall call the Mature Phase, there would be thriving lunar-centric businesses, with both commercial customers and providers on the Moon, possibly even using lunar currency. The Moon would then be providing a theater to try out a parallel with the early years of business on the Earth. It would become a new world able to generate wealth. For at least the next decade, however, which we shall call the Early Phase, government will be the customer for the vast majority of lunar business. There will of course be a gradual transition from the Early to the Mature Phase, when there will be a mix of government and true commercial customers. But within the LCE working group, we shall keep it simple and work to define what will be happening in each of the two main phases. We shall commence with the Early Phase, where data is more readily available.

We need to scope out the kinds of "lunar commerce business" that we can expect, and to be realistic about timescales. What kinds of business can we expect in each of these two defining phases? In particular, we need to get a grasp on the Early Phase activities, because of the need to budget to appropriate taxes, without entertaining any unrealistic expectations about possible revenue generation in this phase as a result of our lunar activities. In this Early Phase, it will be government acting as the customer, to the supplier of products and services. For the purposes of this working group, we shall initially ignore any activities predicated on possible subsequent explorations of Mars and elsewhere in the solar system, and the considerable employment-related benefits associated with any government-funded space program. There may also be other cases that we need to initially ignore, such as revenue for regulatory bodies etc., but these fine points will emerge during the work of the LCE WG.

It is proposed that the LCE will consider that the following main activities will be the business transactions during the Early Phase. It should be understood throughout this document that transport costs are assumed to include associated insurance and financing charges. Most of the activities will involve government as the customer purchasing products, services and supplies. And therefore, the funding for such activities would need to be included in successive Space Agency budget requests during the Early Phase period. A few truly commercial endeavors that may take place that will not require the government as customer, are also included, but the revenues generated from this subset will probably not provide a significant contribution during the Early Phase. Note that the categories itemized below are all in their nature generic, and are therefore not dependent on any specific chosen architecture, although the quantities within some of the categories will be expected to change with changes in the chosen architecture.

**EARLY PHASE MARKET SEGMENTS**

**1.Transport to/from Moon**

1.1 *Robotic taxi service; launch vehicles and spacecraft* (eg, as included in CLPS) - Delivering science, engineering test, ISRU test, crew supplies (food, oxygen, water), infrastructure (including habitats, storage, solar arrays, nuclear power plant, waste processing/recycling equipment. Also, initial agriculture/hydroponics lab). Also, for delivering mining exploration test mission equipment for potential commercial customers.

1.2 *Crewed taxi service; launch vehicles and spacecraft* (eg, as included in Artemis) - Multiple lunar lander missions (different providers – Blue Origin, Dynetics, SpaceX - launch vehicles and spacecraft). Also, for lunar tourism (probably orbital only in this Phase)

**2.Transportation on the Moon**

2.1 *Robotic rovers/hoppers* (eg, as included in CLPS) and also conducting initial surveying/resource mapping for possible commercial customers

2.2 *Crewed rovers/hoppers* (eg, as included in Artemis)

**3. Products and Services on the Moon**

3.1 *Comms system* (eg Lunanet)

3.2 *Navigation system*

3.3 *Power-Energy markets*

3.4 *Construction markets*

3.5 *Facilities markets*

Once we have studied, developed and quantified the market sectors in this Early Phase, the working group will consider the much-expanded Mature Phase. This would be very different, and no longer totally dependent on government funding, although of course there would still, even in 2040 onwards, need to be a continuing governmental presence in a support function – and this would need the appropriate agency budget funding during the period. It is even more critical in this phase to be careful to avoid double counting, by being precise in our descriptive language. The following categories are proposed.

**MATURE PHASE MARKET**

**1.Transport to/from Moon**

1.1 *Robotic taxi service; launch vehicles and spacecraft* - Delivering science and engineering test equipment, crew supplies, infrastructure updates (including habitats, storage, solar arrays, nuclear power plant, waste processing/recycling equipment), for delivering mining machinery and tools, and supplies for the lunar space tourism hotel.

1.2 *Crewed taxi service; launch vehicles and spacecraft* - Lunar lander missions for government astronaut crews, and for lunar tourism guests (probably both orbital and surface hotel in this Phase).

1.3 *Launch and Landing Pads* - Operation and maintenance of common landing zones

1.4 *Central Moonport admin/governance* -Registry, Interference Zoning, Damage assessment, Environmental, Nuclear, Education, Traffic management, Policing

**2.Transportation on the Moon**

2.1 *Robotic rovers/hoppers* – Provided or leased by commercial robotics firms conducting ongoing surveying/resource mapping

2.2 *Crewed rovers/hoppers/EVA systems* – Provided or leased by commercial taxi firms, and as part of lunar surface space tourism, for visiting sites of particular interest.

**3.Comms and Navigation on the Moon**

3.1 *Comms system, including Internet* - Operations and upgrades

3.2 *Navigation system* -Operations and upgrades

**4.Energy and power on the Moon**

4.1 *Power production and Distribution* – Solar, nuclear etc.

**5. Products and services on the Moon**

5.1 *Emergency/Fire/Rescue services*

5.2 *Medical/Health/Centrifuge facilities*

5.3 *Waste processing/recycling*

5.4 *Banking/Lunar currency management*

5.5 *Leisure Facilities*

5.6 *General Provision Stores* – Food, water, oxygen, and equipment supply, maintenance and repairs (spacesuits, equipment, habitations).

**6. Infrastructure, construction and manufacturing on the Moon**

6.1 *Provision of Building materials* – Bricks, Concrete, Radiation Shielding

6.2 *Building of Facilities* – Habitations, hotels, research labs, storage

6.3 *Manufacture from the* regolith - Solar Cells, Circuit Boards and Chips

6.4 *Roadways (sintering) building and maintenance*

6.5 *Possible manufacture of products for export to Earth and Tourists* – products requiring a low-g environment; products needing hard vacuum environment for manufacture (although noting in passing that these products could be produced also at the ISS or elsewhere in LEO).

**7. Mining/Resource Extraction on the Moon**

7.1 *Extraction, Storage and sale of materials for use on Moon* – Water, Oxygen, Aluminum, Titanium, Silicon, Iron and Rocket Fuel

7.2 *Extraction and sale of materials for export to Earth* – PGM's, Rare Earths, Helium 3

7.3 *Extraction and sale of materials for export to GEO/Lagrange Points* – Water, Oxygen, Rocket Fuel

**8. Habitation/Storage**

8.1 *Leasing of habitable space* – Governmental facilities for science and exploration, lunar space tourism hotel, restaurants, bars, casino, entertainment, sports, movie production, computers, private settlements,

8.2 *Storage for Commercial customers* – Archival facilities, etc.

**9. Lunar Agriculture/Food production**

9.1 *Vegetables* – Hydroponics

9.2 *Animal Husbandry* – Meat/fish

By referring to the taxonomy provided above, the working group will be able to avoid double-counting the money transfers, and will have a fairly comprehensive list of areas on which to focus as our planning progresses, and can distinguish between governmental and commercial efforts. Furthermore, the working group will accumulate data on the terrestrial availability and pricing of those resources listed above, in 7.2, and intended for export from the Moon to Earth after lunar mining.

**WORKING GROUP TASK AREAS**

The main task of this Working Group is to characterize and assemble the best available data for each lunar business segment listed above, from multiple sources, and identify the remaining knowledge gaps, with possible approaches for obtaining the missing data. Also, in parallel, data will be assembled on terrestrial reserves of key materials being considered for import from the Moon. Work will commence with the sectors identified above as the Early Phase, and then proceed with the nine sectors identified within the Mature Phase. This documentation will be combined together in the Lunar Commerce Portfolio, which will be maintained as an ongoing source of information in support of commercial lunar developments. The object is to provide added value both to the potential commercial business providers, and to the government planners seeking to assess the timeframe and degree of support to be anticipated from the commercial participants in lunar developments. The Lunar Commerce Portfolio will be available for GEGSLA as it seeks to advise the UNCOPUOS in relevant policy areas.

**REFERENCE SOURCES**

In addition to a number of websites that keep track of terrestrial resource data, a number of books and reports constitute reference sources for building the categorization scheme proposed in this document, some of which are listed chronologically below with a summary of content.

**1991 Heiken, et al "Lunar Sourcebook" Cambridge University Press**

Identified the content of all lunar samples

Results of all experiments and characterization of regolith dust

Assessments of lunar environment – temperature and radiation and atmosphere

Explanation of the standard way of expressing location and navigation on Moon

Tables of mineral composition at Apollo sites eg Armalcolite

Properties and composition of the regolith and core sample analysis

Slope stability data

60% Oxygen, 16% Silicon, 10% Aluminum, 5% Calcium, 5% Magnesium, 3% Iron, 1% Titanium

**2004 Wingo "Moonrush" Apogee Books**

PGM's for Fuel Cells (thus move from oil economy)

He3 for Nuclear Fusion (thus environmentally friendly hydrogen economy)- Moon and Gas Giants (1 million tonnes embedded in lunar surface)

Industrial Processes that require a vacuum

Oxygen and the resulting bi-products of aluminum, silicon, titanium, etc

Club of Rome/ Meadows / Gore models suggest moving from growth to equilibrium – so space resources introduced to transcend the limits to growth.

Platinum needed for fuel cells – terrestrial supply and demand data – due to Nickel/Iron asteroid (NEA's) impacts on the Moon 140 to 590 billion tons of PGM's – enough for a 3000-year supply.

**2006 Schmitt "Return to the Moon" Praxis/Copernicus Books**

Ten square miles X 10 feet deep contains 1000Kg of He3 – enough to power a fusion plant for a year – enough to power a city of 10 million for a year. Apollo concentrations between 20 and 30 parts per billion He3 in titanium-rich regolith. Would need capital investment of $15B. Data on world energy needs (eg Table 3.1). Discussion of problems of fission and progress of fusion technologies and economics (Univ of Wisconsin-Madison). Suggested mining technology approaches and flow diagrams (eg Fig 7.4). Need to change NASA management and structure, and change space law, and maybe follow an Intelsat/Inmarsat model. Lunar commercial development crews would need to be about 25 years old, and accept a one-way assignment.

**2010 Benaroya "Turning Dust to Gold" Springer**

The book is a fictional view of the world 150 years into a future that includes space elevators and lunar colonies. However, it does include some contemporary interviews. Ideas discussed include Lunar Development Corporation, and economics and cost data are provided for a lunar base. Sustaining markets include solar power generation, board and chip manufacturing, hard vacuum processes, entertainment and tourism, sports and artists' facilities, research, support services (including maintenance, food production, waste disposal, medical services, oxygen production). Also included are alternative lunar base designs, lunar concrete discussion, medical issues and space elevators.

**2010 Yingst and Rice "Final Report of Orbitec/Steckler Project" NASA**

Study based on Alan Wasser's "land claims recognition" approach and law interpretation – following the economic business model of Disneyworld in Florida.

For assembling the lunar colony, the lunar resources used are water, oxygen, hydrogen, iron, aluminum, silicon, regolith and basalt.

Study identified (Fig 20, 21, 27) other "secondary" commercial activities beyond the assumed primary commercial motivator of real estate land ownership:

He3 production, solar power/ storage/ solar cell production, LOX/ hydrogen/ water production, raw materials/ radiation shields, communications services/microwave, building materials/bricks, navigation services, entertainment/movies/advertising, transport services/hopper taxi flights, lunar tourism/casino, facilities manufacture, agriculture/food production, repair services, $1/6^{th}$ g large mirror manufacture, medical services/centrifuge facilities, high-vacuum manufacturing, archival services, storage of nuclear materials, lunar satellite operations, life support services, EVA systems/rovers, road building, mining.

The study contains detailed analyses of production processes for lunar resource extraction and a 7-page bibliography of relevant papers.

**2012 Diamandis and Kotler "Abundance" Free Press**

A great source of raw data on terrestrial resources in its reference section, including water, sanitation, food/agriculture, health and energy.

**2013 Anderson "Moon Prospect - Demand for Commercial Lunar Services"- Space Angels Network/Astrobotic**

Study done for Astrobotic and (in Appendix B, C, D) refers to concepts and data from the 2010 Steckler Project. Also included are useful data on international space agency science budgets (in Appendix G, H). The identified market segments and demand estimates in Payload Unit Equivalents (PUE's) for lunar payloads in 2020 (from constrained to growth case), with a PUE being defined as a Lunar Cube or 1KG of lunar surface delivery, or $1.2M in research budget, are:

- Resource Extraction/Mining (38% of total)
  Extraction of lunar resources (mainly water) primarily for use as fuel and life support for continued lunar activity – includes prospecting, intelligence gathering, feasibility, mining machines and tool delivery. 240 – 1200 PUE's
- Tourism (8% of total)
  The Moon as a destination for adventure seekers – includes lunar hotel developers, manned lunar missions. 30-95 PUE's
- Technology Test and Demonstration (small proportion of total)

Aerospace engineering to advance technology maturity or achieve lunar demonstration, qualification, or certification – includes demonstrations requiring lunar environment and hardware qualification and test. 1-30 PUE's

- Science and Exploration (9% of total)
  Basic and applied research in a number of disciplines, leveraging the unique properties of and access to the lunar environment and microgravity – includes Earth and deep space imagery, space physics, biological and physical research, human research and lunar exploration. 57-205 PUE's
- Education/University (small proportion of total)
  Providing opportunities to universities to increase access to and awareness of space and the Moon – includes university educational missions. 2-11 PUE's
- Infrastructure support and supplies (45% of total)
  The market for products and services to support sustained commercial lunar activity – includes energy, manufacturing, construction, life support, medical care, sanitation, transportation, communications. 480-1025 PUE's
- Media and Advertising (small proportion of total)
  Using the Moon to promote products, increase brand awareness, or film Moon-related content – includes media, advertising and sponsorship, film and TV, novelties and memorabilia. 8-64 PUE's

The total (2020) demand in PUE's ranges from 820 to 2600 PUE's, depending on such factors as reductions in government budgets and consumer spending. This translates into a revenue potential of $ 0.9B (constrained) thru $1.9B (baseline) to $3.1 B (growth scenario), assuming Astrobotic prices of $1.2M per PUE to lunar surface.

**2015 Lewis "Asteroid Mining 101" DSI Books**

Table 111.2 – Resources of NEO's (enough for 400 billion people)

Table 111.3 – Resources of the asteroid belt

Mining would usually be confined to the regolith of the asteroids (no ores)

Fig IX.2 – A generalized asteroid processing architecture

**2015 Impey "Beyond - Our Future in Space" Norton**

The book contains some fictional vignettes to establish the reader in the past, present and future of space travel; however, most of the work is sound non-fiction, and the part describing a lunar base is particularly useful in the context of the present analysis. It uses a 2009 report from the Center for Strategic and International Studies (CSIS) as the main resource for data. The project development costs were stated to be $35Billion, probably spread over a decade, and the assumed operating costs were $7.4Billion per year. The operating costs assumed that no local resources would be available, so four tons of supplies per person per year would have to be shipped from the Earth to the Moon. The basic requirements per day per astronaut (assuming

water is efficiently recycled) would be 2.5 liters (2.5 Kg) of water, 0.8kg of oxygen and 1.8kg of dried food. Other cited data is 600 million tons of water ice, oxygen at 40 to 45% of regolith, with 100 grams of breathable oxygen for every kilogram of soil after heating to 2500 K.

**2016 Spudis "The Value of the Moon" Smithsonian Books**

The Clementine mission is described. It also includes LCROSS impactor data of 7% water in the plume. Marburger quote (2006) "…we must learn to use what we find in space to create new capabilities, starting with the material and energy resources of the Moon". The book narrates all the previous presidential initiatives, Commissions and Reports (focusing on the VSE (2004)). Spudis states "..the value of the Moon is that it is close, interesting and useful." Amongst the "useful" category he lists regolith and sintering technologies, the poles for both ice (more than a billion tons of water ice at each pole) and (near) permanent sunlight, thorium (on Western near side), and He3 (less than twenty parts per billion). He states that "the limiting arithmetic of spaceflight cannot be addressed as long as we haul everything we need up from the bottom of the deepest gravity well in the inner solar system"- leading to discussion of propellant depots. He describes a three-part approach to resource extraction and associated creation of a lunar outpost: 1) resource prospecting, 2) resource mining, processing, production, and 3) outpost infrastructure emplacement and assembly. This lunar base would cost $88B over 16 years (see Table 7.1) and produce an operating, human-tended polar outpost that produces 150 tons of water per year.

**2016 Webber "No Bucks, No Buck Rogers" Curtis Press**

Chapter 12 addresses the following market segments:

Lunar Space Tourism (Adventurers' Survey data)

Science/Technology Demonstrator Test

Lunar Colony Support services - Build the infrastructure, maintain the supply lines, provide the energy supplies (solar/nuclear)

Resource Extraction - For Earth (PGM's, Rare Earths, He3), - For Moon and other space destinations (Aluminum, Titanium, Silicon, Water, Oxygen, Rocket Fuel).