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A Moon Consortium for Climate Change Mitigation

Abstract

The moon provides an opportunity for a better earth. Climate change is the grandest challenge. It requires radical movement to provide a sustainable solution and providing a solution for our grandest challenge means a better world. This research project suggests a path to utilize technological innovations on the moon to solve Earth's grandest challenge. This path will enable many commercial and scientific opportunities not related to climate change. Solar Power Satellites (SPSs) are a promising innovation to provide a sustainable solution for the climate change problem. The major enabler for SPSs is low launching cost. The launching cost from the moon to geostationary orbit (where SPSs are located) is cheaper than the launching cost from earth. This research project assumes that returning humanity to the moon will be motivated by establishing activities to solve the climate change problem. These activities will open the door for additional commercial opportunities. Therefore, I propose a business consortium that will potentially attract non-space investors. The investment will target building infrastructure on the moon to manufacture parts for SPSs and to utilize additional associated commercial opportunities.

Introduction and Background

Solar Power Satellites (SPSs) are promising solution to solve the problem of climate change. In addition, SPSs can open a great commercial opportunity. Although no technological breakthrough is required to realize SPSs, further reduction in the launching cost is required for its commercial feasibility. There are many concepts for SPSs. This research project considers the SPS-ALPHA concept.

The SPS-ALPHA concept solar reflector array uses aluminum foil to reflect solar irradiance to a solar power generator. Aluminum foil is light and can concentrate the solar irradiance to a few suns as required for the concept. Also, aluminum is required as a backbone for structure. The generator module will need to be covered by glass. Given the huge mass of the SPS-ALPHA concept, the aluminum and glass required are in the scale of hundreds of tons.[1]

As discussed below, the moon is an excellent place to manufacture aluminum and glass due to the abundance of both elements in the lunar regolith. Most importantly, launching from the moon is much cheaper. However, the moon lacks the infrastructure to manufacture SPS parts and lacks the launching facilities.

Many ideas have been published for a lunar base. I argue that the motivation for going to the moon should be for the benefit of the Earth. Manufacturing some parts of SPSs on the moon and sending them to geostationary orbit might reduce the cost, but capital

[1] John Mankins, *New Developments in Space Solar Power* (Guadalajara: International Astronautical Congress, 2016).

investment in infrastructure will be required. Building the infrastructure of aluminum and glass factories will open new opportunities, which are discussed below.

Energy Transportation from the Moon

The moon has the potential to become the new ground for commercial opportunities that will revolutionize space activities. The moon is a sixth of the size of the Earth, which means it is much easier to escape its gravitational well than that of the Earth. The moon lacks an atmosphere, which means that there is no drag when launching from the lunar surface. In addition, the moon has volatiles and other elements like silicon and aluminum. All these unique aspects of the moon are extremely important for the exploration of Mars and beyond.

Figure 1, which was provided by John Mankins, shows the ΔV to reach different orbits around the Earth, Moon, and Mars. It shows that the ΔV to launch from the lunar surface to geostationary orbit is 3,890 m/s, while it is 4,330 m/s to launch from the Earth to geostationary orbit (high thrust). This difference makes launching from the moon cheaper.

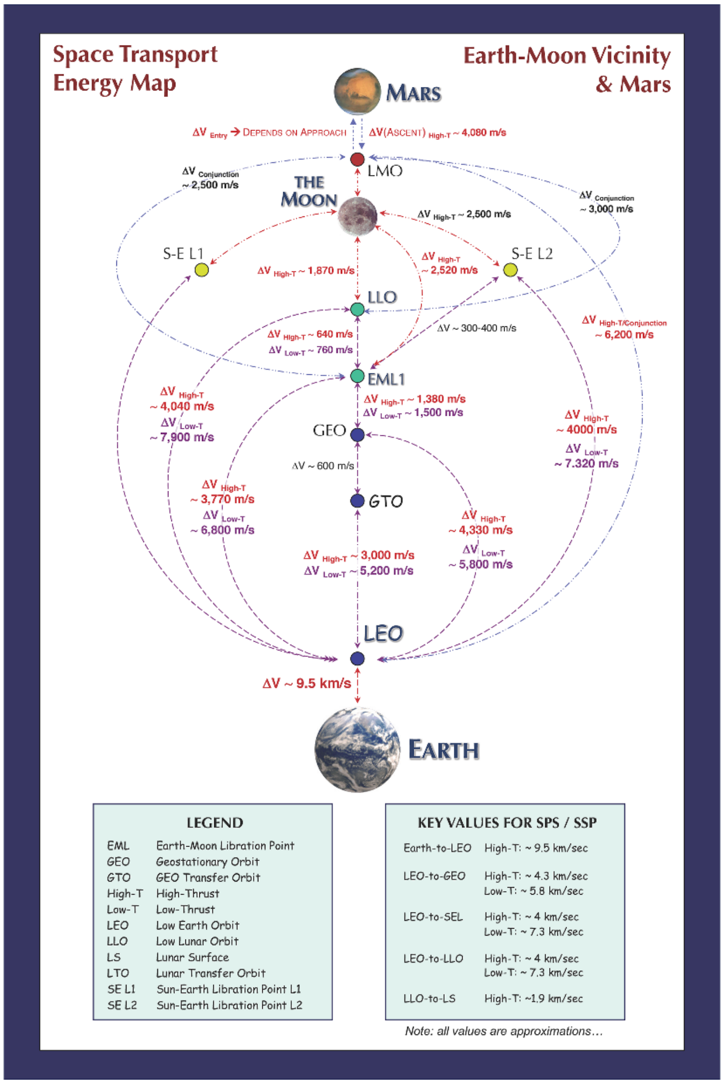

Figure 1: Space Energy Transport Map

Commercial Opportunities on the Moon

Four major promising commercial activities can be identified for the moon in general. They are promising because they take advantage of the moon's unique aspects, and they do not require fundamental technological breakthroughs.

1. Rocket Fuel Manufacturing Using Lunar Resources

Water in the lunar surface is priceless. It can be used for a variety of applications. in addition to its use in life-support systems, water can be used to produce propellants. Although closer examination of the water content in lunar soils and rock is needed, many studies have suggested a variety of plant architectures to extract water from permanently shadowed regions. Those architectures focus on the idea of using mirrors to concentrate solar heat to evaporate water. The water vapor will then be condensed by passing it through a cold surface. This water can be used for life-support systems or it can be split using electrolysis processes. The resulting hydrogen and oxygen can be used as propellants for rockets.

Mining operations, extraction methods, processing, storage, and power demands are all mentioned in more detail in a study by David Kornuta et al.[2] However, it is important to mention that Kornuta et al. identified a demand for 450 metric tons of lunar propellant derived from 2,450 metric tons of processed water, which may provide an annual revenue of about $2.4 billion.

2. *Manufacturing Products to Support Activities on the Lunar Surface, Cis-Lunar Orbit, or Beyond*

Most elements in the periodic table are available on the lunar surface (Table 1). However, the concentrations and the chemical process that formed elements in the lunar surface are different than those on earth.[3]

Table 1: Chemical Elements on the Moon

Compound	Formula	Composition	
		Maria	Highlands
Silica	SiO_2	45.4%	45.5%
Alumina	Al_2O_3	14.9%	24.0%
Lime	CaO	11.8%	15.9%
Iron (II) Oxide	FeO	14.1%	5.9%
Magnesia	MgO	9.2%	7.5%
Titanium Dioxide	TiO_2	3.9%	0.6%
Sodium Oxide	Na_2O	0.6%	0.6%
		99.9%	100.0%

3. *Tourism and Hospitality*

The moon has been a source of inspiration in almost all world cultures. Escaping the gravitational well of earth, viewing the earth from space, landing on the moon, touching the lunar rockets, and seeing the earth from the moon will be a lifetime unique experience.

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[2] David Kornuta, Angel Abbud-Madrid, Jared Atkinson, Jonathan Barr, Gary Barnhard, Dallas Bienhoff, et al. "Commercial Lunar Propellant Architecture: A Collaborative Study of Lunar Propellant Production," *Reach* 13 (2019): 100026, https://doi.org/10.1016/j.reach.2019.100026.

[3] Stevan Akerley, "Space Paradigm Shift," *Journal of Space Philosophy*, 9 (1): 60-87.

This unique experience can be realized when human missions to the moon start in the first half of the twenty-first century. As of 2021, space tourism is not new, and there are ongoing programs for space tourists.

Space flight participant is a term given to individuals who have visited space (orbital or ISS), but they are not professional astronauts. Some space flight participants are pure tourists, while others are part of outreach programs. To date, twelve space flight participants have gone to the ISS.[4] A private company called Space Adventures is today leading space tourism as it provides training for customers and guarantees their safety.[5]

A similar concept can be generalized for tourism on the moon. The space tourism experience has so far proved that it can target a larger audience than wealthy millionaires, which can open commercial opportunities on the moon.

4. *Archiving Data*

Information about the moon is crucial for any activity. High-resolution maps, chemical element concentrations and locations in the lunar surface, and solar irradiance availability in a particular location are just examples. Obtaining information and archiving it can be a commercial opportunity, as many costumers would like to use the most up-to-date information to execute activities.

The Moon for Climate Change

Why go to the Moon? I argue that the best answer is to solve human's grandest challenge—climate change. This simple motivation can focus investment in the moon to create a whole new ecosystem and a new economy that links the moon with the Earth's economy.

Table 1 shows that silicon and aluminum are abundant in the lunar surface. The two elements will be in demand for SPSs and other applications on the moon. In-situ resources utilization is an evolving topic that has many aspects. It is important to answer questions about which elements are useful for what application and how to extract them from the lunar surface. All this should be done comparatively to evaluate the different economic feasibilities. For this research project, the focus is SPSs. Silicon and aluminum are particularly important for the fabrication of the SPA-ALPHA concept. Silicon can be used as cover glass for solar generator modules and aluminum sheets can be used to concentrate solar power. It is possible to extract silicon from the lunar regolith and rocks using microwave furnaces. The technology has been discussed and tested on Earth.[6] However, there are several methods and process to produce aluminum and silicon.

[4] NASA, "Space Station 20th–Space Flight Participants," www.nasa.gov/feature/space-station-20th-space-flight-participants.

[5] Space Adventures, "About Us," spaceadventures.com/about-us/.

[6] Jürgen Schleppi, Joseph Gibbons, Alexander Groetsch, Jim Buckman, and Aidan Cowley, "Manufacture of Glass and Mirrors from Lunar Regolith Simulant," *Ceramics* 54 (2018): 3726-47.

Silicates such as anorthite ($CaAl_2Si_2O_8$) are excellent sources of oxygen. Processing anorthite to produce oxygen was first discussed in 1988. The process has the advantage that it can produce elemental silicon, elemental alloys, and casting alloys of silicon and aluminum. It also produces calcium that can be used for cement production, and most importantly, the process produces oxygen. The process uses magnetic separation of anorthite, a silicon reduction process, and electrolysis for oxygen production. Knudsen and Gibson give the plant schematic diagram and more details about the process.[7]

When this process when was first discussed, water had not yet been discovered on the Moon. Water on the Moon is probably going to be the most important material. Electrolysis can be used to produce water. Water can be used for life-support systems and fuel production. Therefore, it might be feasible to find another way to produce oxygen and to save water. As briefly discussed above, oxygen can be produced from anorthite, which can also save water.

Additional manufacturing process will be required to manufacture final products such as PV cover glasses and aluminum sheets for reflection. Oxygen will be stored for future use and water will be used for rocket fuel and stored for future use.

Infrastructure Investment

The investment to build a plant on the lunar surface to manufacture SPS parts may radically increase the risks when compared with the investment on earth to manufacture the same products. However, investing in the moon will enable the four commercial opportunities discussed above. A huge portion of the capital that will be invested to manufacture parts for SPSs (glass and aluminum) on the moon will go into infrastructure, which will enable these commercial opportunities. This will have many advantages:

1. It will attract investment for climate change.
2. It will attract investment from non-traditional actors, such as tourism and hospitality, and energy to create a permanent base on the moon.
3. It will open the opportunities for emerging space countries by attracting investment.

Interoperability of technologies is key to reducing the cost of investment and improving the capacity factors of services and products. The following is a list of services (infrastructure) that are required to support the plant and its commercial opportunities:

[7] Christian W. Knudsen and Michael A. Gibson, *Space Resources: Materials* (Washington, DC: NASA, 1992), 190.

1. Transportation:
   To transport raw materials to the plant to produce fuel, water and so on.
   To transport products from the plants to a habitat/outpost, rocket pad.
   To transport humans either for operation or for tourism.
2. Storage tanks:
   To store rocket fuels, water, oxygen, and other products (glass and aluminum for SPSs).
3. Power requirement:
   Wireless solar power transmission may be a promising solution. Also, small nuclear reactors can be considered.
4. An Outpost/Habitat:
   This will accommodate humans. In the coming 20-30 years, it will be technically and morally difficult to bring families to live on the Moon. However, astronauts who will work on the moon will need to be accommodated temporarily in a comfortable habitat. The scale of work necessary to build powerplants will require a blend of robots and humans, so investment in a habitat will is important to execute the proposed operation.

Investment and Revenues Options

Capital investment should be structured to contribute to the infrastructure on the moon. It is suggested that the investor can select one of the following investing blocks:

1. The production of rocket fuels.
2. The production of SPS parts.
3. The production of oxygen.
4. The production of water.
5. The production of calcium.
6. Tourism and film making.
7. Archiving.
8. Science.

These investment blocks will generate direct revenues. However, a huge portion of the investment will be directed toward building the infrastructure disused above. It will be extremely important to create a fair evaluation of infrastructure share for each block.

The Role of Science

The moon is a heaven for scientists. The infrastructure that will be built on the moon should also allow for the science demand and provide basic laboratories for scientific use. Universities and scientific institutes will be welcomed to invest in the infrastructure.

The cost of the James Webb telescope has reached nearly $10 Billion.[8] A radio telescope and other astronomical detectors on the lunar surface can have similar or more scientific value than the James Webb telescope. Astronomy on the moon is just a single example, and the scientific value of research on the moon is extremely high, but this is beyond the scope of this paper. A similar model should apply for science. A new block can be added for science, and scientific institutes can invest in that block. A portion of the investment will go to infrastructure.

Impact on the Moon Village

The Moon Village architectural elements represent a high-level description of the types of activities that might occur in a moon village.[9] There are eleven architectural elements, and each element has multiple building blocks. Mankins described three future scenarios: Scenario Alpha, which will be derived by human spaceflight funded by governments; Scenario Beta, which will be dominated by scientific research funded by governments; and Scenario Gamma, which will be dominated by commercial activities. Mankins argues that the actual scenario will be a blend of those three scenarios. Commercial activities are extremely important to boost innovation, and a revolution can happen once large investments start. However, he does not discuss how to kick start commercial activities, or at least he assumes that ongoing moon activities will be the actual start.

The proposed idea in this article is in line with the moon village architecture. The eight investment block opportunities mentioned above and the background infrastructure all relate to all the identified architectural elements. However, this paper suggests a more detailed path to proceed and a more detailed vision.

Consortium

Creating a consortium that involves multinational stockholders from the tourism industry, energy industry, scientific community, and many more will best fit the above discussion. Stockholders will invest in one of these blocks. Part of their investment will go to the infrastructure that will be used for other blocks. For example, a tourism company might be interested in investing in a few rooms in a habitat that will accommodate tourists (customers). The investment of the tourism company will contribute to the infrastructure to build the plant that will produce oxygen. This plant, as discussed earlier, will also produce materials for SPSs.

However, the core concept is that the consortium will be motivated to reduce the price of electricity for delivery to earth when an SPS is deployed in geostationary orbit. This is a direct link to the earth economy and a chance to mitigate climate change.

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[8] NASA, *James Webb Telescope* (2020), www.jwst.nasa.gov/.

[9] John Mankins, *Expanding Humanity to the Moon: Moon Village Reference Architecture* (Vienna: Moon Village Association, 2020).

Conclusion

SPSs offer a promising commercial opportunity in the near future. The opportunity is attractive not only because it can provide inexpensive power, but also because it can radically mitigate climate change. This makes investments in SPSs a necessity. Manufacturing SPS parts on the lunar surface may reduce the price of electricity further, because launching from the lunar surface is cheaper.

The major challenge is that no infrastructure is yet available to support production of SPS parts. However, this challenge can be turned into an opportunity. Building the infrastructure will create many commercial and scientific opportunities.

Most importantly, the proposed plan provides an answer to why humanity should go to the moon. Mitigating climate change will open the door to attract non-space investors and will link the emerging lunar economy with the Earth economy.

As discussed above, a consortium that will gather different stockholders is a good solution. An investor interested in energy or tourism will select the corresponding block. However, part of the investment will go into infrastructure. The more players, the more risk distribution, which is necessary.

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About the Author: Ghanim Alotaibi is a mechanical engineer who works in the Physics department at Kuwait University. He is working on the first space mission in Kuwait and is considered the first person in Kuwait to hold a full-time space-related job. Ghanim is also the project manager for the "Moon Village—Participation of Emerging Space Countries" project. The project's aim is to involve developing countries in moon activities to make moon exploration more diverse.

Ghanim worked for the Kuwait Oil Company for six years before he obtained his master's degree from Freiburg University, Germany in solar energy. Since he was an undergraduate student, he has been involved in many space activities. He was the Middle East Regional Coordinator for the Space Generation Advisory Council and he performed two field rotations as an analogue astronaut at the Mars Desert Research Station. Ghanim is also an amateur astronomer with an interest in the photometry of variable stars and he is a graduate of the International Space University.

Editors' Notes: Ghanim Alotaibi here provides a hypothesis for a huge development on the Moon that would have an array of benefits for both Earth and the future of Solar System developments—including the possible mitigation or solution of Earth's major challenge, climate change. Mr. Alotaiba developed this proposal as a Kepler Space Institute (KSI) scholar working with KSI Professor and Space Scientist/Technologist John Mankins. This is an illustration of the excellent products of graduate level research that has future paradigm-shift thinking for the next Space era now underway. ***Bob Krone and Gordon Arthur.***