Space Solar Power Satellite Systems as a Service Provider of Electrical Power to Lunar Industries

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Space Solar Power (SSP) systems are poised to deliver significant benefits on Earth and elsewhere. SSP systems are based on the concept of collecting large amounts of solar energy in space and relaying the energy, in the form of microwave or laser radiation, to a receiving array that converts the transmitted energy into usable energy at the destination. An increase in space enterprise dictates the requirement for a continuous supply of energy in order to maintain human-supporting and robotic operation. SSP systems can form a part of the solution to this need. They can be utilized as a service provider of electrical power to the lunar and near-Earth transportation industries to support continuous operations.

This paper presents a concept for utilizing a SSP system in support of Earth-moon transport and lunar habitation. It evaluates the economics of utilizing SSP systems as an electrical service provider for lunar and near-Earth transportation industries such as mining, processing, science, and material transportation systems in the Earth-moon and near-Earth asteroid (NEA) environments. Whether SSP systems will provide a return on investment (ROI) within a timeframe that would be considered feasible by most investors is considered. The operations and infrastructure of the proposed SSP systems are presented and the plausible benefits from its implementation are presented and analyzed.

Risk analysis of SSP systems is essential and must be transparent in order to convince potential investors of the viability of the technology and its suitability for investment. To effectively estimate the risk of launching or investing in a SSP firm, it is necessary to understand the continuum of potential suppliers, partners and consumers. It is also critical to have an understanding of relevant political and legal issues, and prospective competitors. This considers these topics to estimate the economic value of not only the service prospectively provided by such a firm, but also of the economic value of those industries in which the firm is servicing. A space economic system is discussed where SSP systems provide an essential service for these industries. This paper shows that SSP systems can exist as a service provider of consistent base load electrical power for lunar industries.

I. Introduction

The growing world population is projected to peak in 2075 at 9.22 billion people [1, 2]. This has created significant growth in energy demand. However, the accelerated rate of the world’s resource exploitation is decreasing their availability to alarmingly low levels (see Figure 1). Studies also show that this model is applicable not just to oil, but also to coal, natural gas, metals, hydro power, and nuclear power—virtually every finite resource [3, 4]. Side-effects from fossil fuels, such as CO₂ emissions, could have negative impacts to the whole of the planet, such as major droughts and floods, decreased air and water quality, and overall climate change.

Dr. APJ Abdul Kalam, who served as the 11th President of India from 2002-2007 and has expertise in aeronautical engineering, stated: “By 2050, even if we use every available energy resource we have, clean and dirty, conventional and alternative, solar, wind, geothermal, nuclear, coal, oil, and gas, the world will fall short of the energy we need by 66%” [5]. This necessitates the identification of sustainable energy solutions to meet the divergent needs of the people. One possible solution is Space Based Solar Power (SBSP) satellite systems. Although potentially a solution to helping solve energy stability, SBSP satellite systems poses many environmental and safety concerns, technical uncertainties, and other impediments due to lack of experimentation and real space wireless power transfer tests [6]. To help strengthen the pathway of a SBSP system for use on Earth, it makes sense to first

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use SBSP systems on the Moon for solving logistical problems for lunar exploration as well as testing SBSP systems for future use on Earth.

**Figure 1. Bell curve for peak oil production [7].**

## II. Background

The SBSP concept was first officially recognized in a 1973 patent by Peter Glaser of the Arthur D. Little Company. This patent [8] introduced a method of collecting and converting solar radiation to microwave energy via a Solar Powered Satellite (SPS) placed in geo-stationary Earth orbit (GEO). It then transmitted that energy to Earth where it was converted to electrical power via a rectifying antenna (rectenna) array for distribution.

From 1976 through the 1980s the National Aeronautics and Space Administration (NASA) and the Department of Energy (DOE) performed work to evaluate SBSP as an alternative energy solution. DOE and NASA came up with the Concept Development and Evaluation Program for Solar Powered Satellites [9]. The central feature of this concept was the creation of a large-scale power infrastructure in space, consisting of approximately 60 Solar Powered Satellites (SPSs), each delivering 5 Giga Watts (GW) of base load power to the U.S. power grid [10]. This was the period of time during which the second American oil crisis was occurring.

Work continued and in 1995 NASA re-evaluated the challenges of large-scale SPS systems with a new study [11]. The goal of this study was to determine whether technological advances since the 1970s might enable viable SPS system concepts. It concluded that space based power generation and transfer was more technically viable than it had been at the end of the 1980s, although it was still exceptionally challenging [11].

In 1998, NASA conducted the SPS Concept Definition Study, at the suggestion of the House Science Committee. The study was a focused one-year effort that reviewed the results of the 1995 study. It included an independent economic and market analysis conducted by Dr. Molly Macauley of the Washington, D.C.-based nonprofit Resources for the Future. It found that SBSP appeared more viable than in the past, largely validating the findings of the 1995 study. A principal product of this was the creation of strategic research and technology road maps for the development of SBSP technologies [10]. The program involved large and small companies, other agencies, laboratories, universities, and several international organizations. It addressed three elements: (1) system studies and analysis, (2) SBSP research and technology, and (3) SBSP technology demonstrations.

During 2001 to 2002, work continued on key concepts and technologies for future SBSP applications [10]. In the winter of 2002, the National Science Foundation (NSF) and the Electric Power Research Institute (EPRI) issued a joint broad-area announcement for high-leverage, high-risk research studies targeting key challenges facing SSP systems. It emphasized projects in four areas: (1) wireless power transfer, (2) intelligent robotics, (3) power management, distribution, and control (PMAD), and (4) understanding of the cost and opportunities and how to maximize SPS’s positive impact on the environment, health, and safety for sustainable worldwide growth.

## III. Literature Review

Oda and Mori [12] and Little and Brandhorst [13] have investigated utilizing SSP to power lunar science missions (e.g., a rover) in the polar regions in search of water-ice and other needed volatiles for any future habitation. They compared various power sources including solar cells, fuel cells, atomic energy, and SSP using either microwave or laser power transfer. Each method had its advantages and disadvantages. SSP offers greater mission flexibility with an altitude advantage that allows aiming the power beam to different locations on the lunar surface. The altitude advantage is especially helpful, compared to surface solar energy, near the polar regions of the
Moon because light comes in at an almost horizontal angle thus does not enter the cater regions of the Moons poles where the water-ice is located.

One very important item to the success of a SPS future business is the ability to manufacture the entire SPS from lunar materials. Potter [14] and others [15-17] found that constructing and launching a SPSs from the lunar surface provides a cost savings, as opposed to constructing and launching it from the Earth. In the future, SPSs to be used for Earth applications may originate from the Moon. Little and Brandhorst [13] provide a cost estimation for large scale production of lunar Photo Voltaic (PV) arrays which are needed for the SPSs. Zidanšek, Ambrozic, Milfelner, Blinc, and Lior [18] provide a cost analysis of launching a SBSP systems from the Moon to GEO orbit. They contend that the most challenging aspect of launching from the Moon is the current state of the art of robotic technology.

Lusk-Brooke and Litwin [19] investigate building an organization and management structure to create, launch, utilize and protect a SPS. Some elements include: (1) research and development, (2) investment, (3) transmission and distribution, and (4) crisis response. Charania, Olds, and Depasquale [20] considered potential niche markets where SPS satellites may be economically viable, given certain government support and Earth-to-Orbit launch cost assumptions. They considered the First Revenue Satellite (FRS) as a hybrid public-private system. Macauley and Davis [21] supplied an economic assessment of space solar power as a source of electricity for space-based activities. They helped develop a conceptual model of the economic value of SSP as a source of power to in-space activities, such as spacecraft and space stations.

Xin, et al. [22] investigated a financial and organization approach for a SPS system. They outlined a plausible business plan for making SSP a reality. They performed a political, economic, socio-cultural, and technological (PEST) analysis and reworked old SSP structures to improve the financial viability of the SSP concept. However, their analysis was conducted from an Earth-based system standpoint.

Zidanšek, et al. [18] took a look at the social impact by estimating job growth scenarios per unit of production of energy. Fan, et al. [23] performed a SBSP industry and technology assessment. Currently, three SBSP firms exist: Solaren, Space Energy, and PowerSat Corporation. Each company has taken a different approach to success and focused on Earth sales. Several patents and business approaches from these firms are of interest. This report provided an economic analysis considering potential markets and applications. Launch cost projections were provided. It also advanced a business strategy proposal for SBSP that helps assess the associated risks.

Woodell [24] takes a different approach to deriving cost and benefit. She proffers that scientific experts should seek active engagement in the policy arena and that SSP’s scientific community has a critical role to play in advocating for the consideration of space-based energy solutions. She states that “for SSP to advance beyond the realm of theory, it must engage comparable collaboration at the international policy level.”

## IV. Analysis and Discussion

Projections of future energy demand vary; however, there is consensus that at current levels of usage the world’s accessible supply of fossil fuels will be exhausted within the foreseeable future [24]. Further, experts largely agree in projecting explosive growth in world population and rapid economic development worldwide [24]. These factors dictate a need for sustainable sources of energy.

One prospective solution to this energy problem is SBSP. Because the social and political hurdles of transmitting large amounts of wireless power from space to Earth have yet to be resolved, it is of interest to utilize the concept of SBSP for applications on the Moon. The implementation of the lunar plan presented in this paper will assist in the future development of SBSP for Earth applications and begin to resolve issues impairing its use on Earth. Demonstrating lunar viability will also suggest economic viability on Earth.

### A. Lunar Manufacturing, Mining, and Processing Companies

The first phase of the proposed project is the assembly of robotic factories on the Moon. By utilizing a completely automated production and fabrication process there will be a reduction in costs. Robots, computers, electronics and building materials (which are not available on the Moon) will be transported from Earth. Let us assume that there exist three factories (mining, processing, and manufacturing) that are operational on the Moon’s surface. These industries are dependent on each other as buyers and partners. They will produce multiple products and have multiple buyers for their products. In particular, one major buyer and partner is the SPS companies. The SPS companies will purchase the SPSs and rectenna arrays from the lunar manufacturing facility. These three factories will need electrical power in order to operate. Let us assume that these operations run initially from a very limited nuclear power supply, enough to build the first three SPS systems including three rectennas. Note that a SPS system includes the SPS along with the rectenna. Once the SPSs systems are produced the SPSs will be launched by
the lunar launching industry. Once the SPSs are in orbit they will begin to supply electrical power to the three lunar industries at retail pricing. The SPS systems will be partially purchased in advance from the manufacturing company in order to help keep the start-ups burn rate lower for a higher chance of success. Once the SPS systems are produced they will be paid for in full.

The Apollo missions found that Lunar soil is composed of useful elements, such as O: 42% (by mass), Si: 21%, Fe: 13%, Ca: 8%, Al: 7%, Mg: 6%, other 3% [15-17]. The elements for space power station construction materials (Fe, Al), for glass reflectors (Si, O) and for semiconductor devices (Si) are thus abundant, and small amounts of other necessary elements can be brought from Earth [18]. It was stated that approximately 99% of an SPS can be built from lunar materials [14]. This offers a very important opportunity of increasing the potential for successful business start-ups on the Moon.

B. Lunar Science Habitation

For any future human habitations on the moon, a continuous source of power is required. Without this, habitation and development of a viable infrastructure and economy is simply unattainable [13]. Several options have been suggested in the past for supplying power to a lunar habitat including fuel cells powered from solar arrays and a buried nuclear reactor power system. The problem with the latter is that it is expensive and there is public concern about its safety during its launch and operations. Regenerative fuel cells, on the other hand, are more promising. In order to use fuel cells on the lunar surface, a recharging mechanism is still required.

In addition to a continuous source of power, the lunar inhabitants will require oxygen and water, which are located in the polar regions of the moon where limited or no light is available for surface solar power. Brandhorst and Little [13] and Oda and Mori [12] have suggested using SSP systems to supply power for both the water mission and habitation. This approach facilitates providing power to sequential sites as research priorities shift towards potentially simultaneously beaming power to multiple sites.

A lunar rover, used for exploration, will also require electrical power. One exploration target is the polar craters, where sunlight is minimal to non-existent. Several energy sources have been considered, such as a radioisotope-fueled source (e.g., with a Stirling converter), an extremely large battery or fuel cell and beamed power from a SPS. The radio isotope option has cost implications and consumes part of the limited supply of Pu$^{238}$ fuel [25]. According to a 2009 report by the US National Research Council, NASA has access to about 5 kilograms of Pu$^{238}$ which could last until the end of the decade [26]. Officials at the DOE say that, if approved now, 2 kilograms could be made annually by 2018 just in time to restock NASA’s supplies [26]. Fuel cells are plausible; however, exploration time in the crater will be constrained by the amount of hydrogen and oxygen that can be carried for the fuel cell and the charging time of the battery [27]. The third option is to beam power to the rover via a SPS. SSP could be an additive and/or catalyst to other energy sources that may be equipped on the rover or lunar habitat. In addition SSP offers more mission flexibility, as stated previously.

C. Earth-Moon Space Transportation

Earth-Moon transportation includes several aspects: transporting humans, supplies and materials to support habitation, and refueling stations for space tourism or other space activities. SSP may be used to create a depot for fueling spacecraft. It would free spacecraft from having to carry power generation and storage (other than for backup purposes) for peak demand or emergencies [21]. One idea for a transportation supply and material cargo system is to implement SSP architecture in space near the Moon and strategically placed along the route towards Earth and for return. The SPSs will be able to supply electrical power forming a virtual space electric railway. This could be made possible by aligning the SSPs energy beam with the space train cargo system to supply electrical power for its electric thrusters. Another company could own the space railway system and pay the SPS company for electric power.

D. Market Summary

In-space activities potentially represent a large market that, perhaps, can be served by SSP sooner than terrestrial customers [21]. However, to narrow the scope of opportunities it is assumed that initial customers include mining, processing, manufacturing, science, and space railway system. To make a space economic system work it is envisioned that all the aforementioned entities will cross-enable one another. This allows a transition to a high-level economy of scale, facilitating low production and energy costs. More economic activities will drive the prices down for future space market growth. Market opportunities are potentially vast.

Complementary technologies for SSP include: solar cells, solar concentrator arrays, rechargeable batteries, flywheel generators and technologies involved with power management and distribution. Competing technologies include primary (full mission sustaining) batteries, and nuclear systems. Technologies that are both complementary
and competing include fuel cells, thermodynamic and static systems. In addition, innovations in lighter-weight spacecraft, more capable batteries, more efficient solar cells, and more efficient high-frequency transmitter and receiver technologies will affect the future economic value of SPS systems. While the markets opportunities mentioned here are only examples relating to SSP, it is reasonable to envision that many others will indirectly benefit by, creating a very large ecosystem driven by SSP.

E. Space Electric Utility Analysis

To begin, the amount of electrical power demanded by customers from mining, processing, manufacturing, science habitat/rover, and space transportation systems must be determined. The total product demanded will provide an amount to design the SPS around. However, electrical energy production from the SPS must be greater than the amount initially required by customers in order to provide room for growth. Another reason why the SPS must have greater production capabilities is because over time solar panels will wear, which decreases their output efficiency, so an end-of-life solar panel power calculation needs to be taken into account.

Many factors play a role in determining how to price the electrical power. First the value of each company (including the SSP Company) is extremely high, given the situation of the start-ups occurring 358,400 km (238,900 miles) from Earth, located on the Moon, and the nature of the complexity never before fully attempted at this magnitude. Because there has been nothing like this before, there are no market reports to suggest accurate predictions. Once the electrical supply amount is known and the value of the company’s service to others is determined, a price can be estimated. More analysis on this lunar ecosystem needs to be conducted as most references relate to the Earth and not the Moon. Furthermore, additional analysis regarding how much energy is required for mining, processing, manufacturing, science/habitat, and space transportation railway is also required.

A prospective provider would supply electrical power to customers and purchase SPSs and rectenna systems from the manufacturing entity. In turn, the manufacturing company would purchase material from the processing industry, and the processing industry would purchase raw substance from the mining industry. The science habitat would be a separate entity that will only be involved in the purchasing of electrical power. The complete science habitat and rover will be sent from Earth to the Moon. The price of SPSs would decrease proportionally to the number of units built and it can be assumed that the price is one order of magnitude lower than the case if the satellite is built and launched from the Earth [18]. The cost of developing a single 5 MW SPS with a 25 year lifetime and assuming no refurbishment mass, a 100% duty cycle, and 100% efficiency to the grid will now be analyzed. Facilities costs were not considered.

Ground power storage and other facility costs are borne by the end-users. However, possible partnerships with lunar energy storage companies may exist, but they are not part of this analysis. An annual cost of $5M and $1.45M (ground-receiver refurbishment cost of $100K, ground-receiver system labor cost of 5x$150K, and ground operations labor cost of 3x$200K) were assumed for space and ground segments recurring operations, respectively [20]. Further cost analysis was done to estimate design development test and evaluation (DDT&E) and acquisition costs. In addition, ground system development and acquisition costs were assumed at $20M and $15M, respectively. These numbers come from [20], referencing a niche Earth market. The cost values are summarized in Table 1.

<table>
<thead>
<tr>
<th>Cost Structure</th>
<th>Recurring</th>
<th>Non-Recurring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Operating</td>
<td>In-space Transport</td>
</tr>
<tr>
<td>Space Segment ($M)</td>
<td>5.00</td>
<td>0.0</td>
</tr>
<tr>
<td>Ground ($M)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Ground receiver refurbishment cost: $100K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) Ground receiver system labor: 5x$150K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c) Ground operation labor: 3x$200K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals ($M)</td>
<td>$1.45</td>
<td>$0.0</td>
</tr>
</tbody>
</table>

Table 1 Estimated Cost of a 5 GW SPS.
Presuming that a launch industry exists on the Moon, the business of this industry may include initial launching of the railway cargo carts into space, and other missions. It is assumed that the price for one launch is $56.5M, based on the cost of the Falcon 9 [28]. It is noteworthy that transporting materials from the Lunar surface into orbit takes less than five percent of the energy needed to do so from Earth [18]. Once the train is launched in to space, the SPS can feed the electric thrusters on the cargo transporters. Another option is to have a ground antenna system transmit energy to the cargo rail train to fuel its electric thrusters instead of having the rail train launch from a rocket.

Roughly 300kW of power is assumed to be needed to run a single manufacturing facility, based on data presented by [29]. Selected data from [29] is shown in Table 2. It is assumed that the mining and processing operations require the same amount of electrical power for operations. Thus a total of about 1 MW of electrical power required by these three industries. Roughly 40KW of usable energy is required to support a moon base [30]. Another 40KW is needed for a next generation rover that could be used for lunar exploration [31]. The transportation industry (including launch, cargo shipments in the Earth-Moon system and space tourism) also needs some amount of electrical power. No number at this time can be reliably estimated for the power requirement of the transportation industry.

<table>
<thead>
<tr>
<th>Process Name</th>
<th>Power Required kW</th>
<th>Process Rate ( \text{cm}^3/\text{s} )</th>
<th>Electricity Required J/cm(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection Molding</td>
<td>35.76</td>
<td>1.40E+01</td>
<td>3.09E+03</td>
</tr>
<tr>
<td>Machining</td>
<td>75.16</td>
<td>4.01E-01</td>
<td>1.87E+05</td>
</tr>
<tr>
<td>Finish Machining</td>
<td>9.59</td>
<td>2.05E-03</td>
<td>4.68E+06</td>
</tr>
<tr>
<td>CVD</td>
<td>15.00</td>
<td>3.24E-03</td>
<td>4.63E+06</td>
</tr>
<tr>
<td>Sputtering</td>
<td>6.75</td>
<td>1.05E-05</td>
<td>6.45E+08</td>
</tr>
<tr>
<td>Grinding</td>
<td>7.50</td>
<td>2.85E-02</td>
<td>3.08E+05</td>
</tr>
<tr>
<td>Waterjet</td>
<td>16.00</td>
<td>1.04E-02</td>
<td>1.58E+06</td>
</tr>
<tr>
<td>Wire EDM</td>
<td>6.60</td>
<td>2.71E-03</td>
<td>2.44E+06</td>
</tr>
<tr>
<td>Drill EDM</td>
<td>2.63</td>
<td>1.70E-07</td>
<td>1.54E+10</td>
</tr>
<tr>
<td>Laser DMD</td>
<td>80.00</td>
<td>1.28E-03</td>
<td>6.24E+07</td>
</tr>
<tr>
<td>Oxidation</td>
<td>21.00</td>
<td>8.18E-07</td>
<td>2.57E+10</td>
</tr>
<tr>
<td>Total</td>
<td>275.99</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

Table 2 Specific electricity requirements for various manufacturing processes as a function of the rate of material processed based on [29].

It is assumed that 3 SPS systems are initially produced, each with a 5MW power capability. Because of so many unknowns it is difficult to determine a price for the electrical power service today. In the terrestrial power market, electrical transactions take place under specific supply contracts between two parties including between the generators and their distributors, marketers, and end-users. It may be that to facilitate up-front investment financing of SSP, a contract market would best ensure adequate capital for the initial operating years. A contract market is based on the trading of futures which are contracts that obligate the seller to provide a commodity or other asset to the buyer at an agreed-upon date [32]. As SSP matures and the number of operators increases, PoolCo arrangements may become attractive to customers to secure long-term contracts to protect them from the risks of major price fluctuations [21]. This will serve as a model for the restructured electric industry that combines the functions of an international organization of standardization and a power exchange [33]. In its least flexible form, a PoolCo also prohibits direct transactions between buyers and sellers (i.e., all producers selling to the pool and all consumers buy from the pool) [33]. Further investigation of power demand from industries, the cost of building an SPS, and the life expectancy of a SPS must be undertaken to develop a more robust economic model.

F. Legality, Risk, and Financing

One challenge for SSP research and development is to demonstrate the ability to deliver an acceptable return on investment (ROI) to funding entities and an acceptable unit cost to the end-user [24]. The vast financial undertaking could benefit from both public and private investment. SSP will benefit from active private interest, both in the power generation enterprise and through commercial exploitation of the technologies created. The ownership and financing of an SSP firm can be a commercial venture. It may operate in partnership with government initially and

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then transition to a commercial wholesale cooperative model. Some have suggested it should be restricted to a role for government [21]. Careful consideration must be given in this effort and the benefits and risks of any potential arrangement must be seriously considered, as the initial precedent may be difficult to disrupt.

Two major subtasks exist for the investment organization. First, it must attract public investment in the infrastructure and engineering of the core systems. Second, it must create vehicles for private investors that encourage risk investment in companies and technologies that may improve efficiency and/or decrease the ongoing cost of SSP. It is generally presumed that if more than 10% of a project requires new and untried technologies and techniques, there will be production problems and delays [34]. Juran [35] has argued that optimizing process results requires “proof of process capability” prior to transfer to operations. Without this the essentials of safety, quality and efficiency are at risk.

The maturation rate and operating costs of these technologies will affect the future economic value of SSP in terms of estimated willingness to pay for a unit of power. The critical importance of power in space activities increases risk aversion in the case of customer acceptance of SSP. Of particular usefulness in introducing SSP to space markets and mitigating risk in the near term would be demonstration of SSP as a “co-fire” power supply (i.e., as a supplement to work in tandem with, rather than fully substitute for, an existing power system on a spacecraft or for lunar industries). Innovation in lighter-weight spacecraft, more capable batteries, and increasingly efficient solar cells and their future operating costs will also affect the SSP value proposition [21].

National and international policy must be considered, as it is in this area that SSP may face its greatest challenges. For SSP to advance beyond the realm of theory, support is required at the international policy level – where issues of cost and benefits, sustainable development, international law, and geopolitical impact must be assessed [24]. SPS by its very nature relies on resources that belong to no specific nation. Just as space is recognized as unclaimed and un-claimable territory, so, too, maybe power from the sun. No single nation or authority can claim it, nor dictate policy on its use [24]. Further considerations include challenges to the security of equipment in space (e.g., from the impacts of meteorites, and international agreements regarding the rights to use and share space).

Woodell [24] suggests integrating technical and scientific expertise into the political arena to facilitate the policy development process. By doing this several benefits are foreseen. These include greater assurance of sound science for the public, improved appreciation of science’s role and contributions for policy makers, and better understanding of the context and impact of their work for the scientist.

G. Social Impact

Since there are many different concepts for SSP, and many complex metrics, it is difficult at this time to provide an accurate general analysis of their social impacts. It should be possible to determine this during the feasibility assessment phase, when specific systems are defined for evaluation. Better technology, such as a robotic production facility for fabricating solar power satellites on the Moon would, in the long term, reduce the labor costs for the production of energy systems. Zidanšek, et al. [18] calculated that 3 jobs were created per 1 MW of space solar power, if the hardware is produced on the Moon and approximately placed in lunar orbit. Also, additional jobs would be created related to the production and launch of the rockets, maintenance and control of the satellites, robotic factories on the Moon, rectenna production and development of other technologies necessary for the operation of orbital power stations. Numerous other jobs could be created within related, derivative and supporting industries. Additional analysis of this is required in future.

V. Conclusion

In conclusion, an economic infrastructure idea has been presented to enable utilization of the Moon and the Earth-Moon system. More analysis needs to be done to attain precise demand levels and dollar amounts. Furthermore, a re-evaluation of the cost of lunar deployment construction of a SPS and their incremental cost needs to be performed. An economic model for supplying a larger customer base (decreasing the cost per kWh) also needs to be investigated. The identification of technologies that will present an early market for power sales that can help fund the larger SPS model must be performed.

To help lower the cost, Lusk-Brooke and Litwin [19] have suggested utilizing an open-source model that may address some of the challenges discussed herein. This is based on the interaction of the organization with its political, economic and social environment. Because of the vast technical, political and social cooperation needed, the SPS organization’s success will depend upon the success of collaboration. It will require technical cooperation and sharing on a global scale never before realized. According to Gerlach [36], the “current growth in the commercial space sector brings new approaches, it creates public and investor excitement, it brings new capital to the table, and it helps to generate credibility for entrepreneurs exploring novel space ventures”.

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Thorough investigations and careful analysis of the implementation of a space economic system, utilizing the Moon and the Earth-Moon system may create a viable solution for the power required to enable the future of humanity. The initial start-ups from mining, processing, manufacturing, cargo railway, exploration, and space solar power need to partner with each other in order to survive in this ecosystem. Many complimentary markets exist from these main markets, and economic activity will gradually increase, lowering the cost of production and sales, thus resulting in growth. Ultimately, humanity will expand towards a more permanent presence in space. There is still much work to be done in terms of figuring out an in-depth economic ecosystem for a project of this magnitude.

References


