Lunar-Based Self-Replicating Solar Factory

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ABSTRACT

Climate change, as currently precipitated by human activity, threatens the Earth's future. The causal activity, burning fossil fuel to generate electricity, remains unthreatened by sources of renewable energy due to renewable energy consistently being significantly more expensive than fossil fuel alternatives. Space solar power (SSP) is a potential solution for a portion of the cost; however, when launch and wireless energy transmission costs are considered, SSP is still more expensive than its fossil fuel counterparts. This proposal asserts that if the solar power satellites were constructed on the lunar surface out of lunar materials, there would be a dramatic enough reduction in cost for SSP to undercut fossil fuels by four orders of magnitude. To generate enough photovoltaic panels to fulfill global energy demand, the factory itself will be a self-replicating system (SRS) able to construct replicas of itself out of the materials of the lunar surface. The SRS would also construct a linear electromagnetic accelerator, or Mass Driver, which would be used to send the SSP components to geostationary Earth orbit, the ideal location for SSP. By constructing all of this with a SRS, only the initial R&D costs would be of any consequence and energy production capacity would grow exponentially at virtually zero cost.

INTRODUCTION

Climate change is potentially the greatest threat Earth, and thus human society, will face for the foreseeable future. Since the dawn of the Industrial Revolution in the 1750, humans have released an ever-increasing amount of greenhouse gases (GHGs) into Earth's atmosphere. Based on the direct findings, deductions, and predictions of the scientific community, the warming of the global climate system due to these emissions is found to be indisputable, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.[1]

By far, the largest share of GHG emissions comes from electricity and heat production, agriculture, forestry, and other land use, industry, and transportation, in decreasing order.[1] In more modern economies, such as the United States, this changes to electricity, transportation, and industry, in decreasing order.[2] With the advent of electric vehicles, an even greater reliance will soon be placed on electricity production. Therefore, it will become increasingly important to generate grid electricity in a responsible, GHG-free method.

The Failures of Earth-Based Photovoltaic

For fundamental reasons, Earth-based solar power will never work on a planetary scale. The simplest and most important reason is reliability, due to most notably weather and nighttime. Because Earth-based solar power peaks during midday, then degrades in the evening, inversely to electricity demand, a "duck curve" is created.[3] When people get home from work at around 5:00 P.M., there is a massive demand spike just as sunlight is fading. What results is a massive power requirement that utility companies cannot accommodate in such a short amount of time. Many utilities then resort to simply running coal and natural gas generators all day (without producing energy, as per legislation when a renewable source is available) and only engaging them during the evening and morning spikes.[4] This pattern is polluting and inefficient and should be minimized if possible.

To use this solar energy, excess energy produced during the day must be stored. This, however, is an extremely complex and costly process, and there is no good solution. Some have proposed using excess energy to pump water back up dams to harvest through hydroelectricity during the evening, or to use the same method compressing air in vast underground chambers. Neither is cost-effective nor efficient.[5]

Thus, the ideal solution would constitute a method of having solar energy that is available 24 h a day and is unaffected by weather.

Space-Based Solar Power

In the past, it has been suggested to use space solar power (SSP) in the form of solar power satellites (SPSs).[6] These are giant assemblies of photovoltaic (PV) panels, (oftentimes) reflectors, and antennae to beam the energy back down to Earth.

Proposals such as this rely on wireless power transmission (WPT), usually in the form of microwaves. The first demonstration of such technology was by Brown in 1964 and again with large quantities of power in 1975.[7] SSP is a sound idea for two reasons: (1) the sun is always shining in space and is not subjected to Earth's seasons or weather, (2) because the sunlight does not have to filter through Earth's atmosphere, it is

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roughly 27% more efficient, which is a margin available to be lost in WPT.[8]

Also integral to the SSP concept are the PV panels on the SPS as well as reflectors used to concentrate sunlight on the PV panels (likely of aluminum composition). Reflectors will reduce launch weight as well as reduce the amount of material consumption and money spent producing PV panels.

John C. Mankins of Artemis Innovation Management Solutions, later cited, has been a notable proponent of SSP and his articles have provided significant inspiration for this component of the proposal. Mankins' design for a SPS is also used later as a basis for further discussion and calculation.

Upon initial glance, SSP seems to be a fitting solution to our energy needs; however, the cost is still unfeasibly high. At current launch prices, it would take tens of trillions of dollars to send enough satellites of meaningful size to account for a significant percentage of worldwide energy needs. Not only is that unfeasible, but also the launch capacity and willingness to undertake such a massive project do not exist.

Self-Replicating Systems

Self-replicating systems (SRSs) have been theorized since the beginning of the space race.[9] In a concept with ties to biomimicry, SRSs are able to (just like any biological organism) replicate themselves out of the materials in their environment, plus a desired output. The unique opportunity presented by not having to send a large factory is that only one small machine, able to self-replicate, can be sent, dramatically reducing launch costs. Although this seed can only produce a fraction of the desired output, the overall output will increase exponentially over time. Fortunately, the Earth's moon is an excellent construction site and materials source as it comprises ideal material for use in mechanical SRSs for three reasons: (1) its direct elemental composition, (2) its relatively uniform composition, and (3) ease of mining its top regolith layer (5–15 m).[10]

The Synthesis

If a lunar-based SRS that can produce SSP components and a mass driver is created, the following benefits would be realized:

- A reduction in up-front costs by several orders of magnitude
- Practically unlimited production potential with capacity increasing exponentially over time
- Practically zero runtime or production cost (as space materials are free and there would be no astronauts on the Moon)
- Dramatically increased adaptability to future challenges or production

In essence, if an SRS that is capable of reproducing itself and producing SPSs on the lunar surface was created, the entire Earth could be powered for contextually minimal cost. Because only a small and (in context) lightweight package will need to be sent and manufactured, the entire system is essentially free, and because all power produced can be sold at a profit, there is very little exposure (in the context of space missions and energy production investments) for practically unlimited upside.

The overall system will function as shown in Figure 1.

1. The SSP components will be manufactured on the Moon by means of an SRS
2. The SSP components will be launched from the lunar surface into geostationary Earth orbit (GEO) by means of an electromagnetic linear accelerator or Mass Driver
3. The SSP components will self-assemble in GEO
4. The SSP will wirelessly transmit the captured energy to stations on the ground
5. (not shown) Rectenna (rectifying antenna) stations near population centers will receive the power and integrate it with local energy grids

REQUIREMENTS OF THE SPS

To fulfill the goal of transmitting meaningful amounts of power to Earth's surface, several requirements must be met in the design and implementation of the SPS. Each individual satellite must (1) be able to automatically fold and unfold for ease of transportation to GEO, (2) be able to intelligently and automatically assemble itself into fully operating status, (3) be able to add additional components and subassemblies (while in GEO) as they arrive from the Moon, (4) contain a proportion of reflectors to PV panels that results in the most efficient gathering of energy, (5) contain the most efficient PV arrays possible (when efficiency of production is taken into account), (6) be able to articulate its transmission array to aim at a different point on Earth's surface quickly, (7) be capable of receiving stationkeeping refueling missions from the Moon, (8) capable of performing self-repairs, (9) be constructed of intelligent and independent modular components (microsats) that can communicate with one other, and (10) be able to operate independent of human control or operation >99% of the time.

Wireless Long-Range Energy Transmission

To transfer all of the power generated to the Earth's electrical grids, there needs to be an efficient method of energy transfer between GEO and various points on the ground. It must be (1) efficient, (2) impervious to weather, (3) capable of being produced on the Moon, and (4) adaptable to different locations on the Earth's surface. As a basis for further

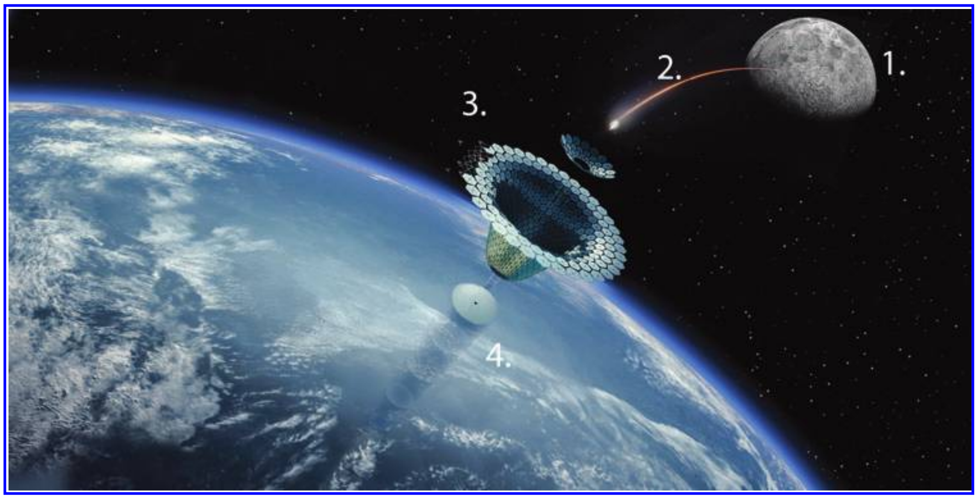

Fig. 1. Overview of Operation. The SSP components will be manufactured on the Moon by means of a SRS, then launched from the lunar surface into GEO by means of an electromagnetic linear accelerator, or Mass Driver. The SSP components will self-assemble in GEO and wirelessly transmit the captured energy to stations on the ground. SSP, space solar power; SRS, self-replication system; GEO, geostationary Earth orbit.

discussion, Mankins' writings (later cited) will be utilized and built upon.

There are currently two major methods proposed for transmitting electricity between GEO and the ground: laser transmission and microwave transmission. For this project, microwave transmission was selected because of its overall high efficiency (peaking at 76%) and it being unaffected by clouds (a characteristic not shared with lasers).[11]

Within microwave energy transmission, there are two distinct components: the transmitting component, known as the WPT Module that converts the electricity on the platform into a coherent RF (microwave) transmission, and the ground-based receiving station that in this case is a rectenna (a rectifying antenna). Other components include high-power and high-efficiency solid-state power amplifiers.

It must be noted that there will be an increase in net energy in the Earth system, as the light intercepted by the SPSs, for the most part, will have not otherwise intercepted Earth's atmosphere. This added energy, however, is not a significant amount, creating a net increase of 0.012%, a worthy increase considering CO_2 emissions would dramatically decrease. To make comparisons with climate studies, this increase in energy due to WPT was evaluated from a solar irradiance perspective and was found to be an increase of 0.04 W/m^2 or an increase of 0.003%. This change is the same in magnitude as the Intergovernmental Panel on Climate Change (IPCC) estimates of changes in natural solar irradiance from 1978 to 2011 and is considered by the IPCC to be of very low impact to climate change.[1]

Overall Design

To easily design a SRS that can build a SPS, the SPS must be made out of a limited number of modular components that can self-assemble in GEO. They should each be as simple as possible, while being adaptable in (1) individual size, (2) number of modules to change system size, and (3) entirely different system formats and designs.

As established, SSP is not a new idea, so it would be imprudent to design an entirely new model for the purposes of this project. It is far more efficient to utilize the best of current scientific methods that utilize a modular approach. To fulfill these purposes, the design pioneered by Artemis Innovation Management Solutions, with John C. Mankins as principal investigator, called SPS-Arbitrarily Large Phased Array (ALPHA) is summarized below:

The basic concept of SPS-ALPHA is to form an exceptionally large space platform from an extremely large number of small, high modular elements, where only a small number of types of modules are used. In the case of SPS-ALPHA, the modular elements (of which there are eight basic types) are combined in various ways to comprise a number of functional assemblies.[12]

Most importantly, for the purposes of the SRS design, Mankins' design consists of eight modular components as follows: (1) Hexbus—basic smallsat structural unit; (2) Interconnect—smallsat to bind structural components; (3) Hexframe—simple deployable beams that provide the base structure for the reflectors and connect the reflector array to the power/transmitter array; (4) Reflectors and Deployment Module; (5) Solar Power Generation Module; (6) WPT Module; (7) Modular Push-Me/Pull-You Robotic Arms—used for self-construction; and (8) Propulsion/Attitude Control Module. It is important to note the number of modular components as these will form the basis for the design of the SRS.

Maintenance and Repair

The more complex task of repair and maintenance, although minimal, must be considered. For this task, it would be impractical to use artificial intelligence. To fulfill this need, a humanoid robot controlled wirelessly from the Earth will be built on the lunar surface and transported to the SPS. Should an error occur that requires human attention, a human can take direct control through virtual reality control, using a goggle and glove system with tactile response similar to the da Vinci surgical system. This reduces risk and cost dramatically, as well as allows the human operator to work on a scale (whether large or small) and precision that is significantly superior to an astronaut. Only a small number of these units would be necessary per SPS, a number that will likely be less than five per satellite.

SELF-REPLICATING SYSTEM

The basic idea of a SRSs is very simple: a machine that can reproduce an exact copy of itself using the materials in its environment. In the context of this project, the machine will not only have to replicate itself but also produce a useful product (SSP and mass driver components). The concept of self-replicating machines or systems is parallel to biomimicry: the ability to replicate oneself out of the materials in one's surrounding is a common ability of every life form. For these reasons, although no SRS has been made to date, a SRS is definitely possible to be produced, although with great mechanical and design complexities. Methods to extract the necessary material out of the lunar regolith have already been designed, although with the possible need of vitamin shipments of some elements from Earth.[9] Nearly all of this mineral extraction technology already exists terrestrially, and this implementation generally modifies terrestrial methods of extracting and refining minerals commercially. The completely designed mineral extraction system will likely resemble that present in the paper Advanced Automation for Space Missions.[9] Small vitamin shipments are of little consequence as the expense to transport these small amounts of materials will be minimal.

Figure 2 illustrates how the SRS (complete with mass driver) might appear from lunar orbit, with the SPS orbiting Earth in the background.

Design Methodology

To design a self-replicating machine, a simple methodology was created. During the final design process, these following steps should be taken: (1) identify all of the output products, (2) break down each product into smaller pieces, until basic parts are apparent, (3) identify all manufacturing machines necessary to manufacture all of the items identified in step 2, (4) repeat steps 1–3 with the components of the machines identified in step 3 until a closed system is outlined, (5) starting with the machines identified in the first pass of step 3, simplify the manufacturing process and required products whenever possible to reduce types of overall parts (including those parts that make up all levels of the manufacturing machine), (6) repeat step 5 with further passes until no more parts can be simplified, (7) abstract the resulting system into machines that can perform broader tasks (such as three-dimensional printers, etc), and (8) repeat step 4–6 with a new manufacturing system until the simplest and most abstract form of the system can be produced.

Throughout the design process, these following four objectives should be kept in mind, listed in order of importance: (1) simplification, (2) efficient materials use (cheap as possible), (3) efficient energy usage, and (4) time usage—quality is more important than quantity only until a certain point to be identified, which can only be found when the rate of failure of entire system is found.

It is acknowledged that there is no prior example of a SRS being constructed, and there has been minimal research performed on complex mechanical SRSs. Therefore, it has not been experimentally proven that it is possible to construct it. Consequently, at this point, only a logical investigation can establish the possibility of a complex SRS. The above recursive logical system demonstrates that there is no inherent logical

Fig. 2. View of SRS on Lunar Surface. This figure depicts what a SRS might look like on the Lunar surface, including the Mass Driver located at the center of the SRS and oriented towards Earth.

flaw in the concept of an SRS, and consequently one is almost certainly possible to be constructed. While it might appear at first glance that new technology needs to be developed to construct such an advanced SRS, because the above logical recursion would only utilize existing technologies, no new technological breakthrough is necessary.

Furthermore, while terrestrial-level manufacturing capabilities would need to exist on the Moon, they would not need to be of aerospace quality. Consumer-level manufacturing specifications are widely employed and adhered to throughout the world, and the engineering understanding of such systems is very complete. Accordingly, it would be reasonable to use consumer-level manufacturing standards for the lunar SRS. This is also reasonable, from a quality standard point of view, because aerospace standards generally arise due to an extremely low margin of error. Often, billions of dollars are resting on every piece of equipment performing perfectly with little available redundancy. In this case, after the first few replications, there would be a very high margin of error. With there being very quickly tens, hundreds, thousands, and eventually millions of units in the ecosystem, many individuals could eventually fail and the ecosystem as a whole would be highly functional. As a consequence, because the units are, in essence, free (after initial R&D and launch costs), these failures would come at no direct capital cost.

Unit Breakdown

While it would appear upon first glance that the most logical way to construct a system such as this would be a large city-scale SRS, upon further investigation, it is not the most efficient way. Designers must take cues from biology (which is really very advanced SRS), where there is not just one mother organism, but many individual organisms that perform specific tasks and work together to create a cohesive environment (for this section, terms from biological classification of organisms will be used). Even in biology, larger organisms are often inhabited and assisted by smaller organisms in symbiotic relationships. Engineers should take the hint from nature and design SRSs as such. When viewed in this context, it would make most logical sense to have a single species for each modular component of the SPS. This is the major reason why having an entirely modular design for the SPS is so vital. Of course, there can be an infinite amount of gradation between one large SRS and an ecosystem of very small organisms, and the most efficient answer lies somewhere in the middle. The key requirement for if a specific function should be abstracted to a species higher up the chain is if this same function is necessary for multiple units. For example, computer components are required for every species for replication and many species for production. If would likewise make sense to abstract the production of the computer components to a species that is solely responsible for this function, saving resource consumption efficiency for all species lower down the production chain. This methodology should be applied to all functions of all species.

There are also two kinds of supply/demand relationships between units. (1) A species could require components from another species solely for the purposes of self-replication. In Figure 3, this is signified with a green arrow and arrows entering/exiting the top/bottom of boxes. This category of relationship is rare. (2) A species could require components from another species both for the purposes of self-replication and component production. This category of relationship is the far majority and, in Figure 3, has been color coded per unit with arrows entering/exiting the sides of boxes.

With all of these variables in design kept in mind, an SRS layout had been designed with a detailed breakdown below. Notes: (1) Two species, harvesters and transport units, are unique cases. In these two cases, the main purpose of the units is to move around quickly and thus it would be inefficient for these fast moving units to self-replicate. These units have harvester production units and transport production units, respectively, which are solely responsible for the manufacturing of their respective child species. (2) Species that are responsible for manufacturing intermediary components are called fabrication units, and species that are responsible for manufacturing end components are called production units. (4) A common grouping of units is known as the computer component production unit block. It includes a microcomputer, Radio-Frequency Identification tags, small batteries, command and data-handling wires, small solar array, power management and distribution, including power wire, switches, and control chips, and telecommunications (including wireless router).

Each arrow in these flowcharts represents a mathematical relationship of supply and demand, and most relationships depend on their child and parent relationships. Each one has been mathematically modeled in detail.

Positioning System

For all lunar operations to be conducted, each unit on the surface will have to know its own position relative to the terrain around it and other units, and it must not require two-way transmission to base, similar to GPS systems. To fulfill this purpose, a system was devised that when fully deployed, will consist of two parts: a ground-based transponder system in addition to a satellite system consisting of satellites at the Lagrange points in the Earth–Moon system. These satellites will be deployed once the SRS is up and running and cash flow

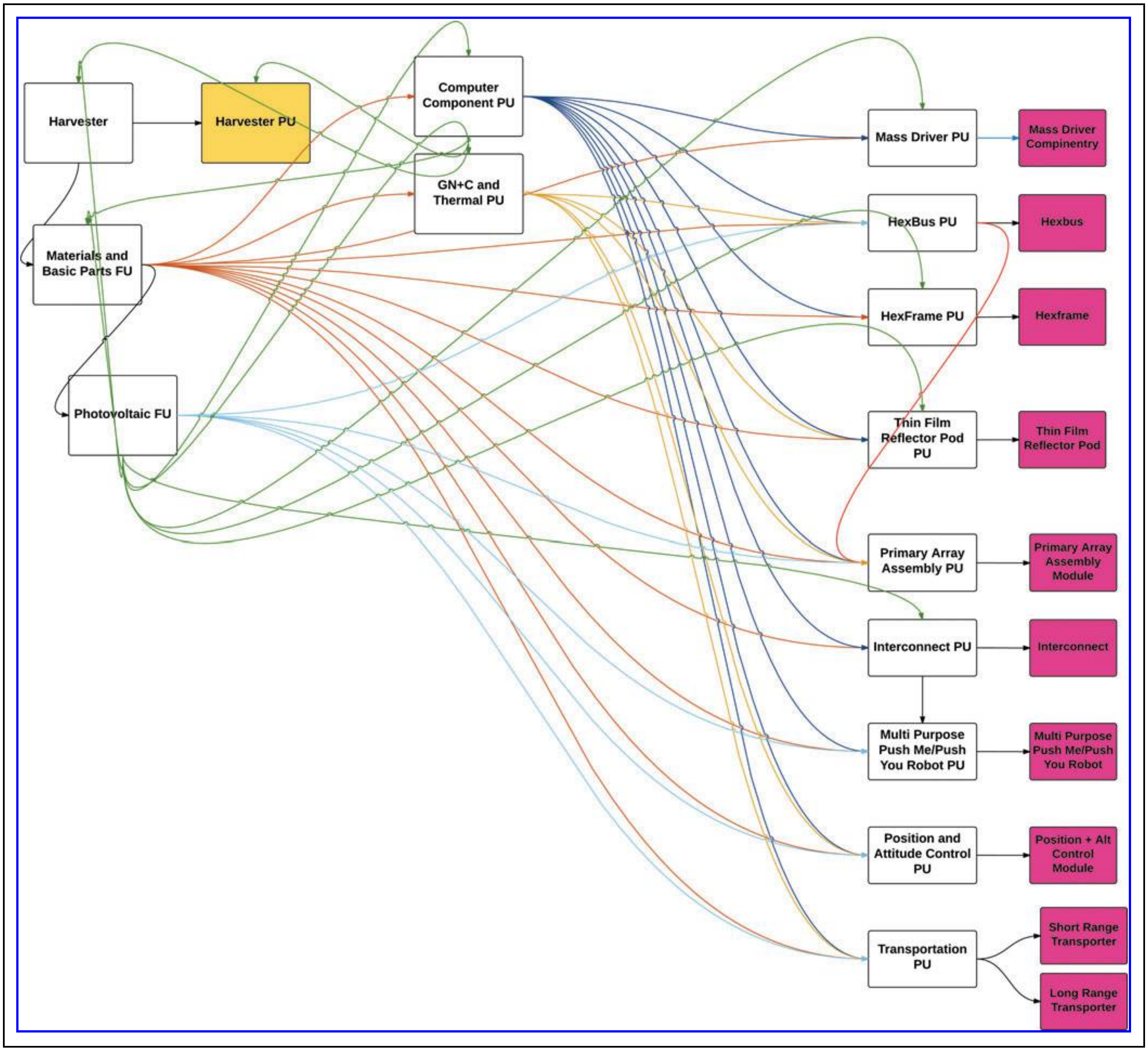

Fig. 3. Flowchart Depiction of SRS Species. This figure systematically depicts the relationships of supply and demand of the species in the SRS. Lines and arrows are color coded per respective species, the pink boxes represent output products (SPS components), and the yellow square denotes a unique relationship configuration. FU, fabrication unit; PU, production unit.

is established; the transponder system will be functioning and expanding with the SRS from initial landing onward.

MASS DRIVER

For the goals of this project to be achieved, it is imperative that completed SPS components be safely, efficiently, and rapidly transported to GEO. Its requirements are to have a completely modular design, be able to vary its launch angles, and have its bucket launching vehicle be reusable.

Design

Electromagnetic linear accelerators have been developed and built countless times in the past. The instance proposed here will be the largest to date, but the mechanical design of such a mass driver is quite simple, consisting of large number of stator coils, among other components. The properties of such a mass driver makes this attractive as a space launch facility.[13] There are a multitude of variables that will affect the overall size (length, most importantly) of the system; however, it will be about 2 km long.

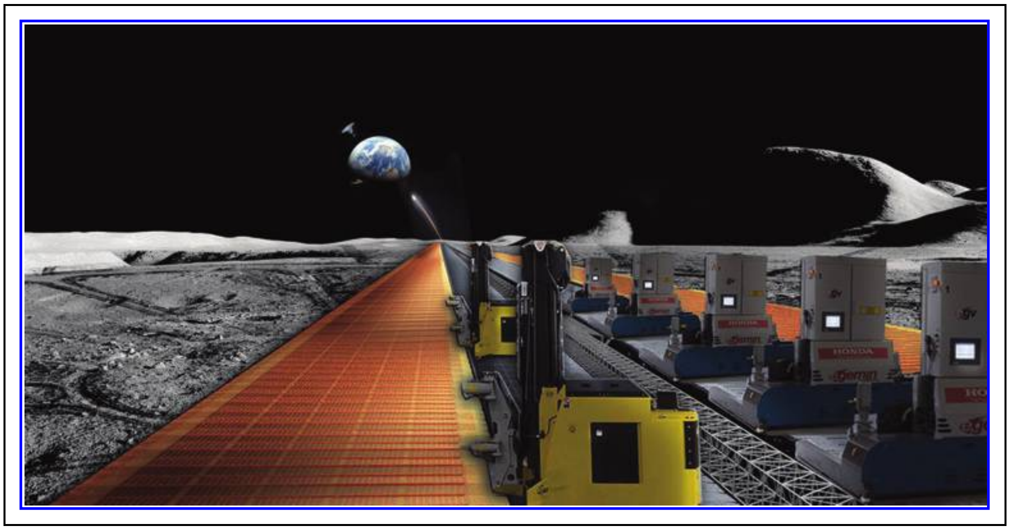

Fig. 4. Mass Driver on Lunar Surface. Depicted in this picture are the Mass Driver, a package in transit, and a SPS orbiting the Earth in the background.

Figure 4 illustrates how such a mass driver might appear on the lunar surface, including how solar panels will lay on either side of the driver for its entire length.

Due to the relatively simple mechanical design, research suggests that the basic design of a small-scale Mass Driver can be simply scaled up with moderate modification. The hurdles for a terrestrial mass driver are the cost of the track and the cost of the energy storage device. With a lunar-based SRS where there is no cost of materials or production of said energy storage device (or track), this previously insurmountable challenge is irrelevant. A variety of past research discussing in detail the construction and design of a mass driver-purposed linear electromagnetic accelerator already exists; therefore, no new novel design is necessary.[14]

Catchment System

Due to the simple laws of orbital mechanics, objects cannot simply be launched into GEO, rather they require two distinct velocity changes (or one long one—which is not applicable in this case due to the limited distance mass drivers apply force). Therefore, while the mass driver can launch the object resulting in the correct periapsis, there must be a catching system that can decelerate the objects and lower the apoapsis to GEO. The idea of each object launched being able to independently decelerate was immediately discarded due to the inherent mechanical complexity associated with such a system. Furthermore, it is grossly inefficient in terms of mass launched as a considerable amount of the mass launched would be wasted in deceleration (not just in terms of propellant mass offset but also in duplicated tank, engine, etc.). Instead, a new idea was proposed, with inspiration from technical articles derived from the 1976 Summer Study at NASA Ames.[15] It will be a terrestrially launched system that forms the small initial structure of the SPSs and allows all further materials to be decelerated from their journey.

Specifications:

(1) Cone-shaped catch with internal structures designed to decelerate objects without damage. (2) Articulable mount to begin construction of satellite, thereby allowing the catcher to face incoming packages and satellite be constructed at the

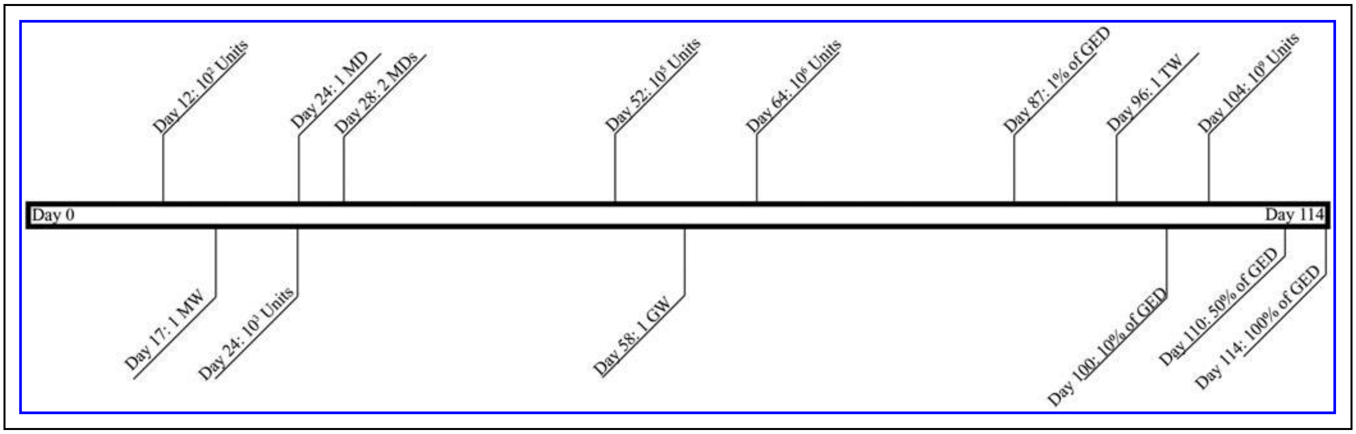

Fig. 5. Project Timeline After Initial Deployment. Note that the unit is "working" time (when the Sun is visible from the SRS location). The proportion of working time to downtime will depend on the location of the SRS.

optimum orientation. (3) Cold gas rocket system to provide deceleration to GEO: incremental pushback to offset momentum of incoming packages; remain on satellite for its lifetime, with the ability of the cold gas rocket system to be resupplied from lunar shipments of highly compressed oxygen.

It must be noted that having a continually firing cold gas rocket system to maintain a stable position will release a cloud of gaseous oxygen at GEO. Therefore, once enough of the satellite is constructed (allowing energy to be produced) and there are sufficient funds, an electrically powered ion thruster will be terrestrially launched and will be the primary method of pushback thereafter.

ENGINEERING TIMELINE

Due to the fundamental concept of an ecosystem model SRS, there are dozens of mathematical relationships between each species type. In most cases, each relationship in some way affects multiple other relationships. The delicate balance of supply versus demand harmony must be achieved for the SRS to perform at its maximum potential. Should the SRS not perform in harmony, wasted potential will grow exponentially.

Table 1. Coefficients Used for SRS Timeline Calculations

	Starting Number	Replication Coefficient per Hour	Production Coefficient per Hour
Harvester PU	1	1/96	2
Materials and basic parts FU	6	1/96	28
Photovoltaic FU	2	1/96	4
CCPU	4	1/96	9
GN&C PU	2	1/96	9
Hexbus PU	1	1/96	5
Hexframe PU	1	1/96	2
TFRP PU	1	1/120	1/2
Mass driver PU	1	1/96	1/3
PAA PU	1	1/96	4
PAC PU	1	1/144	1/4
Trans PU	1	1/96	1/2
MPMPU PU	1	1/96	1/4
IC PU	1	1/96	26

CCPU, computer component production unit; FU, fabrication unit; PU, production unit.

The groundwork for these calculations remains a constant mathematical certainty, but because the SRS in question has not been designed yet, the author must make an educated assumption of production rates, replication rates, demand rates, and number of starting units. The author has outlined, formulated, and performed these calculations to the time of world energy demand fulfillment. The results, of course, are not perfect; however, these coefficients were chosen by the author based on reasonable mechanical assumptions. The formulas behind these results are adaptable, and as components of the SRS are designed, engineering constraints can be calculated to guide the engineering process. It is also important to note that production and starting unit values, although assumed, are not wholly important to the process. These coefficients mostly affect the results within an order of magnitude; the replication rate affects the order of magnitude. For the purposes of these calculations, an order of magnitude is as close as can be calculated with any reasonable certainty.

Table 1 contains the coefficients the author has chosen, with time in hours. Note that most replication rates are one replication per 96 h. As these species are farther up the supply chain, it becomes imperative that they all replicate at a slower or same rate than those above them.

TIMELINE AND RESULTS SUMMARY

Figure 5 is a visual representation of the calculated timeline for the progression of the project. Significant milestones were chosen to demarcate overall progress. Please note that MD refers to the number of mass drivers produced, units refers to the total number of units in the ecosystem, GED refers to global energy demand (21 TW), and _W refers to the watts produced and delivered to Earth.

All of these times specified are in operational days. For example, if the chosen site is near the equator, all time numbers should be doubled for an approximation in time. If the site chosen is at one of the lunar poles (where there is no interruption in sunlight), these raw numbers can be used.

It must be noted, however, that while these results will change as the chosen coefficients are changed, the results will not be meaningful and different in the context of the larger project. The current coefficients project that Earth's global energy demand will be fulfilled in 114 Earth days. Even if worse coefficients are chosen, due to the nature of exponential growth, the time will not change in a meaningful way, likely remaining less than 5 Earth years.

There are two further events that need to take place during this time, although at exactly which time will depend on the final design of the SRS. (1) The Lunar Positioning System Satellite Constellation will need to be deployed. (2) The Earth-based rectenna stations will need to be built, although they can be built at any time due to capital convenience. This time frame ranges from when the SRS is being developed until there are SPSs in orbit (and thus the power transmitted from them is guaranteed).

There are three other important calculated outcomes of this proposal:

- R&D costs are estimated to be between \$5 and \$10B, on par with a project such as the Nimitz Class Aircraft Carrier where there are great mechanical complexities to be solved, but no novel technology needs to be developed. For comparison, a single Nuclear power plant costs between approximately \$9 billion to \$17 billion, and a single coal power plant costs approximately between \$2 billion and \$3 billion.[17,18]
- Assuming 184,634 TWh/year of energy demand in 2020, 150 W/m^2 PV, \$1.75/W installed, and a 1.75 cost multiplier for extra PV and energy storage to compensate for night and weather, this plan would convert the entire world to renewable energy for 0.015% the cost of Earth-based PV, a four order of magnitude cost reduction.
- Assuming 184,634 TWh/year of energy demand, the levelized cost of coal over 25 years at \$.0951/kWh, with natural gas and Earth-based PV at \$.0752/kWh and \$.1252/kWh, respectively (all projected for 2020), the levelized cost of this proposal over the same period (assuming operation and maintenance costs at a much higher than expected average of \$100 billion/year) is \$.00040/kWh, a reduction of two orders of magnitude.[16] Even if the current estimations of R&D costs are underestimated by an entire order of magnitude (now assuming a now \$100 billion R&D cost), the levelized cost would increase to only \$0.00042/kWh.

CONCLUSION

It has been shown that a lunar-based self-replicating solar factory, as a means of producing SPSs, is a potential solution to the worldwide renewable energy crisis. This proposal represents a combination of existing ideas in the SPS and SRS fields that when synthesized in this manner demonstrate a feasible plan for removing Earth from fossil fuel energy sources by exploiting simple laws of economics. By choosing a construction material that is of no cost except transportation, the manufacturing cost of the PV panels is eliminated. To reduce transportation cost, one small and lightweight seed factory will be sent. By the laws of exponential population growth, global energy demand will likely be fulfilled in less than 1 year and almost certainly less than 5 years. There are, of course, significant engineering hurdles to be overcome in the design process of the SPS, SRS, and ancillary components of this proposal. Yet, not a single component has been found to be unfeasible, and many components have already been repeatedly demonstrated in both the laboratory and real-world testing. Research and development costs are then likely to be in the single digit billions of dollars, meaning that total project cost will be approximately the same. This proposal, therefore, is a potential way to reduce the cost of solar panels by four orders of magnitude.

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AUTHOR DISCLOSURE STATEMENT

No competing financial interests exist.

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