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Space Based Solar Power

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ABSTRACT

Space-based solar power (SBSP) is the concept of collecting solar power in space for use on Earth. It has been in research since the early 1970s.This paper projects how SBSP would differ from current solar collection methods in that the means used to collect energy would reside on an orbiting satellite instead of on Earth's surface. Besides the cost of implementing such a system, SBSP also introduces several new hurdles, primarily the problem of transmitting energy from orbit to Earth's surface for use. Since wires extending from Earth's surface to an orbiting satellite are neither practical nor feasible with current technology, SBSP designs generally include the use of some manner of wireless power transmission. The collecting satellite would convert solar energy into electrical energy on-board, powering a microwave transmitter or laser emitter, and focus its beam toward a collector (rectenna) on the Earth's surface. Radiation and micrometeoroid damage could also become concerns for SBSP

Introduction

The solar energy available in space is literally billions of times greater than we use today. The lifetime of the sun is an estimated 4-5 billion years, making space solar power a truly long-term energy solution. As Earth receives only one part in 2.3 billion of the Sun's output, space solar power is by far the largest potential energy source available, dwarfing all others combined. Solar energy is routinely used on nearly all spacecraft today. This technology on a larger scale, combined with already demonstrated wireless power transmission can supply nearly all the electrical needs of our planet. Another need is to move away from fossil fuels for our transportation system. While electricity powers few vehicles today, hybrids will soon evolve into plug-in hybrids which can use electric energy from the grid. As batteries, super-capacitors, and fuel cells improve, the gasoline engine will gradually play a smaller and smaller role in transportation — but only if we can generate the enormous quantities of electrical energy we need. It doesn't help to remove fossil fuels from vehicles if you just turn around and use fossil fuels again to generate the electricity to power those vehicles. Space solar power can provide the needed clean power for any future electric transportation system. While all viable energy options should be pursued with vigor, space solar power has a number of substantial advantages over other energy sources.

Technological background:

Space solar power is thought to have several advantages over other forms of alternative energy, particularly over terrestrial implementation of solar power. The chief general advantage is that the SBSP satellite is that it is relatively isolated, neither taking up space on Earth nor being vulnerable to degradation from nature. As will be addressed in following sections, deploying SBSP satellites do release small amounts of pollution, and the effect of beaming large amounts of energy through the ionosphere is not yet adequately documented. However, these effects are generally agreed to be overshadowed by the potential benefits, including the risk of hydroelectric damming, petroleum storage, coal mining, and nuclear waste. SBSP is thought to be especially attractive against terrestrial solar power for the reason of persistence. Land based solar panels are illuminated for only the daytime, subject to seasonal variation in daylight, as well as the filtering of a large amount of solar energy through the atmosphere by the time it reaches the land based panel no matter its efficiency. By contrast, an SBSP satellite is illuminated for 99% of the day on most days, and 95% of the day even on seasonal equinoxes. Furthermore, SBSP satellites receive 450% additional solar energy than terrestrial solar panels, which couples particularly well with recent advances in metamorphic solar cells that exceed the theoretical limit of conversion efficiency from solar power. Space based solar power is comprised of two major technologies which have been experimentally demonstrable in some form since the 1980s. These are architecture of the satellite and receiver module, and the means to beam energy back to Earth. Both architecture and transmission technology have one main challenge each. For architecture, a major challenge is the cost of infrastructure, both of launch costs associated with deploying the massive SPSB satellite and of building a land receiver rectenna that may be on the order of kilometers. For transmission technology, the challenges are more dire. Three current paradigms are radio frequency, laser, and microwave beaming techniques, but all three suffer loss through Earth’s atmosphere, and may indeed harm either the atmosphere or signals from other satellites. Moreover, the transmission technologies of all three techniques are fairly nascent, and there are some difficulties in packaging power on the order of MW or GW into a coherent beam. Currently, startup ventures in SBSP are either in the process of developing solutions, or have already patented innovative technologies that address the many issues of SBSP. As such, the burgeoning SBSP startup sector is currently dominated by whichever corporations have viable plans to address the technical hurdles.

Benefits of SBSP:

- Higher collection rate: In space, transmission of solar energy is unaffected by the filtering effects of atmospheric

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gasses. Consequently, collection in orbit is approximately 144% of the maximum attainable on Earth's surface.

- Longer collection period: Orbiting satellites can be exposed to a consistently high degree of solar radiation, generally for 24 hours per day, whereas surface panels can collect for 12 hours per day at most.
- Elimination of weather concerns, since the collecting satellite would reside well outside of any atmospheric gasses, cloud cover, wind, and other weather events.
- Elimination of plant and wildlife interference.
- Redirectable power transmission: A collecting satellite could possibly direct power on demand to different surface locations based on geographical baseload or peak load power needs.

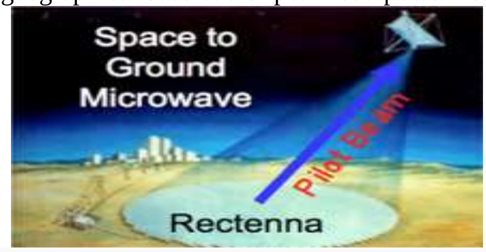


Fig shows A laser pilot beam guide the microwave power transmission to a rectenna.

Disadvantages of Space Solar Power

High development cost. Yes, space solar power development costs will be very large, although much smaller than American military presence in the Persian Gulf or the costs of global warming, climate change, or carbon sequestration. The cost of space solar power development always needs to be compared to the cost of not developing space solar power.

Requirements for Space Solar Power

The technologies and infrastructure required to make space solar power feasible include:

- Low-cost, environmentally-friendly launch vehicles. Current launch vehicles are too expensive, and at high launch rates may pose atmospheric pollution problems of their own. Cheaper, cleaner launch vehicles are needed.
- Large scale in-orbit construction and operations. To gather massive quantities of energy, solar power satellites must be large, far larger than the International Space Station (ISS), the largest spacecraft built to date. Fortunately, solar power satellites will be simpler than the ISS as they will consist of many identical parts.
- Power transmission. A relatively small effort is also necessary to assess how to best transmit power from satellites to the Earth’s surface with minimal environmental impact.

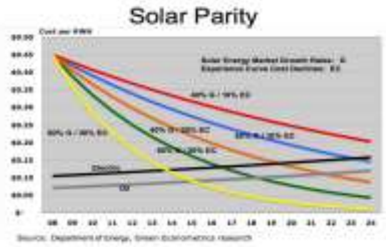
All of these technologies are reasonably near-term and have multiple attractive approaches. However, a great deal of work is needed to bring them to practical fruition.

In the longer term, with sufficient investments in space infrastructure, space solar power can be built from materials from space. The full environmental benefits of space solar power derive from doing most of the work outside of Earth's biosphere. With materials extraction from the Moon or near-Earth asteroids, and space-based manufacture of components, space solar power would have essentially zero terrestrial environmental impact. Only the energy receivers need be built on Earth.

Economic analysis:

Using accumulated data sources from the internet, over a wide range of online web sites and discussion forums, we obtained general estimates of output per surface area of solar panels, the mass per area, and the mass of a laser or microwave transmission setup. The launch costs are derived from data on SpaceX’s new launch system, as well as assuming a 0.8 reduction in launch costs per year.

We take the chart of solar cell efficiency to obtain a trend for solar panel efficiency over time. Linearizing the trend from the beginning to the end of the chart, we come out with a 6% annual increase in solar efficiency. We then notice that recently, there has been a high trend in efficiency gains, so we assume that a 10% annual increase is obtainable. Furthermore, an actual efficiency change has to be of form where there is a decrease in inefficiency per year. Thus, from our current efficiency rating, we can obtain a 95% annual decrease in inefficiency.

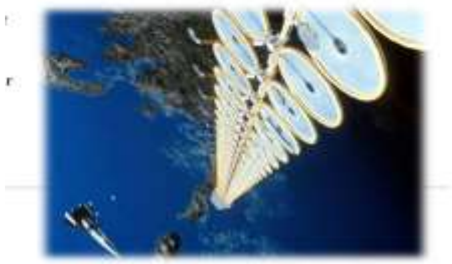


From Green Econometrics, they derived that a median estimate is to have 40% market growth in solar energy, and a 20% experience curve. Utilizing that data, when linearized, we find that there is a 10% per year reduction in cost. Noting similarities among the high tech fields, which during the initial periods are highly correlated between efficiency and reduced costs, this confirms our 10% efficiency annual gains, or in other words, a 95% yearly inefficiency reduction.

Technology analysis:

1.Middle Earth Orbit (MEO) Sun Tower:

It is composed of a 15 km long structure with 340 pairs of solar collectors. Atthe bottom of the structure is a circular 300-m transmitter that would beam power to the Earth. The satellite would be in a circular equatorial orbit. This is the standard option.



GEO Sun Tower:

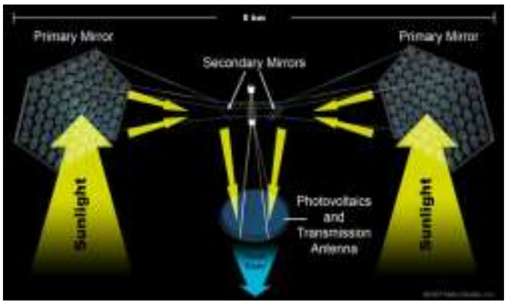
This architecture is similar to that of the MEO Sun Tower. However, it will have a geostationary Earth orbit (GEO) instead. The geostationary orbit allows a single satellite to supply power continuously to a given receiving station on Earth. This makes this architecture more versatile. Also, the total power will be greater due to the reduction in scanning loss. Due to the geostationary orbit, this structure will be deployed at a greater distance from earth, which will reduce encounters with space debris.

Clipper Ship:

This architecture has pointing transmitter array with long mast-like solar collectors . The “Borealis” orbit that is used is sun-synchronous and elliptical; therefore, the collectors will not have to rotate to track the sun. Although, power cable lengths are much shorter than that used on other designs (15 km long Sun Tower), transporting this structure into space and scanning to beam down power are more difficult.

GEO Heliostat/Concentrator:

This architecture uses a geostationary orbit. This GEO Heliostat consisting of a mirror or system of mirrors that tracks the sun and reflects light onto a power generator/transmitter array. This architecture allows the Heliostat to be smaller and shorter than the Sun Tower architecture. This helps with power management and distribution.



GEO Harris Wheel: This geostationary uses a central photovoltaic power generation/transmission system, and a wheel of co-orbiting mirrors. Each mirror controls its orientation to reflect sunlight onto the central power generation system. The mirrors move in a circle about the generator/transmitter. Like the GEO Heliostat, the GEO Harris Wheel is smaller and shorter than the Sun Tower architecture. This helps with power management and distribution.

Lunar Station:

This architecture consists of arrays of photovoltaic solar collector/microwave transmitter panels on the ends of the Moon. Therefore, one array will always be exposed to sunlight and all arrays have line of sight to the Earth. Power will be available only when the Moon is in direct line with the receiving station

Transmission:

What allows Space Based Solar Power to be viable is increased, rapid advancement in wireless power transmission technology. There are two primary options for transferring power from the spacecraft to a receiver: microwave and laser. One key factor that must be considered to select the optimum technology is conversion efficiency (solar to microwave or laser, and microwave or laser to prime electrical power at the receiver). Another factor is the transmission losses due to attenuation, diffraction, scattering, etc.

Laser based technology is generally considered to be less viable for space based solar power because of the inefficient conversion from DC to laser to DC again. Also the absorption from the atmosphere makes laser based technology a poor choice. The microwave technology consists of three parts: the transmitter, beam control, and receiving rectifying antenna (rectenna). The transmitter takes the DC produced by the solar panels and beams it in the form of microwaves. The beam control accurately points the transmitter towards the receiver and adjusts the beam amplitude/ phase so that the system can transmit energy with high efficiency. Finally, the rectifying antenna receives the microwaves and converts it back to DC. Some draw backs of microwave technology is that the transmitter and receiver are much larger than that of laser based technology. However, microwave based technology can be converted much more efficiently and will experience less loss during transmission. Using some laboratory results, and a mixture of experimental technology and current technology, currently we can hope for 45% transmission efficiency to convert energy from DC to DC when transmitting from space to Earth. It is also suggested that longer wavelength be used to decrease transmission loses. However, this could have undesired interference with existing communication systems.

Conclusion:

From our preliminary analysis and interviews, we discovered that currently SBSP is still in the “early” stages of the S-Curve. The amount of future capital and R&D needed to simply begin the process of SBSP is in the billions, and are all early stage. Most of the technology used in this report is what NASA would term below Stage 6. Much of it is experimental, in laboratory settings only, or has yet to be tested in a space environment. There could be considerable technical roadblocks to ensure all parts work for 30 years in space. As such, there are significant R&D problems that must first be addressed. The cost of space launches are another potential roadblock. If the price per kg does not decrease at a significant rate, large scale, capital intensive projects such as SBSP will most likely not be feasible. However, disruptive technology such as a space elevator can quickly make SBSP a realtiy. A further roadblock will be the potential dual use of any space based platform. A satellite which can beam power at a receiving station can also beam power at any arbitrary location. Large, urban infrastructure is built on an abundance of (relatively) cheap energy. If SBSP is successful, it has the potential to be part of the new frontier of space, which is currently opening up. There is significant and large potential in this market, especially as our analysis shows that current sources of energy are not enough to meet growing demands within the next 30 years.

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