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Implementation of Space based Solar Power

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Abstract

In outer space there is an uninterrupted availability of huge amount of solar energy in the form of light and heat. So the use of satellites primarily aimed at collecting the solar energy and beam it back to the earth is being considered. In geosynchronous orbit, i.e. 36,000 km (22,369 miles), a Solar Power Satellite (SPS) would be able to face the sun over 99% of the time. No need for costly storage devices for when the sun is not in view. Only a few days at spring and fall equinox would the satellite be in shadow. Unused heat is radiated back into the space. Power can be beamed to the location where it is needed, need not have to invest in as large as a grid.

Keywords: *Solar Power, Geosynchronous Orbit, Storage Devices, Energy Consumption.*

Introduction

The human population on Earth has been experiencing an exponential increase in numbers since the industrial revolution. The total population did not reach its first billion till the early 1800s C.E, whilst it only took another 130 years for this value to double (Roser, 2015). Within the next 90 years, the population had increased to over 7 billion and by 2050 it is estimated the population will reach 9.7 billion (DESA, 2015). Additionally, the amount of resources each person has been consuming has been increasing due advances in numerous fields, such as medicine and science. These advances have led to not only higher life expectancies, but also an increase in the consumption of resources per capita across the world due to emerging technologies reducing the labour in the securement of resources. Specifically, there have been many changes in the sources of energy used since the industrial revolution. The diversity in the types of fuels used has increase since the industrial evolution which started the shift from using biofuels such as wood to using more energy dense materials such as coal and oil. With the human population growing at an exponential rate, and energy consumption of fossil fuels almost tripling in the last two centuries, it is clear an alternative source of energy needs to be established as the main source for energy before Earth is stripped of these finite resources. This has led to the development 2 and increasing popularity of renewable sources of energy, such as solar, wind and hydro power in the past few decades. The conventional way to use solar energy is one of to collect the radiation from a solar panel and to convert it into usable form of electricity. Over the last decade the installation of solar power stations in US has been drastically increased to produce 100MW of power to1.6GW of energy. This is not widely popular because it is the less reliable source of energy. Collecting Solar power on the earth's surface depends on various factors like day & night cycle, weather (like clouds opposing the Sun light to reach earth), Earth's atmospheric gases, etc. In order to store this form of energy solar cells (photovoltaic cells) are used and hence naming it Solar photovoltaic power. Most of the Solar Photovoltaic power is installed in Europe because of the geographical conditional and hence contribution for a major 57% in the world's installation.

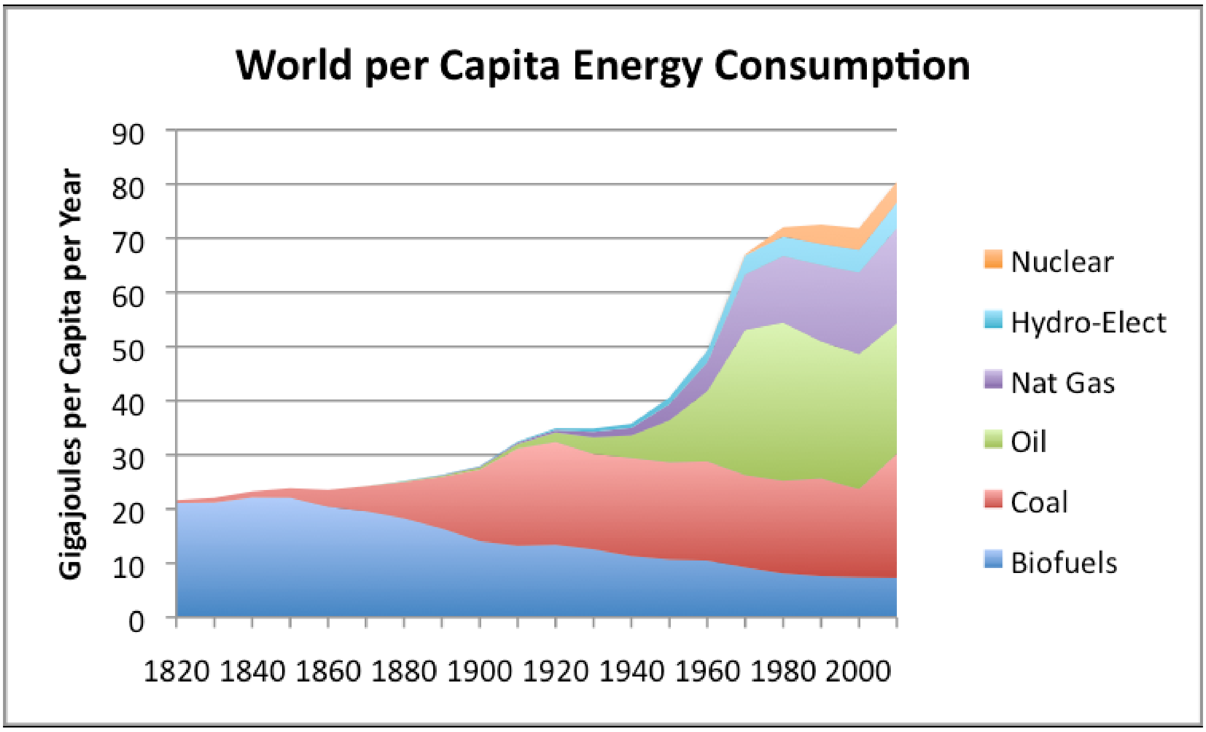

Figure 1: The Increase in Energy Consumption per Capita over Time

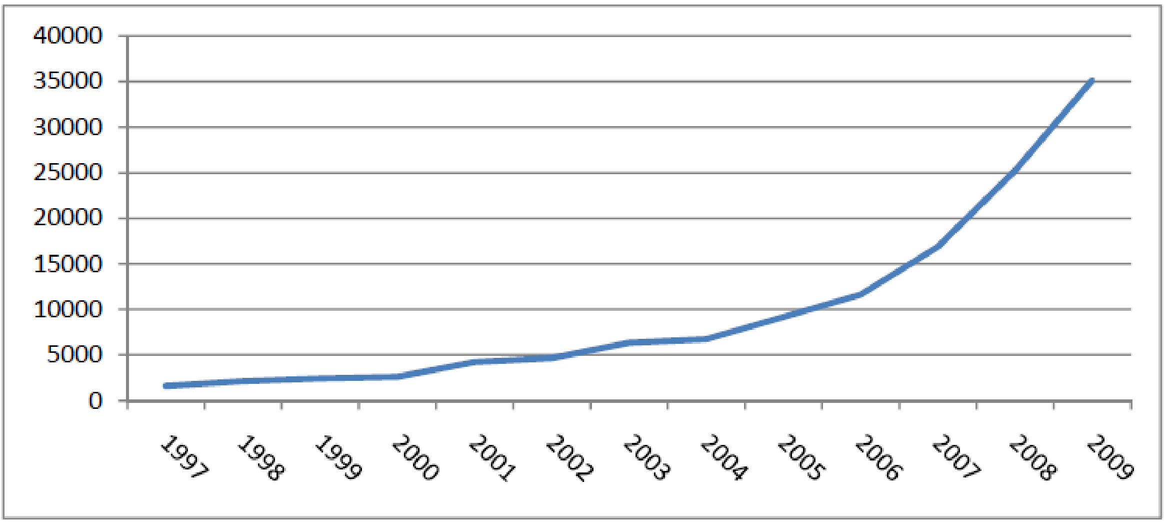

Figure 2: US Installed Wind Turbine Power (in Megawatts)

Wind energy is converted to electricity using wind turbines. As shown in figure 2 over the past decade US increased the installation capacity from 2GW to 40GW. Wind energy in the US is more installed in the mountain region, the world statistics of installed wind turbine power in 2009. Europe and the US contribute for major contribution of Wind power in the World according to the EIA statistics 2009. The major problem with the wind turbines is the maintain cost. Also the geographical location when wind energy is available in abundance.

Benefits of SBSP over Other Fuels

All the above section stated the various energy resources production. This is very important for the current thesis because the need for SBSP (Space Based Solar power) is clearly understood after stating all the above data. At present the power demand by the world is 8000GWe. This number is supposed to be increased in the coming 10 years by twice the amount and by 2050 it almost 4 times the demand as of now. But with the present available resources including all the above stated resources, we could only meet 25% of the needs. This is a serious problem to be considered and the Best way to produce will be a clean, efficient, reliable, abundant power. Which leaves us no option else the sun. As the power produced by sun is stated earlier in chapter 1, we could meet the demand for at least 4 million years from now if we could use the solar power. But the photovoltaic power is not reliable because of weather condition, day& night, etc. Hence the plan for SBSP would long for years and will be a mile stone for mankind leading into a powerful new source of energy.

1.4 The Solution

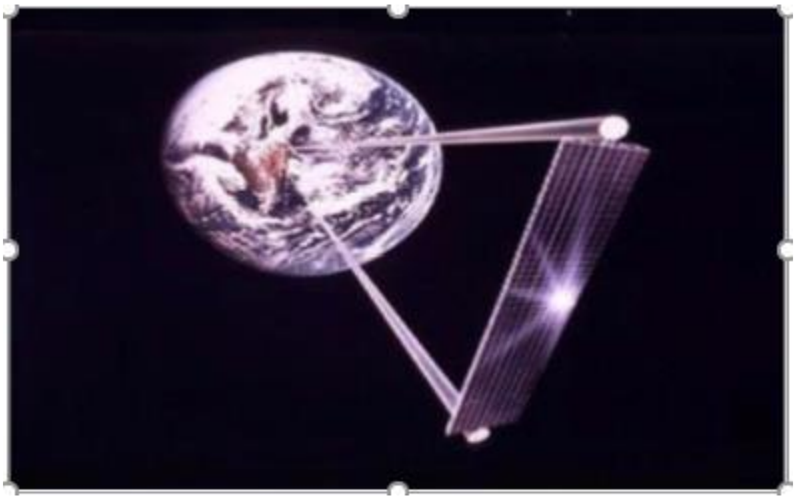

Figure 3: Artist's rendition of the initial space based solar power concept (Space based Solar Power - American Security Project)

1960s and has since appeared in many forms of sci-fi Space based solar power (SBSP) is not a new concept. The term was first coined by Dr Peter Glaser, a Czechoslovakian scientist and aerospace scientist in the late media. However, this concept may one day become a reality as it promises to solve many issues related to renewable source of energy. The concept of space based solar power generation is to send to space a large satellite equipped with a modular array of solar panels that would be able to generate a large amount of power. As satellites have been sent to space numerous times in the past and photovoltaics are a tried and tested technology, the biggest challenge that the proposition faces is a method of transporting the energy generated in space back down to Earth. The proposed method to transmit the power generated is to convert it into a signal be sent down to Earth via wireless transmission where it will be converted back to electricity.

There are two types of transmission technologies that have been considered for implementation: microwave power transmission and laser power transmission. Both technologies have pros and cons which would greatly impact the design of the satellite that the solar panels would be attached to. This piece will mainly focus on the proposed designs that utilise microwave power transmission due to the great deal of interest foreign space agencies have recently shown in that technology.

Solar Energy Conversion

Solar Photons to DC Two basic methods of converting sunlight to electricity have been studied: photovoltaic (PV) conversion, and solar dynamic

(SD) conversion. Most analyses of solar power satellites have focused on photovoltaic conversion (commonly known as "solar cells"). Photovoltaic conversion uses semiconductor cells (e.g., silicon or gallium arsenide) to directly convert photons into electrical power via a quantum mechanical mechanism. it and processing issues during production affect performance; each has been progressively improved for some decades.

Some new, thin-film approaches are less efficient (about 20% vs. 35% for best in class in each case), but are much less expensive and generally lighter. In an SPS implementation, photovoltaic cells will likely be rather different from the glass-pane protected solar cell panels familiar to many from current terrestrial use, since they will be optimized for weight, and will be designed to be tolerant to the space radiation environment (it turns out fortuitously, that thin film silicon solar panels are highly insensitive to ionizing radiation), but will not need to be encapsulated against corrosion by the elements. They do not require the structural support required for terrestrial use, where the considerable gravity and wind loading imposes structural requirements on terrestrial implementations.

Converting DC to Microwave Power

To convert the DC power to microwave for the transmission through antenna towards the earth's receiving antenna, microwave oscillators like Klystrons, Magnetrons can be used. In transmission, an alternating current is created in the elements by applying a voltage at the antenna terminals, causing the elements to radiate an electromagnetic field. The DC power must be converted to microwave power at the transmitting end of the system by using microwave oven magnetron. The heat of microwave oven is the high voltage system. The nucleus of high voltage system is the magnetron tube. The magnetron is diode type electron tube, which uses the interaction of magnetic and electric field in the complex cavity to produce oscillation of very high peak power. It employs radial electric field, axial magnetic field, anode structure and a cylindrical cathode.

Transmitting Antenna

Power transmission via radio waves can be made more directional, allowing longer distance power beaming, with shorter wavelengths of electromagnetic radiation, typically in the microwave range. Power beaming using microwaves has been proposed for the transmission of energy from orbiting solar power satellites to Earth and the beaming of power to spacecraft leaving orbit has been considered. The size of the components may be dictated by the distance from transmitter to receiver, the wavelength and the Rayleigh criterion or diffraction limit, used in standard radio frequency antenna design, which also applies to lasers. In addition to the Rayleigh criterion Air's diffraction limit is also frequently used to determine an approximate spot size at an arbitrary distance from the aperture. The Rayleigh criterion dictates that any radio wave, microwave or laser beam will spread and become weaker and diffuse over distance; the larger the transmitter antenna or laser aperture compared to the wavelength of radiation, the tighter the beam and the less it will spread as a function of distance (and vice versa). Smaller antennae also suffer from excessive losses due to side lobes. However, the concept of laser aperture considerably differs from an antenna. Typically, a laser aperture much larger than the wavelength induces multi-mode radiation and mostly collimators are used before emitted radiation couples into a fibre or into space.

Transmission

As the electro-magnetic induction and electro-magnetic radiation has disadvantages we are going for implementation of electrical conduction and resonant frequency methods. Of this, the resonant induction method is the most implement able due to the reasons given later. In the distant future this method could allow for elimination of many existing high tension power transmission lines and facilitate the inter connection of electric generation plants in a global scale. The microwave source consists of microwave oven magnetron with electronics to control the output power. The output microwave power ranges from 50w to 200w at 2.45GHz. A coaxial cable connects the output of the microwave source to a coax-to-wave adaptor. This adapter is connected to a tuning waveguide ferrite circulator is connected to a tuning waveguide section to match the wave guide impedance to the antenna input impedance. The slotted wave guide antenna consists of 8 waveguide sections with 8 slots on each section. These 64 slots radiate the power uniformly through free space to the rectifying antenna (rectenna). The slotted waveguide antenna is ideal for power transmission because of its high aperture efficiency (>95%) and high power handling capability. Microwaves are situated on the electromagnetic spectrum with frequencies ranging from 0.3 to 300 GHz.

Magnetron is a high powered vacuum tube device that generates microwaves owing to the motion of clouds of electrons in a crossed electric and magnetic fields. Magnetron originally developed in 1916 as an alternative to grid control in vacuum tubes. It was discovered during the DEO/NASA study of SPS that the microwave oven magnetron along with the external passive circuitry can perform as phase locked high gain of 30dB amplifier for direct use in the transmitting section. For ground based transmitter, the microwave oven magnetron can be used directly. However for space use, based on the same principle, special space magnetron is required.

Wet

Wireless Electricity Transmission (WET) technology Wireless power transmission is a process that takes place in any type of system in which electrical current is conveyed from a power source to an electrical load. What makes this process unique is that there is no usage of any type of wiring to connect the system to a source of power. Wireless electricity (Power) transmission basically is the transmission of electricity with the help of microwaves and there is no need to use cables, towers and grid stations there are three methods or approaches which can be developed. These are

- ✓ Short Range (Induction)
- ✓ Medium Range
- ✓ Long Range

Short Range (Induction)

Transfer takes these ranges few cm e.g. transformer in which place due to mutual induction.

Moderate Range

Moderate range (Adaptive Inductive Coupling) Wireless power transfer technology can be used to charge the electronic objects automatically. The ability of our technology to transfer power safely, efficiently, and over distance can improve products. This principle of wireless electricity works on the principle of using coupled resonant objects for the transference of electricity to objects without the use of any wire.

1) Power from mains to antenna, which is made of copper

2) Antenna resonates at a frequency of about 10MHz, producing electromagnetic waves

3) Tails‟ of energy from antenna „tunnel‟ up to 2m (6.5ft)

4) Electricity picked up by laptop's antenna, which must also be resonating at 10MHz. Energy used to recharge device

5) Energy not transferred to laptop re-absorbed by source antenna. People/other objects not affected as not resonating at 10MHz

Long Range

Long range Plans for wireless power involve moving electricity over a span of miles. Long distance wireless power is the technology of sending power to earth. There are many new techniques but we use only two here. 300 kW power to tesla coil resonated at 150 kHz. The RF potential at the top sphere reached 100 MV. Unfortunately he failed due to diffusion in all directions.

Working of Satellites

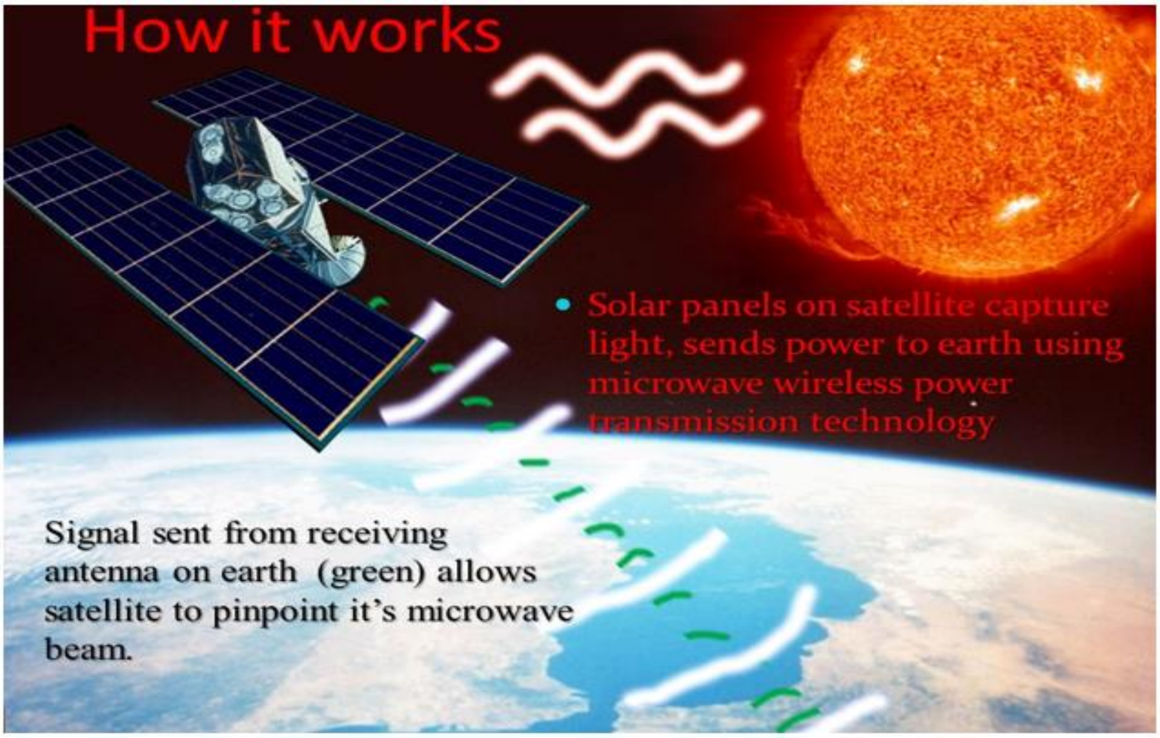

Figure 4: Transmission of Power

Self-assembling satellites are launched into space, along with reflectors and a microwave or laser power transmitter. Reflectors or inflatable mirrors spread over a vast swath of space, directing solar radiation onto solar panels. These panels convert solar power into either a microwave or a laser, and beam uninterrupted power down to Earth. On Earth, power-receiving stations collect the beam and add it to the electric grid. The two most commonly discussed designs for SBSP are a large, deeper space microwave transmitting satellite and a smaller, nearer laser transmitting satellite.

Microwave Transmitting Satellites

Microwave transmitting satellites orbit Earth in geostationary orbit (GEO), about 35,000 km above Earth's surface. Designs for microwave transmitting satellites are massive, with solar reflectors spanning up to 3 km and weighing over 80,000 metric tons. They would be capable of generating multiple gigawatts of power, enough to power a major U.S. city.

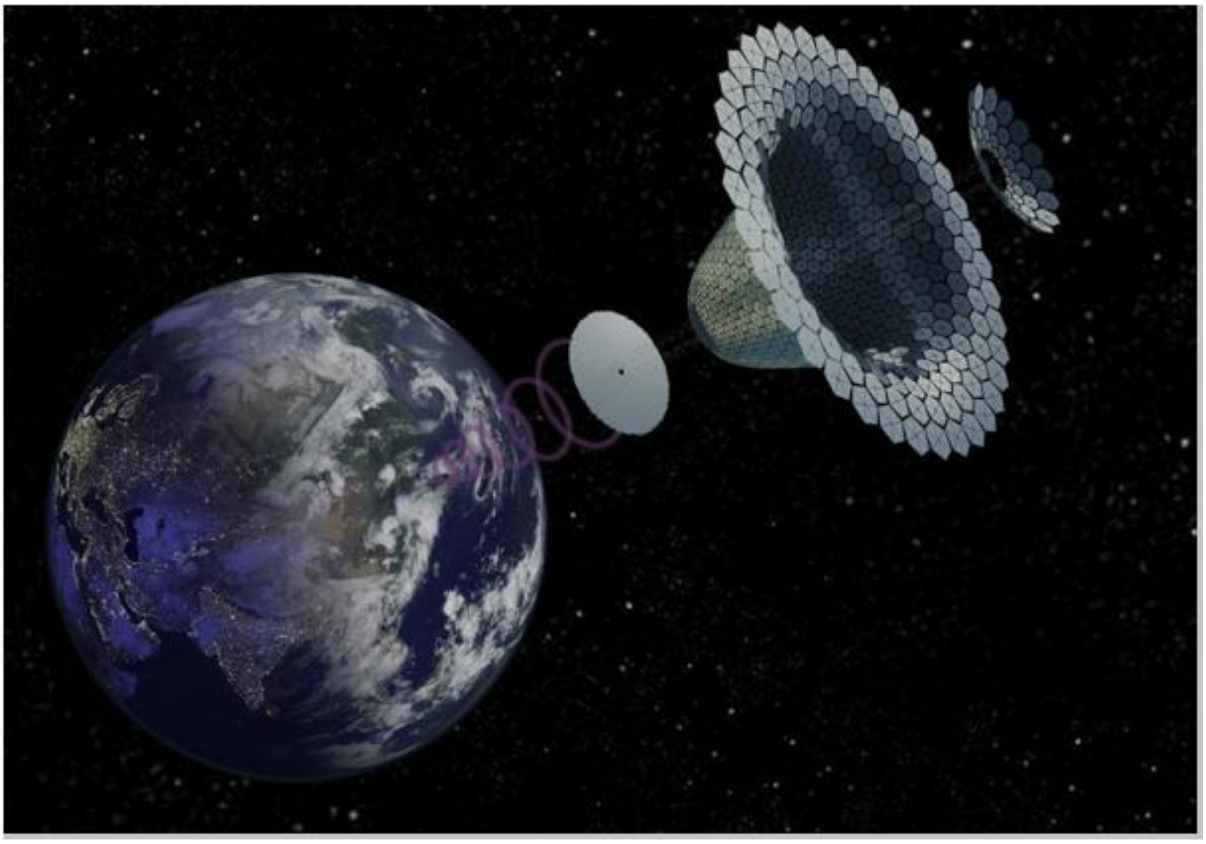

Figure 5: Microwave Transmitting Satellite

The long wavelength of the microwave requires a long antenna, and allows power to be beamed through the Earth's atmosphere, rain or shine, at safe, low intensity levels hardly stronger than the midday sun. Birds and planes wouldn't notice much of anything flying across their paths.

The estimated cost of launching, assembling and operating a microwave-equipped GEO satellite is in the tens of billions of dollars. It would likely require as many as 40 launches for all necessary materials to reach space. On Earth, the rectenna used for collecting the microwave beam would be anywhere between 3 and 10 km in diameter, a huge area of land, and a challenge to purchase and develop.

Laser Transmitting Satellites

Laser transmitting satellites, as described by our friends at LLNL, orbit in low Earth orbit (LEO) at about 400 km above the Earth's surface. Weighing in in at less than 10 metric tons, this satellite is a fraction of the weight of its microwave counterpart. This design is cheaper too; some predict that a laser-equipped SBSP satellite would cost nearly $500 million to launch and operate. It would be possible to launch the entire self-assembling satellite in a single rocket, drastically reducing the cost and time to production. Also, by using a laser transmitter, the beam will only be about 2 meters in diameter, instead of several km, a drastic and important reduction.

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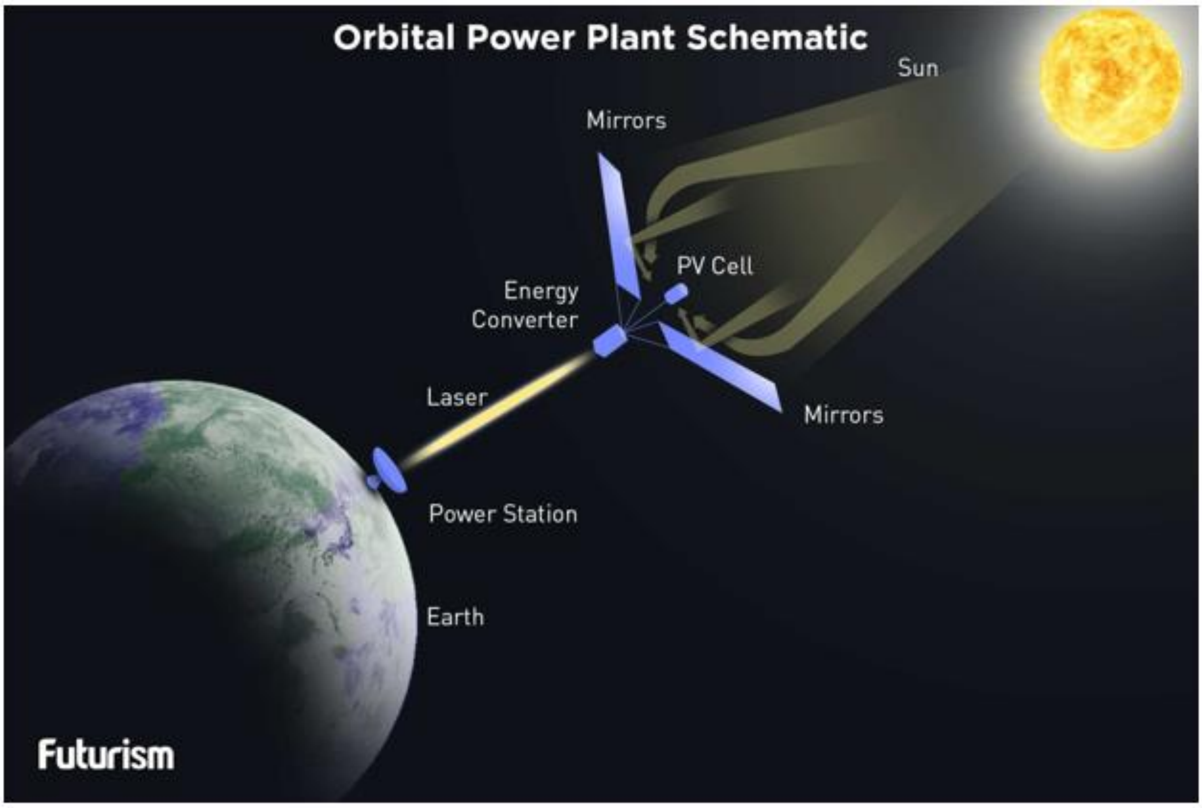

Figure 6: Laser Transmitting Satellite

To make this possible, the satellite's solar power beaming system employs a diode-pumped alkali laser. First demonstrated at LLNL in 2002 -- and currently still under development there -- this laser would be about the size of a kitchen table, and powerful enough to beam power to Earth at an extremely high efficiency, over 50 percent. While this satellite is far lighter, cheaper and easier to deploy than its microwave counterpart, serious challenges remain. The idea of high-powered lasers in space could draw on fears of the militarization of space. This challenge could be remedied by limiting the direction that which the laser system could transmit its power.

At its smaller size, there is a correspondingly lower capacity of about 1 to 10 megawatts per satellite. Therefore, this satellite would be best as part of a fleet of similar satellites, used together. We could say SBSP is a long way off or pie in the sky (puns intended) -- and we'd largely correct. But many technologies already exist to make this feasible, and many aren't far behind. While the Energy Department isn't currently developing any SBSP technologies specifically, many of the remaining technologies needed for SBSP could be developed independently in the years to come. And while we don't know the future of power harvested from space, we are excited to see ideas like this take flight.

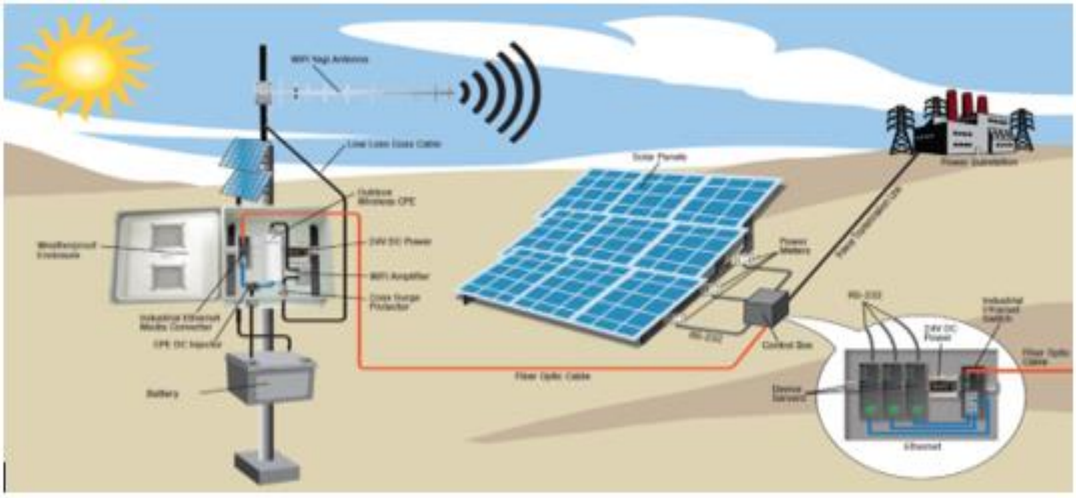

Figure 7: Earth Based Receiver

The Earth-based receiver would likely consist of many short dipole antenna connected via diodes. Microwave broadcasts from the satellite would be received in the dipoles with about 85% efficiency. With a conventional microwave antenna, the reception efficiency is better, but its cost and complexity are also considerably greater. Rectennas would likely be several kilometers across.

Future of SBSP

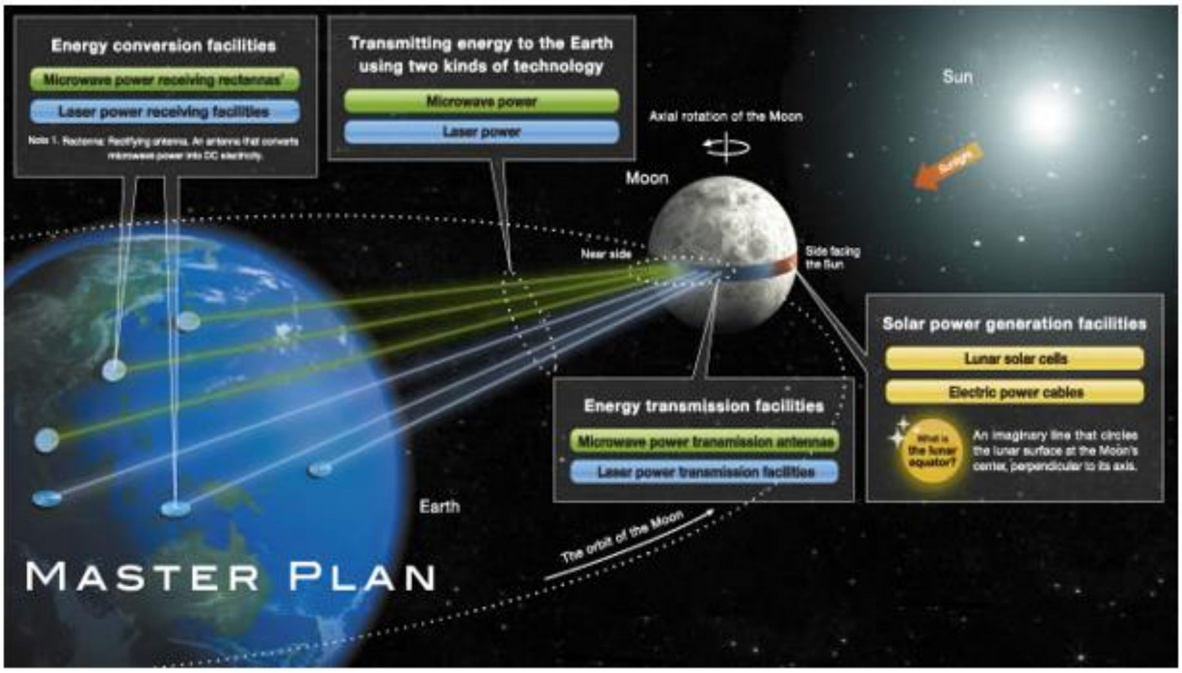

Figure 8: Future Plans of SBSP

SBSP's ability to provide clean, reliable power for the planet 24/7 at a cheaper cost than any other energy source is real. It will take decades of investment, building, testing, and successful implementation before the system can begin to recoup its initial costs.

There are a number of potential applications of these technologies in future human exploration missions, including the moon, Mars and asteroids in the inner solar system. These include: megawatt-class SEPS Lunar cargo 16 space transfer vehicles Lunar orbit W PT for Lunar surface power affordable human Mars mission transportation systems. Of these, the concept of using multi-megawatt-class space solar power systems to achieve very low cost Mars mission concepts appears to have particular leverage. By using systems that are amenable to low-cost, multi-unit, modular manufacturing, even though the overall system masses are not lower, the cost appears to be significantly lower. Example: The "Solar Clipper". An especially intriguing opportunity is that of using affordable megawatt-class space power for interplanetary space missions. It appears to be possible to reduce the cost for Earth surface-to-Mars orbit transportation dramatically through the use of very advanced, large-scale space solar power in a solar electric propulsion system (SEPS) approach.

Potentials

With SBSP, we could solve our energy and greenhouse gas emission problems with little environmental impact. Professor Sergio Pellegrino of Cal Tech recently said an SBSP system would receive eight times more energy than Earth does. With SBSP’s continuous massive energy output capability and the fact that our sun is slated to exist for another 10 billion years, we can safely assume we will not run out of this energy source anytime soon.

The SBSP concept is attractive because space has several major advantages over the Earth's surface for the collection of solar power:

- It is always solar noon in space and full sun.

Collecting surfaces could receive much more intense sunlight, owing to the lack of obstructions such as atmospheric gasses, clouds, dust and other weather events.

- Consequently, the intensity in orbit is approximately 144% of the maximum attainable intensity on Earth's surface.
- A satellite could be illuminated over 99% of the time, and be in Earth's shadow a maximum of only 72 minutes per night at the spring and fall equinoxes at local midnight. Orbiting satellites can be exposed to a consistently high degree of solar radiation, generally for 24 hours per day, whereas earth surface solar panels currently collect power for an average of 29% of the day.
- Power could be relatively quickly redirected directly to areas that need it most. A collecting satellite could possibly direct power on demand to different surface locations based on geographical baseload or peak load power needs.
- Elimination of plant and wildlife interference.
- With very large scale implementations, especially at lower altitudes, it potentially can reduce incoming solar radiation reaching earth's surface. This would be desirable for counteracting the effects of global warming.

Conclusion

The increasing global energy demand is likely to continue for many decades. New power plants of all sizes will be built. However, the environmental impact of those plants and their impact on world energy supplies and geopolitical relationships can be problematic. Renewable energy is a compelling approach - both philosophically and in engineering terms. However, many renewable energy sources are limited in their ability to affordably provide the baseload power required for global industrial development and prosperity, because of inherent land and water requirements. Based on the recently-completed "fresh look" study, space solar power concepts may be ready to re entre the discussion. Certainly, solar power satellites should no longer be envisioned as requiring unimaginably large initial investments in fixed infrastructure before the emplacement of productive power plants can begin. Moreover, space solar power systems appear to possess many significant environ mental advantages when compared to alternative approaches to meeting increasing terrestrial demands for energy - including requiring considerably less land area than terrestrially-based solar power systems. The economic viability of such systems depends, of course, on many factors and the successful development of various new technologies - not least of which is the availability of exceptionally low cost access to space. However, the same can be said of many other advanced power technologies options. Space solar power may well emerge as a serious candidate among the options for meeting the energy demands of the 21st century.

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