# Space based solar power versus ground based solar power 

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#### Abstract

This paper aims to give a comparison between space based solar energy and ground based solar energy ,their efficiencies and the cost of transporting a specially designed solar power plant into space with current technology. Also this paper will suggest a ways to transmit energy received by the solar power plant at space back on earth. It is a scientific approach to determine which method is better in terms of efficiency and the practicalities such as cost and reliability of the method. The efficiencies of technologies used will be of the highest order that humanity has ever created. This study's conclusion indicates that space based solar power has a huge leap when compared to ground based solar power. Further research must be done to elevate this idea.


Keywords: Solar power efficiency, Space versus ground based energy, energy transmission

## I. Introduction

From Stone Age humans are on a quest to find a source of energy that best suits them. Initially it was simple as only fire could solve all the requirements for a human at that time but as the time passed humans started to consume more energy for the leisure and comfort. Also as the time passed population on the earth increased, so did energy requirements. A solution to our question of energy is fossil fuel, but there are problems with it. First is that it is limited and eventually we will run out of it, second is that we are extracting the energy under the earth's crust and putting that energy into our environment which is naturally built to hold the sun energy only. The results are in the form global warming, rising sea levels, scarcity of freshwater, air pollution. Now there are only two options left which are able to fully takeover the energy
demands, first one is nuclear energy and the second one is solar energy .The problem with nuclear energy is that it produces nuclear waste in case of fission and in case of fusion it is very difficult to harness the large amount of energy produced by it with temperatures in the reactors reaching $20000{ }^{\circ} \mathrm{C}$. So ultimately we are left with solar power to think upon. Outer space has uninterrupted continuous availability of light at all the time and we can harness that energy if we can somehow manage to place our solar panels out in geosynchronous orbit, i.e. $36,000 \mathrm{~km}$ ( 22,369 miles) where panels will always get energy from the sun ,unlike the earth where we cannot get that benefit at night. Also if we are placing our panels up in the
geosynchronous orbit we will not require any battery or power storage system as we can directly send it back on the earth with the same device that we use in microwave owen called magnetron. In 1968, Dr. Peter Edward Glaser introduced this concept of a large solar power satellite system of square miles of solar collectors in high geosynchronous orbit (GEO is an orbit $36,000 \mathrm{KM}$ above the equator), for collection and conversion of sun's energy into an electromagnetic microwave beam to transmit usable energy to large receiving antennas (rectennas) on earth for distribution on the electric power grid [5]. But after looking the technology and cost of project American space agency, NASA and American Government spent $\$ 20$ million studying it, only to conclude that it was too complex and expensive. But now times have changed and we have new advancements in technology which can make it possible, cheaper than what was supposed earlier. It is the most clean and direct energy resource with no dangerous implications as in the case of nuclear energy.

| Planet or dwarf planet | distance (AU) |  | Solar radiation (W/m²) |  |
| :--- | :--- | :--- | :--- | :--- |
|  | Perihelion | Aphelion | maximum | minimum |
| Mercury | 0.3075 | 0.4667 | 14,446 | 6,272 |
| Venus | 0.7184 | 0.7282 | 2,647 | 2,576 |
| Earth | 0.9833 | 1.017 | 1,413 | 1,321 |
| Mars | 1.382 | 1.666 | 715 | 492 |
| Jupiter | 4.950 | 5.458 | 55.8 | 45.9 |
| Saturn | 9.048 | 10.12 | 16.7 | 13.4 |
| Uranus | 18.38 | 20.08 | 4.04 | 3.39 |
| Neptune | 29.77 | 30.44 | 1.54 | 1.47 |
| Pluto | 29.66 | 48.87 | 1.55 | 0.57 |

## II. ENERGY ON EARTH AND IN SPACE

There is a huge difference in the amount of energy that hits earth's crust and the amount of energy. Sun light levels at space are 8 times more than earth's surface and it goes without saying that sunlight hits earth with an angle which also affects the way in which solar panels receive photons and hence the power generated by them. The average power flux reaching at the top of earth's atmosphere from sun, considering the fact that earth and sun have differences distances throughout the year is 1362 watts $/ \mathrm{m} 2\{1412$ watts $/ \mathrm{m} 2$ in January to 1321 watts $/ \mathrm{m} 2$ in July\}. Now the average power flux that reaches earth throughout a span of 24 hours considering the effect of angle at which it strikes
earth and that the earth has about half of the time when sunlight is not available(night time) is 340 watts $/ \mathrm{m} 2$.

At most about $75 \%$ of the solar energy actually reaches the earth's surface, as even with a cloudless sky it is partially reflected and absorbed by the atmosphere. Even light cirrus clouds reduce this to $50 \%$, stronger cirrus clouds to $40 \%$. Thus the solar energy arriving at the surface can vary from $550 \mathrm{~W} / \mathrm{m}^{2}$ with cirrus clouds to $1025 \mathrm{~W} / \mathrm{m}^{2}$ with a clear sky at any particular instant.

Right now humanity has developed solar panels with efficiency up to $46 \%$ (established in Europe, after a multijunction solar cell developed through a French-German collaboration achieved 46 per cent efficiency, Multijunction cells were used in concentrator photovoltaic (CPV) systems to produce low-cost electricity in photovoltaic power plants, in regions with a large amount of direct solar radiation) and the trends shows that soon we will reach $50 \%$ efficiency [4]. The weight of these solar panels is yet to be specified by the inventors but the special designs can be made to make these panels usable into space. Some of these designs were shown in the proposals which were given earlier to NASA by different researchers working on this problem including Dr. Peter Edward Glaser [5]. Most of these designs advised the use of concentrator or reflector to properly focus sunlight on the solar panels.

(These are two designs that were proposed by designers for this project)

## III. Transmission

For space based solar power transmission we will require a special equipment to beam out the collected energy in the form of microwaves and a receiving equipment to collect these microwaves. We choose microwaves for the transmission because they can pass through our atmosphere, efficiency of transmission is very high (up to $85 \%$ ) and also microwaves are not harmful humans even after prolonged exposure. Although the use of microwaves to transmit energy from space down to earth is attractive, most part of the microwaves receives significant interference due to atmosphere. Still there are certain frequency windows in which these interactions are minimized. The frequency windows in which there is a minimum of atmospheric signal attenuation are in the range of $2.45-5.8 \mathrm{GHz}$, and also $35-$ 38 GHz ; specifically we might expect losses of $2-6 \%$, and $8-$ $11 \%$ respectively for these two microwave signal ranges. Wireless Power Transmission (using microwaves) is well proven [2]. Experiments in the tens of kilowatts have been performed at Goldstone in California in 1975 and more recently (1997) at Grand Bassin on Reunion Island.

For transmission from space a Magnetron (a high powered vacuum tube that works as self-excited microwave oscillator) will be used [1]. Modern magnetrons are very powerful and can work on a variety of frequencies with efficiencies up to $85 \%$ and these efficiencies are only going to increase as the time passes. Now for receiving the power on earth, large rectennas will be used at receiving station and these also have conversion efficiencies up to $95 \%$ [3].

## IV. Efficiency Calculation

It is very necessary to have an efficiency calculation for both the systems in order to compare them and also to justify the investment and need of shift in the technology. For this we will have to consider different factors which cause losses to both of these systems.
A). Ground based solar power: -

- Maximum solar panel efficiency $=46 \%$
- Power flux that reach earth on a sunny day = 75\%
- Assuming Average factor of 24 hours $=40 \%$
(Average factor can be described as the ratio of the total energy that is received by a unit area on the earth in 24 hours to the energy the same unit area would have received if the sun would shine continuously for 24 hours above that area. This factor depends upon day and night hours on earth at a particular place and the angles at which sunlight strikes on it)

Total efficiency
$=46 / 100 * 75 / 100 * 40 / 100$
$=0.138$ or $13.8 \%$
B). Space based solar power:-

- Maximum solar panel efficiency
$=46 \%$
- Magnetron conversion efficiency
= $75 \%$
- Microwave diffusion in atmosphere is ( $2 \%-6 \%$ )
= 95\%
- Rectenna conversion efficiency
= $90 \%$

> Total efficiency
> $=46 / 100 * 75 / 100 * 95 / 100 * 90 / 100$
> $=0.294975$ or $29.4975 \%$

This is a massive difference between the efficiencies of the both systems. Even after giving ground based solar a leap with a high average factor in comparison to space solar with low magnetron efficiency( in comparison to the maximum efficient magnetrons that humanity has made) ,space based solar system clearly outshines the ground based solar systems with efficiency more than twice that of ground based solar systems.

## V. COST OF TRANSPORTING CARGO IN SPACE

This was one of the major reasons for abandoning of earlier space based solar projects. Some speculations were there that the cost of the project would be trillions of dollars. But recent advancements in space technologies have changed the way in which we send cargo out in space. SpaceX (Space Exploration Technologies, a privately owned space agency) has developed reusable rockets and they are constantly increasing the cargo carrying capacity of their space flights .Falcon heavy is the best rocket with maximum payload capability that is going to be launched in near future. It will cost something around $\$ 90 \mathrm{M}$ to make a falcon heavy which will be able to launch up to 26,700 kilograms of payload into GTO (geostationary orbit). The special part is that this rocket has reuse capability. Predecessor of falcon heavy is falcon 9 , it costs $\$ 60$ million to make a falcon 9 rocket but only $\$ 200,000$ to refuel it. Falcon Heavy's first stage is comprised of three Falcon 9 engine cores, all of which are expected to return and land back on Earth much like Falcon 9's first-stage boosters. So if we suppose that the refueling cost of falcon heavy would be $\$ 600,000$ than we can list some facts.

- Payload capacity of falcon heavy
$=26,700 \mathrm{~kg}$
- Cost of launching after first launch (only refueling)
$=\$ 600,000$
- Cost of launching 1 kg payload into space after first launch
$=600000 / 26700=\$ 22.47 / \mathrm{kg}$
- Weight of solar panels with all fittings per $\mathrm{m}^{2}$ $=10 \mathrm{~kg}$
- Total surface area of a plant with radius of 5 km $3.14 * 5000 * 5000$
$=78500000 \mathrm{~m}^{2}$
- Total weight of the plant 78500000*10 $=785000000 \mathrm{~m}^{2}$

Therefore total cost of transporting this much cargo into space via current technology will be
$=785000000 * 22.47$
$=\$ 17640449440$ or $\$ 17.6404$ billion for one plant
This is significantly lower than previous speculations that were made for the same project and obviously much lower than America's defense budget $\$ 600$ billion. We will have to build several such plants in space, according to our needs here on earth.

## VI. CONCLUSION

This paper showed two methods of harvesting solar energy from the sun and it is clear that in terms of efficiency space based solar energy has a huge leap also space solar technology will not require much maintenance because of no environment in space and will provide continuous power for 24 hours. Ground based solar leads in its cheap installation costs but is often not usable in every part of the world for example Netherlands where it rains 145 days a year. So space based solar leads in reliability. This method has potential to solve all the energy problems here on earth and also cost of transporting payload to space has significantly decreased in last decade and surely we will see deduction of many folds in upcoming years which will make these numbers much more smaller and eventually more attractive to work on this project. Hence major economies should come up together for working on this project. Sooner or later this method will prove to be the single most reliable method for power generation.

## VII. DECLARATION

All author(s) have disclosed no conflicts of interest.

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