National Space Society

Position Paper:

Space Solar Power:
Enabling a Green Future with Economic Growth

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The Importance of Space Solar Power

The United States and the rest of the world face a two-fold energy problem: (1) the need to find clean alternative sources of energy to move away from fossil fuels and eliminate greenhouse gas emissions, and (2) the need to increase total energy production to meet global demands for an increased standard of living. The National Space Society (NSS) believes that one of the most important long-term solutions for meeting both energy needs is Space Solar Power (SSP), which gathers energy from sunlight in space and sends it to Earth. We believe that SSP can solve our future energy requirements and greenhouse gas emissions problems. Not just help, not just take a step in the right direction, but *solve*.

Space solar power is both clean and inexhaustible and is by far the largest potential energy source available, dwarfing all others combined. SSP can provide large quantities of clean energy to every person on Earth with very little environmental impact. NSS recommends that SSP be included along with ground-based solar collectors and wind turbines as a safe, renewable, and clean energy option.

Energy and Quality of Life

Access to energy has been a foundation of an increasing quality of life since humans first learned to make fires and domesticate animals. The usefulness of more energy has inspired many technological innovations—giving us water wheels, steam engines, factories, automobiles, air conditioning, air travel, and even space exploration. Two centuries ago, the use of fossil fuels, with their dense energy content and affordability, put human economic growth on an exponential curve.

The good news is that the availability of ever larger amounts of affordable energy has granted a steadily improved standard of living for many and the promise of the same for the rest. The bad news is that increasing levels of fossil fuel combustion are seriously harming our precious planet and cast serious doubt on the wisdom of or even our ability to increase energy consumption further. It is simply not sustainable for a fossil fuels-based global economy to continue to grow sufficiently to support a high standard of living on a global basis.

NSS believes that SSP can be a key element in achieving a much greener and more abundant future, where every human has access to inexpensive energy, contributing to a much higher quality of life. In this future, fossil fuels will have been replaced by a mix of carbon-neutral energy sources, with SSP playing a major role.

What Is Space Solar Power?

SSP extends terrestrial power grids into space where the sun shines almost continuously, and where there is no atmosphere or clouds to diminish its intensity. A solar power satellite, placed in a high, geostationary Earth orbit could harvest sunlight, convert it into a focused but low intensity microwave beam for transmission to receivers near markets on Earth as much as 99.5% of the time each year. Solar power on Earth is available only 50% of the time (day-night annual average) at best. In many locations of the world, weather eliminates this option for days or weeks at a time. As a result, terrestrial solar is not a reliable source of baseload power even with major advances in battery technologies, and coal continues to be the number one source of baseload electricity.

A major economic and practical advantage of SSP for baseload power utilities is that it requires almost zero energy storage because sunlight is continuously available in space. Although SSP would primarily be used to provide continuous baseload power, some of the power can be used for intermittent or emergency use as needed, partly due to its ability to be redirected from one receiver to another in less than a few seconds.

An SSP system to deliver 10 gigawatts of baseload power at an average of 100 watts per square meter to the receiving antenna would cover a ground area of about 36 square miles. However, 10 GW of baseload power delivered on average by ground solar power would require a solar array covering about 360 square miles, after accounting for nighttime, seasonal variations in solar intensity, spacing of the solar collectors, and the effects of clouds and other weather conditions. This is 10 times as much area as the SSP requirement. As another comparison, the 3-Gorges dam project in China required the inundation of over 100 square miles of valuable farmland to produce on average 10 GW of electrical power[1].

There are natural concerns over the safety of the power beams from space to Earth. Technical studies show that the low-density beams will be able to meet all radio frequency safety standards for both humans (including onsite workers) and wildlife. However, NSS recommends an extensive test program before deployment and then continuous monitoring during operations.

The Limits of Earth-bound Green Energy

NSS sees terrestrial green energy as a crucially important step on the evolution towards a cleaner, less polluted Earth. However, terrestrial renewable sources provide power only when the wind blows or the sun shines, or where mountains enable hydroelectric power (and when the water is not needed urgently for farming). Moreover, not all geographic regions are suitable for economically-viable large-scale terrestrial solar or wind power generation either due to weather conditions (e.g., frequent overcast or low wind speeds), inherently low sun angles at high (i.e., near polar) latitudes or just the absence of available and suitable land (e.g. not rain forest, crop lands, too mountainous, etc.). On the other hand, orbiting solar power satellites (SPS) connected to terrestrial energy networks could provide continuous energy to almost any region on Earth. SSP can complement and enhance terrestrial green energy. SSP would not generate carbon dioxide or other greenhouse gases, would produce no radioactive waste for disposal, and would require no water withdrawal or consumption for cooling. See table below.

Energy Source	**CO_2 (lbs/MWh)**	**Waste Heat (BTU/MWh)**	**Water Withdrawal (Ga/MWh)**	**Water Consumption (Ga/MWh)**
Coal	~2,170	7,016,000	15,000	500
Oil	~2,115	7,402,000	11,000	400
Natural Gas	1,700	4,495,000	2,000	180
Nuclear	~0	7,047.000	17,000	500
Hydro	~0	6,098,000	~0	~0
SSP	~0	570,000	~0	~0

Terrestrial green solutions alone may only support humanity's increasing energy needs for a relatively short period, perhaps a few decades. As argued by Hoffert, *et al* in *Science*: "a broad range of intensive research and development is urgently needed to produce technological options that can allow both climate stabilization and economic development"[2]. This is because there are real life limits to the deployment of solar, wind, hydro power, and other non-fossil fuel energy systems. Eventually the increasing demand for energy will likely overwhelm the combined capacity of these green sources, absent significant reductions in the global standard of living.

While all viable energy options should be pursued with vigor, SSP has a number of substantial advantages over other energy sources:

- Unlike oil, gas, ethanol and coal, SSP does not emit greenhouse gases.
- Unlike nuclear power plants, SSP will not produce hazardous waste, which needs to be stored and guarded for hundreds of years.
- Unlike terrestrial solar and wind power plants, SSP can be available 24 hours a day, 7 days a week in huge quantities. It works regardless of cloud cover, daylight, or wind speed.
- Unlike nuclear power plants, SSP does not provide death-inducing targets for terrorists.
- Unlike coal and nuclear fuels, SSP does not require environmentally problematic mining operations.
- SSP will provide energy independence and even energy dominance for the nations that develop it.

Making Space Solar Power Affordable

Space solar power facilities must be numerous and large to generate the levels of power humanity desires. For space solar power to be a reality, we need fully reusable rockets utilizing, as much as possible, non-polluting propellants.

With SpaceX repeatedly flying its Falcon 9 and Falcon Heavy boosters safely back to launch sites or drone ships, the company has already achieved great success in making at least the first stages of its launch vehicles reusable[3]. SpaceX is also working on a new large *fully* reusable rocket called the Starship/Super Heavy[4]. Blue Origin is also developing reusable rockets and has repeatedly launched and landed its New Shepard rocket successfully during flight tests[5]. Against a backdrop of already plunging launch costs provided by SpaceX’s first-stage reusable vehicles[6], the company’s Starship, with its Super Heavy first stage, is expected to enable a very significant reduction from the launch cost of the Falcon Heavy (currently below $1700 per kg to LEO[7]), thereby making it much easier to close the SSP business case.

It is estimated that with the developing reductions in launch costs, SPS electricity can be potentially delivered to end users for less than 5 cents per kW-hour[8], which is below current end-user electricity cost worldwide[9].

Longer-Term Prospects

NSS advocates development of the vast resources of space for the dramatic betterment of humanity. This includes not only energy from space (the subject of this paper) but also material resources from space, including mining of the Moon and asteroids.

Space based solar power will eventually have an even more positive impact on Earth if we derive most of the required mass for the orbiting solar power facilities from lunar or asteroid materials. With the Moon's gravity being one-sixth that of Earth's, it may prove to be far easier to get the mass from the lunar surface than from the Earth's surface.

Near Earth asteroids are another potential source of materials for the construction of space based solar power systems. As the use of SSP grows, the potential market for materials mined and processed in space will grow with it, eventually allowing for large scale construction of SPS while minimizing the number of rocket launches required.

SSP not only can provide abundant energy and economic growth on Earth but can provide energy and economic growth in space. Space-to-space solar power beaming could provide energy for cis-lunar and lunar surface vehicles carrying out exploration and construction, while improving technologies for beaming to Earth[10]. Using space-to-space power beaming from an SPS has the potential to greatly reduce the cost of Earth-Moon and Earth-asteroid transportation[11], in turn lowering the cost of constructing solar power satellites. Combined with the usage of water mined on the Moon or asteroids as fuel, space-to-space power beaming heralds a new age of "greener" cis-lunar transportation.

Space Solar Power and Geopolitical Dominance

Energy plays a decisive role in global geopolitics, and the country that develops a working SSP system will be tapping into an enormous energy resource which is capable of rapid growth, which is very easy to export, and which will transform global energy markets. China knows this, but the U.S. is ignoring it. China has plans to put a commercial-scale solar power station in orbit by 2050[12]. Because inexpensive, emissions-free power will be hard for many countries to turn down, China will gain great international leverage with that move. Solar power stations in orbit will also advance China's goal of creating the world's first global electrical "supergrid" as part of its Global Energy Interconnection Initiative, itself a part of China's broader Belt and Road Initiative[13].

Recommendations

NSS recommends government investment of at least $500 million per year with the goal of an orbiting demonstration in 5-10 years and full-size operational units in 10-15 years. This would put SSP funding on a par with federal funding for fusion energy, which would be a minimum reasonable amount considering the enormous benefit either energy source would confer. While NSS also supports funding for fusion energy[14], we note that whereas SSP requires significant engineering development, unlike fusion energy it requires no major breakthroughs in science or technology to be implemented. Therefore, SSP offers a nearer term opportunity than fusion's uncertain development timeline. Had SSP been funded at the same level as fusion research for the last 10-20 years we could now be deploying full-scale operational systems. NSS recommends that the United States, and the world, diversify energy investments by adding SSP to the mix.

References and Notes

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[14] Fusion may be safer and cheaper than fission power on the Earth, but fusion also, both for electricity and for powering rockets, will eventually be important in the exploration, development, and settlement of the outer solar system where solar power gradually becomes less and less useful at farther distances from the sun.

About the National Space Society (NSS): NSS is an independent non-profit educational membership organization dedicated to the creation of a spacefaring civilization. NSS is widely acknowledged as the preeminent citizen's voice on space, with over 50 chapters in the United States and around the world. The Society publishes *Ad Astra* magazine, an award-winning periodical chronicling the most important developments in space. To learn more, visit space.nss.org.