# Green Electricity Generation using Novel Space-Based Power Station

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*Abstract— The concept of space-based solar power was first proposed by Dr. Peter Glaser in 1968 and since then the Space Based Power Station Technology (SBPST) has become the newest jargon that has proclaimed its presence in the technical arena. SBPST is a technology that harnesses the sun's energy twenty-four hours a day that works not only when we have daylight, but also at night, during rain or snow and even on cloudy days. This technique is based on a more efficient way to gather solar energy by launching satellites into orbit around the Earth, where the satellites can capture solar energy, change it into another wavelength and send it to Earth where power stations convert it into usable electricity. All solution options to these challenges should be explored, including opportunities from space. This paper presents a novel space based power station that harnesses the space based power unlike traditional contracted architecture studies. The proposed concept relies on electronic hardware compiled through an innovative and collaborative approach that relies heavily upon interdisciplinary approach to power generation and utilization. The proposed work aims to move the power generation technology beyond the nuclear power generation and seek answer to the question of whether SBPST can be developed and deployed to provide affordable, clean, safe, reliable, sustainable and expandable energy for mankind.*

***Keywords— Efficiency, Electricity, Green Power. Power Generation, Space Based Power.***

## I. INTRODUCTION

The modern day inter-connectivity among objects and people due to evolution in internet and communications technology id largely attributed to the existence of electrical energy. The very basic definition of electricity is: "Electricity is the Electric Potential Energy which can flow electrons or force electrons to flow. This electric current is generated in a power Station, and then sent out over a power grid to your homes, and ultimately to the end users' your power outlets" [12]. Electricity is a general term encompassing a variety of phenomena resulting from the presence and flow of electric charge. These include many easily recognizable phenomena, such as lightning, static electricity, and the flow of electrical current in an electrical wire. In addition, electricity encompasses less familiar concepts such as the electromagnetic field and electromagnetic induction. Electrical phenomena have been studied since antiquity, though advances in the science were not made until the seventeenth and eighteenth centuries [4]. Practical applications for electricity however remained few, and it would not be until the late nineteenth century that engineers were able to put it to industrial and residential use [6]. The rapid expansion in electrical technology at this time transformed industry and society. Electricity's extraordinary versatility as a source of energy means it can be put to an almost limitless set of applications which include transport, heating, lighting, communications, and computation [12]. Electrical power is the backbone of modern industrial society, and is expected to remain so for the foreseeable future. The proposed SBPST needs basic hardware in place, a techno savvy mind and passion for cool gadgets to put together your own SPACE BASED POWER STATION device and experience the power of the digital world on the go [6].

During the late twentieth century, studies confirming the feasibility of SBSP marked the first step toward realizing Dr. Glaser's futuristic proposal. From a scientific standpoint, sending satellites into orbit and building receiving stations on the ground were both feasible because the applicable technology dates back to the 1960s. Even though the science was feasible, a sustainable legal framework for implementing SBSP technology did not exist in the late twentieth century, nor does such a framework exist today [13]. SBSP necessarily involves utilizing outer space for commercial purposes, and international agreements prohibit any country from appropriating space. The paper is organized in the following sections. The next section highlights the traditional methods for power generation, so as to focus on the advantages offered by the SPPST [2]. Section III dives deeper into the evolution of the space based power station technology with the current status of research and future applications. Section IV investigates how SBPS can be a viable alternative to international energy crisis, and to deal with the scarcity and fast depletion of coal. Section V discusses the technical aspects of the SBPS technology. The section analyses how the launching of SBPS would lead to orbital aspects of satellite launching and message transmission. Section VI outlines a possible set o challenges that need to be addressed while implementing SBPS. The paper concludes outlining some contributions of the present work and draws attention to some immediate future work that the authors intend to carry out [27].

## II. TRADITIONAL METHODS OF POWER GENERATION

*A. `Nuclear Power Station*

A nuclear power plant (NPP) is a thermal power station in which the heat source is one or more nuclear reactors. As in a conventional thermal power station the heat is used to generate steam which drives a steam turbine connected to a generator which produces electricity [15]. Electricity was generated by a nuclear reactor for the first time ever on December 20, 1951 at the EBR-I experimental station near Arco, Idaho in the United States. On June 27, 1954, the world's first nuclear power plant to generate electricity for a power grid started operations at Obninsk, USSR. The world's first commercial scale power station, Calder Hall in England opened in October 17, 1956 [5].

*Fig. a: Thermal Power Plant [5]*

A nuclear reactor is a device to initiate and control a sustained nuclear chain reaction. The most common use of nuclear reactors is for the generation of electric energy and for the propulsion of ships [17]. The nuclear reactor is the heart of the plant. In its central part, the reactor core's heat is generated by controlled nuclear fission. With this heat, a coolant is heated as it is pumped through the reactor and thereby removes the energy from the reactor. Heat from nuclear fission is used to raise steam, which runs through turbines, which in turn powers either ship's propellers or electrical generators. Since nuclear fission creates radioactivity, the reactor core is surrounded by a protective shield [5]. This containment absorbs radiation and prevents radioactive material from being released into the environment. In addition, many reactors are equipped with a dome of concrete to protect the reactor against external impacts. In nuclear power plants, different types of reactors, nuclear fuels, and cooling circuits and moderators are sometimes used [17].

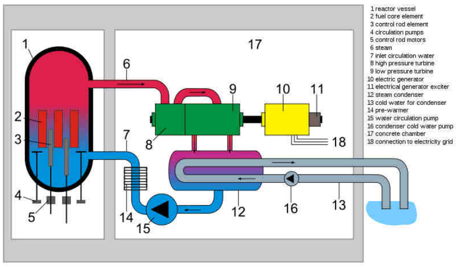


*Fig. b: Schematic of Nuclear Power Plant [17]*

*B. Safety valves*

In the event of an emergency, two independent safety valves can be used to prevent pipes from bursting or the reactor from exploding. The valves are designed so that they can derive all of the supplied flow rates with little increase in pressure. In the case of the BWR, the steam is directed into the condensate chamber and condenses there. The chambers on a heat exchanger are connected to the intermediate cooling circuit [4] – [6].

*C. Thermal Power Station*

A thermal power station is a power plant in which the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser and recycled to where it was heated; this is known as a Rankine cycle [3]. The greatest variation in the design of thermal power stations is due to the different fuel sources. Some prefer to use the term energy centre because such facilities convert forms of heat energy into electricity [9]. Almost all coal, nuclear, geothermal, solar thermal, electric, and waste incineration plants, as well as many natural gas power plants are thermal. Natural gas is frequently combusted in gas turbines as well as boilers. The waste heat from a gas turbine can be used to raise steam, in a combined cycle plant that improves overall efficiency. Power plants burning coal, fuel oil, or natural gas are often called fossil-fuel power plants. Some biomass-fuelled thermal power plants have appeared also. Non-nuclear thermal power plants, particularly fossil-fuelled plants, which do not use co-generation, are sometimes referred to as conventional power plants [20]. Commercial electric utility power stations are usually constructed on a large scale and designed for continuous operation. Electric power plants typically use three-phase electrical generators to produce alternating current (AC) electric power at a frequency of 50 Hz or 60 Hz [3]. Large companies or institutions may have their own power plants to supply heating or electricity to their facilities, especially if steam is created anyway for other purposes. Steam-driven power plants have been used in various large ships, but are now usually used in large naval ships [20].

## III. SPACE-BASE POWER STATION: PAST, PRESENT, AND FUTURE STAGES OF EVOLUTION OF SBSP

The world's first power station was built by Sigmund Schuckert in the Bavarian town of Ettal and went into operation in 1878 [1]. The station consisted of 24 dynamo electric generators which were driven by a steam engine. It was used to illuminate a grotto in the gardens of Linderhof Palace. The first public power station was the Edison Electric Light Station, built in London at 57, Holborn Viaduct, which started operation in January 1882 [4]. This was an initiative of Thomas Edison that was organized and managed by his partner, Edward Johnson. A Babcock and Wilcox boiler powered a 125 horsepower steam engine that drove a 27 ton generator called Jumbo, after the celebrated elephant [9]. This supplied electricity to premises in the area that could be reached through the culverts of the viaduct without digging up the road, which was the monopoly of the gas companies. The customers included the City Temple and the Old Bailey. Another important customer was the Telegraph Office of the General Post Office but this could not be reached though the culverts. Johnson arranged for the supply cable to be run overhead, via Holborn Tavern and Newgate. In September 1882 in New York, the Pearl Street Station was established by Edison to provide electric lighting in the lower Manhattan Island area; the station ran until destroyed by fire in 1890 [8]. The station used reciprocating steam engines to turn direct-current generators. Because of the DC distribution, the service area was small, limited by voltage drop in the feeders. The War of Currents eventually resolved in favour of AC distribution and utilization, although some DC systems persisted to the end of the 20th century [16].

DC systems with a service radius of a mile (kilometer) or so were necessarily smaller, less efficient of fuel consumption, and more labor intensive to operate than much larger central AC generating stations [21]. AC systems used a wide range of frequencies depending on the type of load; lighting load using higher frequencies, and traction systems and heavy motor load systems preferring lower frequencies [19]. The economics of central station generation improved greatly when unified light and power systems, operating at a common frequency, were developed. The same generating plant that fed large industrial loads during the day, could feed commuter railway systems during rush hour and then serve lighting load in the evening, thus improving the system load factor and reducing the cost of electrical energy overall. Many exceptions existed, generating stations were dedicated to power or light by the choice of frequency, and rotating frequency changers and rotating converters were particularly common to feed electric railway systems from the general lighting and power network [5]. Throughout the first few decades of the 20th century central stations became larger, using higher steam pressures to provide greater efficiency, and relying on interconnections of multiple generating stations to improve reliability and cost [25].

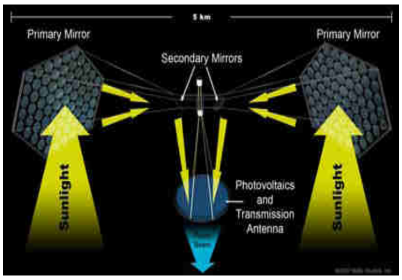


*Fig. c: Current Design Proposals - Illustrations by Mafic studios Roots of the Study [18]*

High-voltage AC transmission allowed hydroelectric power to be conveniently moved from distant waterfalls to city markets. The advent of the steam turbine in central station service, around 1906, allowed great expansion of generating capacity. Generators were no longer limited by the power transmission of belts or the relatively slow speed of reciprocating engines, and could grow to enormous sizes [21]. For example, Sebastian Ziani de Ferranti planned what would have been the largest reciprocating steam engine ever built for a proposed new central station, but scrapped the plans when turbines became available in the necessary size [25]. Building power systems out of central stations required combinations of engineering skill and financial acumen in equal measure. Pioneers of central station generation include George Westinghouse and Samuel Insull in the United States, Ferranti and Charles Hesterman Merz in UK, and many others [1].

## IV. SOLUTION TO AN INTERNATIONAL ENERGY CRISIS: SPACE BASED POWER STATION TECHNOLOGY

There is a growing need to successfully creating a solar power satellite system. Space Energy systems need to be designed at research level to develop solar power satellite and transmit electricity to the Earth's surface by creating and launching a test satellite into low earth orbit [8]. Photovoltaic cells can be used to then convert the captured microwave power into radio frequencies of 2.45 or 5.8 GHz where atmospheric transmission is very high.

These frequencies can be then beamed toward a reference signal on the Earth at intensities approximately 1/6th of noon sunlight [23].

The beam could be received by a rectifying antenna and converted into electricity for the grid, delivering approximately 5 to 10 GW of electric power.

The roots of this study track back to the continuing environmental scan in HQ USAF's internal think tank "DeepLook" (AF/A8XC Future Concepts), which identified several major factors that could drive conflict or undermine

U.S. planning assumptions in the far term future [28].

These included the following strategic problems for the United States:

- Energy Security (both from unstable sources and from depleting resources) [11].
- Climate Change, with possible anthropogenic causes [4].
- Eroding Technology Overmatch due to lower production of science technology engineering & math (STEM) professionals vs. competitors [23].
- Erosion of Space Dominance and corresponding reduction in space security [19].

DeepLook subsequently explored a number of future concepts that might offer potentially game changing solutions to these problems, specifically looking for projects that would lessen USAF and U.S. dependence on fossil fuel, reduce emissions that might lead to climate change, provide a lead in space technology, and energize interest in recapitalization of the U.S. aerospace tech base [19]. Among the ideas explored, was Space Solar Power Satellites. Air Force DeepLook forwarded the concept to AF/A4/7 and the USAF Energy Strategy Board, the OSD Energy Security Integrated Product Team (IPT), the OSD Energy Strategy Defence Science Board (DSB), and finally NSSO Advanced Concepts Office, each of which requested higher fidelity information before further consideration. An informal interagency study group coalesced to attempt to provide better quality information on the subject and advocate for more formal exploration [20].

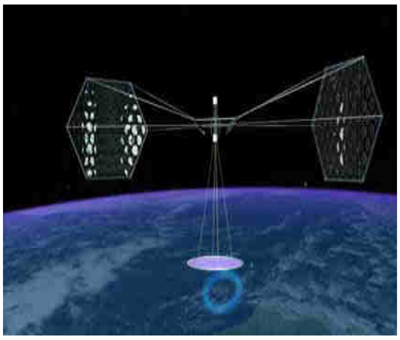

*Fig. d: Current Design Proposals - Illustrations by Mafic studios Roots of the Study 3-D view of the sample prototype [20]*

## V. SPACE BASED POWER STATION TECHNOLOGY

The basic idea to implement a SBPS is to place very large solar arrays into continuously and intensely sunlit Earth orbit (1,366 watts/m2), collect GW of electrical energy, electromagnetically beam it to Earth, and receive it on the surface for use either as base load power via direct connection to the existing electrical grid, conversion into manufactured synthetic hydrocarbon fuels, or as low intensity broadcast power beamed directly to consumers [3]. A single kilometer wide band of geosynchronous earth orbit experiences enough solar flux in one year to nearly equal the amount of energy contained within all known recoverable conventional oil reserves on Earth today [7]. This amount of energy indicates that there is enormous potential for energy security, economic development, improved environmental stewardship, advancement of general space faring, and overall national security for those nations who construct and possess a SBSP capability [9].

NASA and DOE have collectively spent $80M over the last three decades in sporadic efforts studying this concept (by comparison, the U.S. Government has spent approximately $21B over the last 50 years continuously pursuing nuclear fusion). The first major effort occurred in the 1970's where scientific feasibility of the concept was established and a reference 5 GW design was proposed. Unfortunately 1970's architecture and technology levels could not support an economic case for development relative to other lower cost energy alternatives on the market. In 1995-1997 NASA initiated a "Fresh Look" Study to re examine the concept relative to modern technological capabilities [9]. The National Security Strategy recognizes that many nations are too dependent on foreign oil, often imported from unstable portions of the world, and seeks to remedy the problem by accelerating the deployment of clean technologies to enhance energy security, reduce poverty, and reduce pollution in a way that will ignite an era of global growth through free markets and free trade. Senior U.S. leaders need solutions with strategic impact that can be delivered in a relevant period of time. In March of 2007, the National Security Space Office (NSSO) Advanced Concepts Office ("DreamWorks") presented this idea to the agency director [11]. Recognizing the potential for this concept to influence not only energy, but also space, economic, environmental, and national security, the Director instructed the Advanced Concepts Office to quickly collect as much information as possible on the feasibility of this concept [13].

### *A. How SBSP Satellites Will Change the GSO Slot Allocation Regime*

Whether Lunar, LEO, or GEO based, whether at radio or optical frequencies, Space-Based Solar Power is an immense and cross-disciplinary technological challenge, requiring contributions from many diverse disciplines [17]. A Space Solar Power Satellite is a huge construction, requiring expertise in large structures, control and orbital dynamics. Its construction requires sophisticated techniques and careful logistics. Its power generation, be it solar-dynamic, thermo-electric, or photovoltaic, requires expertise in solid-state electronics, optics and thermodynamics. SPS power collection and distribution require electrical engineering, and the conversion of the electrical power generated in space into a coherent wireless power beam requires significant knowledge of the physics of electromagnetic wave propagation [6].

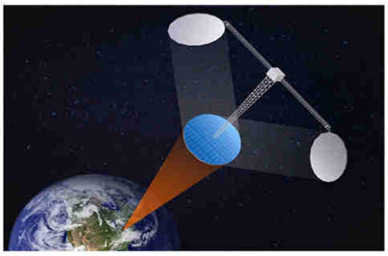

*Fig. e: The proposed and requisite Deployment scenario of orbit satellites for SBPS architecture [6]*

Each of these challenges in turn also depends on competence in advanced material sciences. In all areas, there has been tremendous progress since the idea was first proposed by Dr. Peter Glaser in 1968 and some of the most impressive leaps have taken place since the “Fresh Look” study in the 1990s [21]. In evaluating the long term potential of SBSP, it is instructive to consider that global space utilities that are taken for granted today such as Global Positioning System (GPS) and Geostationary Satellites (“The Clarke Belt”) were once scoffed at and treated as mere science fiction until technology was able to catch up [25]. The SBSP Study Group found that significant progress in the underlying technologies has been made since previous government examination of this topic, and the direction and pace of progress continues to be positive and in many cases accelerating. Significant relevant advances have occurred in the areas of computational science, material science, photovoltaic cells, private and commercial space access, space maneuverability, power management and robotics [26].

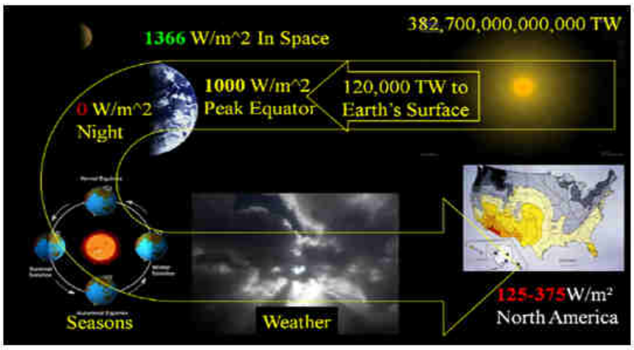


*Fig. f: Geostationary Orbit SBPS working model [26]*

### B. Emerging Set-ups of LEO SBPS hardware

Working with a major focus on emerging nations, the Reference Concept defined by the US Department of Energy and NASA involve advanced concepts involving technologies that have not yet been validated in the laboratory [10]. Following a preliminary assessment of technical and economic risks and projected costs, 7 SSP system architectures and 4 specific SPS concepts were chosen for employing in greater depth using a comprehensive, end-to-end systems analysis employing a desktop computer modeling tool that was developed for the study [12]. Several innovative concepts were defined and a variety of new technology applications considered. The 1979 SPS Reference platforms, comprised as they would have been of large, erected structures and installed systems, were envisioned to be deployed through the use of a massive, unique infrastructure [10] - [12]. This infrastructure included a fully-reusable two-stage-to-orbit (TSTO) Earth-to-orbit (ETO) transportation system as well as a massive construction facility in low Earth orbit (LEO) that would have required hundreds of astronauts to work continuously in space for several decades. The financial impact of this deployment scheme was significant: more than $250 billion (in 1996 dollars) was estimated to be required before the first commercial kilowatt-hour could be delivered [12].

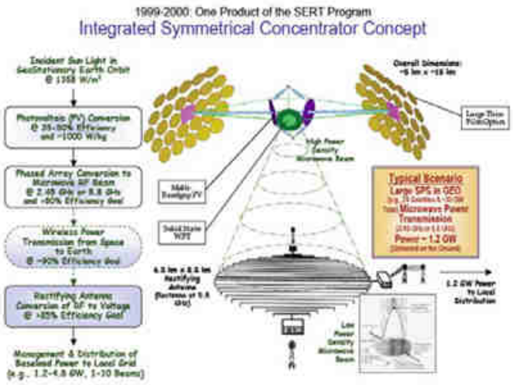


*Fig. g: Hardware Implementation Model of SBPS system [10]*

## VI. CHALLENGES AND SOLUTIONS

Although the individual technologies for SBSP have been produced, tested, and used in other application areas, the overall system has not been integrated to date. This paper proposes to enhance this work by introducing a company's prototype in the subsequent works that will be the first of its kind [3]. Accordingly, there would be a risk that assembling the overall system may prove to be more technically difficult and costlier than originally anticipated. Space Energy will also require clearances from numerous governmental and worldwide agencies, such as the FCC for transmitting radio frequencies from satellites to ground-based receivers. This type of clearance is usually composed of a specific spectrum allocation for transmission, as well as criteria for satellite-based radio frequency intensity [14]. The UN also has some collaborative oversight function via the Committee on the Peaceful Uses of Outer Space (COPOUS). The authors plan to work closely with entities affiliated with COPOUS to obtain adequate orbital slots for its commercial satellites, but there is no assurance that the desired orbital allocations will be available. The core science involved in Space-Based Solar

Power (SBSP) is proven, but a number of technical challenges are yet to be overcome. These include:

- Improving launch capabilities and capacity [21].
- Assembly of the full satellite in space [23].
- Power transmission of this scale [17].
- Managing space debris [11].
- Managing solar winds [16].

The aerospace industry has suggested many solutions to these problems. Until proven at a global scale, however, they remain theoretical, underscoring the importance of being first to market [21]. There are commercial challenges and risks that include:

- Obtaining all required regulatory permits and approvals [22].
- Competition from new sources of energy or larger, better financed companies or governments that could enter the SBSP arena [24].
- Threats of cost overrun, time overrun and potential failure [8].

## VII. ENVIRONMENTAL BENEFITS OF SBPS: FIGHTING CLIMATE CHANGE

SBSP offers a real and practical energy solution which does not require fossil fuels which generate climate-changing CO2 emissions. The authors are keen to demonstrate SBPS's commitment to sustainability, not just through the production of clean energy but also through adhering to UN's policies of corporate and social responsibility [19]. Right now, the primary energy source for power generation is coal; roughly two-thirds of all global electricity is generated from coal power plants. Burning coal in power plants releases more CO2 per unit of energy created than virtually anything else on Earth. Unfortunately, coal is quickly becoming the fuel of choice for India and China, countries with already-massive pollution issues [23]. Between them, these two nations are currently scheduled to build over one large coal-fired power plant every week for the next 20 years. Once mature, SBSP will be as economically viable as coal, especially if costs required to mine, transport, process, burn, and partially capture its carbon emissions are considered. It is important to note, however, that Space Energy does not see itself competing in any way with current providers of energy [18]. SPSP can be best viewed as a vital compliment to existing energy sources and an essential technology to help mitigate the coming energy gap. In fact, SBSP will even allow developing countries to avoid the construction of new fossil fuel power plants and thus earn carbon credits [15].

## VIII. CONCLUSION AND FUTURE WORK

SBPS transmitting satellites usually orbit in low Earth orbit (LEO) at about 400 km above the Earth's surface. Weighing at less than 10 metric tons, this satellite is a fraction of the weight of its microwave counterpart. This design is cheaper too; an approximation estimates 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 [1]. 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. To make this possible, the satellite's solar power beaming system employs a liquid diode-pumped laser [17]. The authors wish to demonstrate the work at a subsequent stage. This laser would be about the size of a room 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 [7]. 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 [21]. At its smaller size, there is a correspondingly lower capacity of about 1 to 10 megawatts per satellite. So, this satellite would be best as part of a fleet of similar satellites, used together [13].

Thus, SBSP is a long way off but many technologies already exist to make this feasible, and many aren't far behind. Also, many of the remaining technologies needed for SBSP could be developed independently in the years to come. As an immediate future work, the authors wish to

- Study LEO orbit satellite launching mechanisms and to seek funding from reputed organizations such as ISRO and IISc.
- To prepare a cost model for the entire hardware and to find the best frequencies for operation.
- To simulate the structure using advanced simulation software such as LabView, Simulink and Matlab.
- To set up a prototype and demonstrate the working of the prototype. The prototype would act as a framework for the actual system deployment.

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