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Space Based Solar Power: Energy Harvesting from Orbit

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ABSTRACT : Space-based solar power (SBSP) has emerged as a promising solution to address the increasing global energy demand and the need for clean and sustainable power sources. This technical seminar paper presents an in-depth exploration of SBSP and its potential for energy harvesting from orbit. The paper begins by introducing the concept of SBSP, highlighting the advantages of harnessing solar energy in space, including uninterrupted sunlight and higher energy intensity. The paper then delves into the process of power transmission from space to Earth via microwaves. It explores the technological advancements and potential environmental impacts associated with power transmission. Moreover, the paper examines the potential applications and benefits of SBSP, ranging from providing renewable energy to remote areas to reducing reliance on conventional power sources. Through this seminar paper, readers will gain comprehensive insights into the concept of SBSP and its significance in shaping the future of energy harvesting from orbit.

KEYWORDS : Space-Based Solar Power (SBSP), Renewable Energy, Long-Term Energy Generation, Space Debris Mitigation, Greenhouse Gas Emissions, Fossil Fuel Alternatives

I. INTRODUCTION

In an era where the demand for energy continues to surge and the urgent need for sustainable and clean power sources has become apparent, Space-Based Solar Power (SBSP) has emerged as a promising solution. Space-based solar power (SBSP) is a concept that involves harvesting solar energy in space and transmitting it to Earth for use as a sustainable and clean energy source. This approach involves placing solar panels or mirrors in orbit around the Earth to capture sunlight and convert it into usable energy. Space-based solar power falls within the domain of renewable energy and space exploration. It combines principles of solar energy harvesting, satellite technology, and wireless power transmission.

Harnessing solar energy from space offers a myriad of advantages over traditional terrestrial solar power generation methods. By situating solar power platforms in orbit, SBSP allows for uninterrupted exposure to sunlight, free from atmospheric interference and night-time limitations. Furthermore, the energy intensity of sunlight in space is significantly higher, enabling more efficient power generation. These inherent benefits of SBSP make it a compelling avenue for meeting the escalating global energy demand in a sustainable and environmentally friendly manner.

One of the crucial aspects of SBSP explored in this seminar paper is the process of power transmission from space to Earth. Utilizing microwave technology, the transmission of solar power collected in space becomes feasible and efficient. This paper investigates the technological advancements in microwave power transmission and also delves into the potential environmental impacts associated with this method. Understanding these aspects is crucial for comprehensively evaluating the viability and sustainability of SBSP as an energy solution.

The seminar paper also investigates the diverse applications and benefits of SBSP. One significant advantage lies in its ability to provide renewable energy to remote and underserved areas. By harnessing solar power from space, energy access can be extended to regions lacking proper infrastructure for conventional power generation. Additionally, SBSP has the potential to reduce the world's dependence on fossil fuels and mitigate the negative consequences of conventional energy sources on the environment, including air pollution and greenhouse gas emissions.

Through an in-depth analysis of the concept, technological aspects, environmental implications, and potential applications of SBSP, this seminar paper aims to equip readers with a comprehensive understanding of this groundbreaking energy solution. By exploring the possibilities of energy harvesting from orbit, SBSP has the potential to reshape our energy landscape and pave the way for a cleaner, more sustainable future.

II. LITERATURE SURVEY

Some of the key findings from the papers are some studies focus on overall design of the space based solar power system like from solar panels to converting electrical energy to microwaves and beaming it into earth and receiving through rectennas and converting them to DC again[2][4][6][7]. But Some of the paper focuses on particular part of the SBSP that is either the design of capturing sunlight or the design of wireless transmission to earth The different technologies the studies focus on are multi-junction solar cells[1], Luminescent Solar concentrator device over PV Cells[3], microwaves over laser beams[7], thin phased array tiles for the microwaves transmitter portion[5] and origami design of solar cells[1]. All these designs focus on making the system Lighter, Cost Effective, Efficient and Sustainable.

III. ADVANTAGES AND BENEFITS OF SBSP

Space-Based Solar Power (SBSP) offers remarkable advantages as a transformative technology for meeting global energy demands. Firstly, it provides a consistent and uninterrupted power supply, as solar panels in space are not affected by weather conditions or Earth's day-night cycle, ensuring reliable energy generation 24/7. Secondly, SBSP unlocks an abundant and virtually limitless source of clean power, harnessing solar energy from space, which far exceeds what is available on Earth's surface. This presents an opportunity to reduce our dependence on finite fossil fuels and significantly curb greenhouse gas emissions, making a substantial contribution to combat climate change. Additionally, SBSP's long-term sustainability stands out as space-based solar power satellites can operate for decades without major maintenance or replacements, ensuring stable energy production over extended periods. Moreover, locating solar panels in space addresses land usage and environmental concerns, preserving valuable land resources and wildlife habitats on Earth.

IV. TECHNOLOGICAL & ECONOMIC CONSIDERATIONS

The technological considerations of SBSP encompass the various challenges associated with generating and transmitting solar power from space to Earth. Firstly, solar power generation in space requires the development of advanced solar panels or mirrors capable of efficiently capturing sunlight in the harsh space environment. These technologies must be lightweight, durable, and highly efficient to maximize energy harvest.

Power transmission is another crucial technological aspect of SBSP. Microwave power transmission has emerged as a viable option for transmitting collected solar energy from space to Earth. This technology involves converting the captured energy into microwave radiation and beaming it to receiving stations on Earth. Developing reliable and efficient microwave transmission systems is a key technological challenge.

A. Origami design vs normal design of solar cells

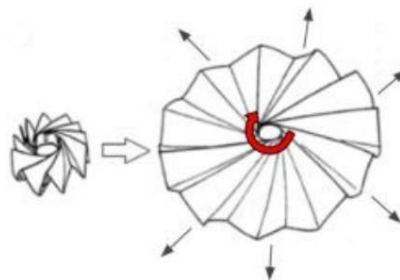
It is not possible carry such huge structure solar arrays in space having wide dimensions so packaging, stowing, unwrapping and deployment is required[8]. Origami designs are becoming increasingly relevant for the deployment of solar panels in space-based solar power systems due to their unique advantages and challenges presented by space missions. Origami designs allow solar panels to be folded into compact configurations during launch, reducing the volume and weight of payloads. This space-saving feature is critical in space missions, where payload capacity is limited and costly. Origami designs allow solar panels to be folded into compact configurations during launch, reducing the volume and weight of payloads. This space-saving feature is critical in space missions, where payload capacity is limited and costly. Once in space, the panels can unfold to maximize their surface area and energy capture, enhancing the efficiency of the solar power generation.

Figure 1 : Origami Design [8]

B. Single Junction Solar cells vs Multi Junction solar cells

The energy levels in semiconductors are categorized into the 'valence band,' representing the lower energy level, and the 'conduction band,' indicating the energy level where an electron is free to move and participate in conduction. The energy difference between these two bands is known as the 'band gap,' measured in electron volts (eV). The band gap represents the minimum energy required to excite an electron from the valence band to the conduction band, enabling it to conduct electricity.

Multi-junction solar cells capitalize on the properties of semiconductors found in the III and V columns of the periodic table. Among these materials, gallium arsenide (GaAs) is commonly used due to its close-to-optimal band gap of 1.43eV. GaAs offers six times higher electron mobility than silicon, leading to faster operation. Additionally, multi-junction solar cells combine GaAs with indium gallium phosphide (InGaP) and germanium (Ge) layers, each having band gaps of 1.85eV and 0.67eV, respectively.



By integrating these different semiconductor layers, multi-junction solar cells can capture a broader range of sunlight, including both visible and non-visible light. This enables them to achieve higher energy conversion efficiencies compared to single-junction cells. Multi-junction cells are also more adept at utilizing sunlight under varying light conditions, making them an ideal choice for space applications and concentrated photovoltaic systems. While multi-junction solar cells may be more complex and expensive to manufacture, ongoing research is continually reducing costs and making them increasingly competitive for various high-efficiency solar energy systems.

Group	Material	Band Gap
IV	Silicon	1.14
IV	Germanium	0.67
III-V	Gallium Nitride	3.4
III-V	Gallium Phosphide	2.26
III-V	Gallium Arsenide	1.43

Figure 2 : Band Gap Values of some Materials

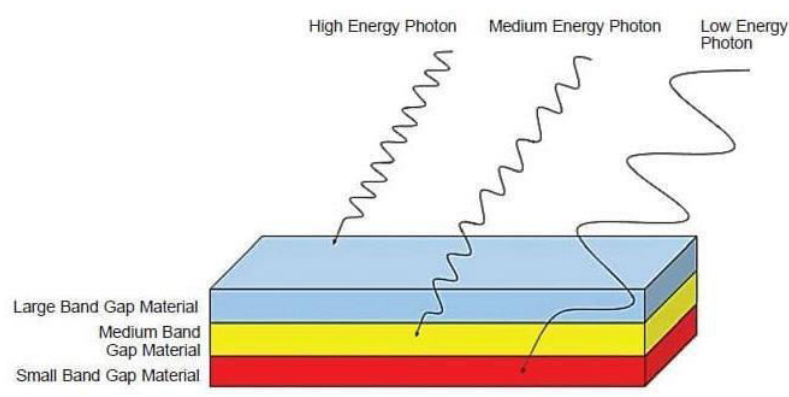


Figure 3 : Multi-Junction Solar Cell

A. Microwaves Over Lazer Beams

When it comes to transmitting solar power harvested in space to Earth, two main technologies have emerged as potential options: microwaves and laser beams. While both methods have their advantages and considerations, the utilization of microwaves for power transmission in space-based solar power (SBSP) systems offers several significant benefits compared to laser beam transmission.

Transmission of the microwave energy could be as fast as speed of light[7] wherein laser beam transmission has its own disadvantages. As per the article published by The United States Department of Energy some of the cons of using laser beams are that they are Comparatively low power of each individual satellite, in the area of 1 to 10 MW per satellite, would require several satellites to make a substantial impact. Laser transmitting satellites would have trouble beaming power through heavy clouds and rain. There are several safety concerns with lasers in space, such as blinding and weaponization. Laser transmitting satellites would have trouble beaming power through heavy clouds and rain whereas microwave transmissions are steady, uninterrupted transmission of power through rain, clouds, and other atmospheric conditions, they also safely transmit power through air at intensities no greater than midday sun and provide upwards of 1 GW of energy to terrestrial receiver, enough to power a large city.

B. Luminescent Solar concentrator device over PV Cells

One method for decreasing the overall mass of a PV system is to concentrate the irradiance impinging on a large area onto a smaller area, thereby decreasing the overall amount of required cell material. Typical geometric concentrators are made with mirrors or lenses, and must be accurately pointed at the sun, which in turn requires massive structures to maintain the concentrator shape and orientation, as well as to adequately cool the solar cells. An alternative to geometrical concentrators is the luminescent solar concentrator (LSC) [3].

When the luminescent solar concentrator (LSC) module is placed above PV cells, it functions by absorbing sunlight and converting it into lower-energy photons through photon downshifting via absorption. These lower-energy photons are then trapped and guided within the planar dielectric waveguide of the LSC. As they travel through the waveguide, the photons get concentrated onto the small-area PV cells beneath. The concentrated photons enhance the PV cells' light absorption, boosting their electricity generation efficiency. By harnessing luminescence and photon downshifting, this technology optimizes solar energy capture and utilization, offering a promising approach to improve the overall performance and efficiency of PV cell systems for more effective solar power generation.

LSCs that employ modern, state of the art luminophore materials can achieve specific power values over 1 kW/kg, , while spectrally optimized QDs would push performance closer to 2 kW/kg [3].

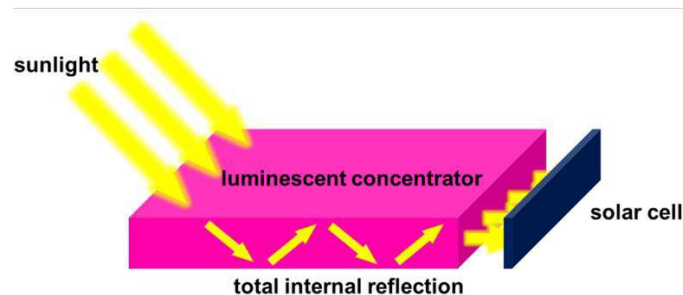


Figure 4 : Luminescent Solar concentrator device over PV Cells

C. Thin phased array tiles

The technology of using thin phased array tiles for the microwave transmitter in a space-based solar power satellite involves a sophisticated approach to transmit solar energy from space to Earth. Phased arrays are devices that consist of multiple antenna elements working together coherently to steer the direction of the transmitted signal.

In this context, thin phased array tiles are utilized as the transmitting element for the microwave signals generated by the solar power satellite. These tiles are designed to efficiently convert the captured solar energy into microwave signals that can be directed towards Earth. The phased array system allows for precise control and manipulation of the microwave beam's direction, enabling accurate transmission of energy to specific target areas on the Earth's surface.



V. CHALLENGES AND FUTURE DIRECTIONS

A. Cost Analysis

In the pursuit of Space-Based Solar Power (SBSP), the estimated cost, as reported by Frazer-Nash, is approximately 16 billion euros, equivalent to 1.28 billion dollars. Although this figure may appear significant, it pales in comparison to the expenses incurred by other ambitious space projects. Notably, the space shuttle program alone accounted for a staggering 209 billion dollars. Despite its relatively lower cost, SBSP promises to be a game-changing technology with the potential to revolutionize our energy landscape, offering a sustainable and economically viable solution for clean and renewable energy generation from orbit. The combination of advanced technology, cost-effectiveness, and environmental benefits makes SBSP an exciting and beautiful prospect for a greener and more sustainable future.

B. Space Debris

In the vast expanse of space, a significant challenge that arises is the presence of space junk, which includes spent rocket parts, defunct satellites, and various hardware fragments. With an estimated 8000 tonnes of debris orbiting the Earth, there is a legitimate concern about potential collisions with crucial components like solar panels. However, to address this issue, space agencies and operators have implemented guidelines for space debris mitigation.

The guidelines emphasize responsible satellite disposal practices, mandating that operators remove satellites from their orbits within 25 years of completing their missions. For geostationary satellites, a higher orbit called the "graveyard orbit" is designated, where the satellite is positioned beyond Earth's gravitational pull, minimizing the risk of collision. For satellites in low Earth orbit, they must be steered into the atmosphere to burn up upon re-entry, ensuring safe and controlled disposal.

To tackle existing space debris, upcoming missions like the European Space Agency's ClearSpace-1 have been planned. The mission's goal is groundbreaking—to remove an item of space debris from orbit by 2025. By adhering strictly to these guidelines and actively conducting debris removal missions, the space solar system can significantly reduce the risks posed by space junk collisions. Embracing responsible space debris mitigation practices offers the promise of a safer and more sustainable space environment, ensuring the continued functionality and integrity of vital space technologies, including space-based solar systems.

VI. CONCLUSION

In conclusion, Space-Based Solar Power (SBSP) holds great promise as a transformative and sustainable solution to address the world's increasing energy demands. With advantages like uninterrupted power supply, abundant solar energy, and long-term sustainability, SBSP emerges as a compelling alternative to conventional energy sources. Leveraging microwave technology for power transmission offers advantages over laser beams, ensuring reliable energy delivery regardless of atmospheric conditions. Innovative approaches such as origami design for solar cells and multi-junction solar cells enhance efficiency and cost-effectiveness. However, challenges in cost analysis and space debris management must be addressed. By pursuing responsible practices and continuous research, SBSP can revolutionize the energy landscape, offering a cleaner and greener future for humanity.

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