



Space-Based Solar Power: Frequently Asked Questions

Technology Innovation Spotlight

Photo Credits: NASA

Overview

- A 2023 EPRI fact sheet ([3002027739](#)) explored the question, “Can space-based solar power plants beaming energy down to the Earth’s surface make meaningful contributions to global decarbonization by 2050?” Based on recent technical milestones and assessments conducted by US and international agencies, EPRI concluded that this novel technology holds significant promise.
- This follow-on tech brief, developed after extensive consultation with experts in the field, provides a deeper dive into questions regarding technology status and the challenges and complexities that will need to be addressed in the decades ahead. The answers provided synthesize expert opinions rather than draw on published information resources.

1. What is space-based solar power (SBSP), and how does it work?

SBSP involves harnessing solar energy in space for delivery to and use on Earth. End-to-end SBSP systems integrate on-orbit solar energy capture and conversion with wireless power transmission (WPT) to ground-mounted rectifying antennas (rectennas) that supply DC power for terrestrial use. The choice between WPT technologies leans toward microwave over laser transmission as a more reliable and safer option for space-based power beaming. Overall, SBSP research is in its early stages, with challenges and complexities yet to be fully addressed.

2. How feasible is SBSP, and what are key challenges and benefits?

SBSP holds great promise as a sustainable energy source for the future. The 2023 demonstration of WPT in space and the beaming of detectable (milliwatt-scale) levels of power through the atmosphere to the Earth’s surface by a research team at California Institute of Technology (Caltech) signifies theoretical feasibility. However, the journey to practical implementation faces substantial challenges. The foremost concerns lie in the economic viability and the extensive infrastructure needed to harness solar energy from space for terrestrial use.

Overcoming these hurdles requires significant advancements in WPT technology, the development and deployment of interim space-based energy solutions, and the formulation of new regulations and policy frameworks to govern this novel energy source. Moreover, successful SBSP implementation necessitates international cooperation and collaboration between various agencies, institutions, developers, and end users. While SBSP offers immense potential benefits, including a constant and abundant non-carbon energy supply, addressing these challenges will be pivotal in realizing its true potential.

3. What are the typical power generation levels and distances involved in SBSP, including transmitter-to-receiver and orbital considerations?

The typical power levels and distances involved in SBSP are critical considerations in assessing feasibility. Power levels vary across concepts, with estimates ranging from 100 megawatts to 2 gigawatts. Both geostationary (circular) and Molniya (highly elliptical) orbits are suitable options. Geostationary positioning requires advanced launch capabilities to achieve a fixed altitude of about 35,800 km (22,300 miles) but offers the advantage of a solar generation capacity factor above 99%. For practical use, gigawatt-level power generation in space is deemed necessary due to power loss during transmission through the atmosphere. Mid-earth orbit emerges as a more practical choice due to cost and feasibility considerations.

4. Is SBSP technology safe, and what are the potential implications for communications and other infrastructure?

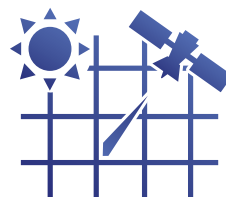
SBSP raises safety considerations, particularly regarding WPT methods currently under development. Experts emphasize the importance of maintaining low energy intensity levels to ensure safety for both humans and the environment. Microwave beaming—using radio-frequency phased array antennas with intensity levels below mid-day sunlight—is deemed less harmful, with potential physiological effects manageable through thermoregulation.

By contrast, the use of high-power lasers for transmission of grid-relevant quantities of energy is considered by many experts to be unsafe and politically unfeasible. Laser beams could cause bird and bat mortality, strike aircraft, and disrupt communications networks, necessitating safety and interference precautions—such as exclusion zones and shielding or other mitigation measures—that would represent significant barriers to SBSP implementation.

5. What is the target unit size, and what is the critical manufacturing capacity required for SBSP systems?

To achieve economic viability, SBSP systems likely need to supply gigawatts of electricity to grids on the Earth's surface, deploying novel PV cell, transmitter, and array designs at massive scale. A key challenge lies in WPT efficiency, with

an estimated energy loss of 40% to 60%—even after the technology matures—due to long beaming distance and atmospheric interference during transmission.



Currently, it's challenging to specify the critical manufacturing capacity required due to the technology's evolving maturity level. Nonetheless, consensus exists that defense applications, already driving WPT and other key areas of SBSP research and development (R&D), will also be the first to deploy. Given the financial resources of defense agencies, these applications could potentially support the critical manufacturing capacity needed for civilian SBSP systems supplying terrestrial grids.

6. What is the capital cost target for SBSP systems in dollars per kilowatt (\$/kW), and what is the expected cost of energy delivered to the grid in dollars per megawatt-hour (\$/MWh)?

The capital cost model target is variable and context-dependent. Current estimates (including launch) shared by experts suggest cost targets ranging from \$100,000 to \$1,000,000/kW. The target cost of energy for economic feasibility is \$100/MWh, with a focus on achieving commercial scalability. That said, it's too early for meaningful cost estimates of on-orbit PV arrays and WPT from space to Earth-based rectennas, all operating at gigawatt scale.

Defense applications and niche customers prioritizing reliability in energy supply over cost are targets for early adoption before SBSP is able to compete in grid markets as technology matures and costs decrease. Initial applications of high-power WPT systems are expected to involve ground-based beaming to airborne platforms and then back to the Earth's surface for reliable energy supply to forward bases and other remote end users. In summary, SBSP cost models vary, but the importance of niche market entry and cost-effectiveness before broader commercial competitiveness is consistent among the experts' insights.

7. Are any rare or toxic materials required for SBSP, and what does the overall supply chain look like?

In the upscaling of the SBSP market, quantities of required rare materials are expected to be manageable, and major components will predominantly consist of inert materials integrated in multijunction photovoltaic (PV) cells. SBSP development primarily relies on three key supply chains: the PV industry including its specialty space sector, the transmitter/receiver industry, and the rocket building and launching industry. Based on the current state of knowledge, these industries are expected to prove capable of collectively supporting early deployment, market expansion, and maturation of SBSP technology.

8. What regulatory approvals are necessary for implementing SBSP, including orbital and wireless transmission considerations?

Currently, SBSP lacks established standards and regulations due to its early-stage status, but ongoing global R&D may lead to the evolution of existing frameworks and emergence of new ones as the technology matures. At present, regulatory approvals for space-based implementation primarily involve the US Federal Communications Commission (FCC) and International Telecommunications Union (ITU). To operate the orbital components, a commercial license and spectrum allocation broadcast license are necessary, handled by the FCC in the United States and the ITU for companies based elsewhere.

Local land use regulations generally govern ground station permitting, typically involving environmental impact assessments conducted under the purview of authorities having jurisdiction. Additional agencies, including those responsible for space launch, flight control, aviation, and environmental resource protection, also are likely to be involved in SBSP permitting and regulation.

9. What are the estimated launch capacity requirements and associated costs?



Launch capabilities required for SBSP systems remain uncertain at this early development stage, but launching SBSP components is widely acknowledged as a significant cost driver for the overall

technology development and deployment process. This cost challenge is amplified by the necessity for multiple rocket launches to assemble a functional SBSP station, underscoring the importance of cost-effective launch strategies as the technology advances.

10. What specific challenges are unique to space-based construction and assembly, and is modularity a consideration in SBSP system design?

Modularity plays a pivotal role in SBSP system design. The prevailing strategy involves constructing equipment on Earth for delivery into space orbit through multiple launches. These modular components can autonomously unfold and assemble in space, offering flexibility for maintenance and potential decommissioning. Given the evolving nature of SBSP programs and startups, further experimentation and testing are crucial to determine the most effective station architecture. Future advancements, like the potential for moon-based manufacturing, assembly, and launching, may reshape the SBSP landscape after about 2070.

11. Who is actively developing operational strategies for SBSP systems?

Operational strategies are being actively developed by various entities—predominantly government organizations with a focus on military applications but also including universities and startups. US defense research laboratories, space agencies in Europe and Asia, and Caltech are pursuing R&D toward operational system-level demonstrations. Virtus Solaris, one of a number of SBSP startups, has expressed intentions to establish an operational SBSP site within 5 years, although this timeline may face challenges in aligning with market consensus and feasibility considerations.

12. What are key on-orbit power electronics considerations and architectural aspects?

Typical SBSP system designs incorporate space-based power electronics for converting DC generated by PV cells to gigahertz-range microwave beams. While existing technology can be repurposed for SBSP, durability in the harsh space environment is a concern. Custom components may be needed, potentially increasing costs.

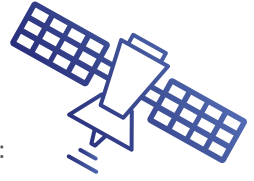
Feasibility has been established for multijunction PV cells that offer lifetimes of 20 to 30 years and incorporate individual semiconductor layers with different bandgaps to capture a larger portion of the solar spectrum. Modular converters are proposed, with each subunit operating at hundreds of watts or kilowatts to support scaling to meet the challenges of megawatt- and gigawatt-level operation in space. Silicon carbide and gallium nitride are considered as potentially viable materials platforms, but no current power electronics devices meet the requirements.

13. Can space-based manufacturing and assembly be viable, and if so, how would it be accomplished?

Space-based manufacturing of large structures, as it currently stands, is not feasible and unlikely to become a reality within the next 30 to 40 years. The prevailing approach used for space stations and anticipated for early SBSP systems involves manufacturing and assembly of components on Earth, followed by multiple rocket launches to deliver modular packages into orbit, where they can then be assembled—under operator control or, increasingly, autonomously—to form larger structures. The prospect of manufacturing SBSP components in space may gain feasibility as moon-based stations and economies further develop, potentially enabling innovative approaches in the future.

14. How are component failures addressed for on-orbit systems, and what are plans for SBSP system decommissioning?

Future policies and regulations are expected to guide how these challenges are addressed. Some experts suggest a modular approach to deal with “if a part dies, it dies” scenarios:



Through modularity, the SBSP station can continue functioning even if a module or part fails. Others propose sending malfunctioning parts further into space or down to the stratosphere to burn upon reentry.

Looking ahead, there is optimism that autonomous robots could be deployed for repairs. Recycling and reuse of ex-service components are currently not addressed in available sources, and decommissioning SBSP systems remains an open question with no consensus at this stage. Clarification and development of decommissioning protocols will be crucial as SBSP technology advances.

For more information, contact:

EPRI Customer Assistance Center
800.313.3774 • askepri@epri.com



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EPRI

3420 Hillview Avenue, Palo Alto, California 94304-1338 USA • 650.855.2121 • www.epri.com

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