

Space-Based Solar Power Beyond Terrestrial Energy Infrastructure: Revisiting O'Neill's Space Industrialization Paradigm

Abstract

Space-Based Solar Power (SBSP) has regained global interest due to the reduction in launch costs, increasing worldwide energy demand, and advancements in reusable launch systems and wireless power transmission technologies. Most modern SBSP concepts focus on addressing terrestrial energy demand through Earth-manufactured and Earth-launched systems. Recent commercial companies and research institutions largely frame SBSP as a utility-scale energy infrastructure problem that can be solved through improvements in launch economics, modular satellite architectures, and orbital assembly techniques.

This paper revisits the fundamentally different approach proposed by Gerard O'Neill during the 1970s. Unlike modern commercial approaches, O'Neill viewed SBSP as part of a broader space industrial ecosystem involving rotating space settlements, extraterrestrial resource utilization, orbital manufacturing, and long-term economic expansion into space. In this vision, solar power satellites are not isolated infrastructure projects, but rather commercial products manufactured by space settlers using lunar and asteroid resources.

The paper compares the modern Earth-centric SBSP paradigm with O'Neill's space-industrialization paradigm from economic, infrastructural, scalability, and strategic perspectives. The analysis highlights the limitations of Earth-based manufacturing for large-scale SBSP deployment and discusses how current commercial developments may serve as transitional architectures toward future in-space manufacturing capabilities. Finally, the paper proposes a phased transition pathway from Earth-built demonstrators toward orbital manufacturing and extraterrestrial resource utilization.

1. Introduction

The global demand for energy continues to increase due to industrial growth, population increase, digital infrastructure expansion, and geopolitical instability affecting conventional energy systems. Simultaneously, growing concerns regarding climate change and carbon emissions have accelerated investments in renewable energy technologies. Among the proposed long-term energy solutions, Space-Based Solar Power (SBSP) has recently regained significant international attention.

Modern developments in reusable launch systems, robotics, lightweight structures, and wireless power transmission have encouraged several companies and research institutions to revisit the feasibility of SBSP systems. Most modern concepts propose large solar power

satellites placed in Earth orbit, particularly Geostationary Orbit (GEO), where solar energy can be collected continuously and transmitted wirelessly to Earth.

Historically, the idea of beaming power from space to earth was mentioned in science fiction short stories by Isaq Asimov in the 1940s. However, Peter Glaser was the first to patent the idea. The first assessment for SBSP by the American government was not encouraging neither from commercial viability nor from technical feasibility perspective. However, technology has evolved dramatically since the 1980s and SBSP is gaining momentum recently.

Despite the recent commercial momentum surrounding SBSP, significant skepticism remains regarding the economic competitiveness of SBSP compared to terrestrial photovoltaic systems. Most modern companies frame SBSP primarily as an energy-generation problem and rely heavily on reductions in launch costs and improvements in technology readiness levels.

Gerard O'Neill proposed a fundamentally different vision. Rather than treating SBSP as an isolated energy infrastructure project, O'Neill viewed it as part of a broader space-industrial ecosystem involving rotating habitats, lunar resource extraction, orbital manufacturing, and long-term human settlement in space. In this framework, SBSP becomes one of the first commercially viable products manufactured by space settlers.

This paper compares the modern commercial approach to SBSP with O'Neill's space-industrialization paradigm and evaluates the implications of both approaches from economic, infrastructural, scalability, and strategic perspectives.

2. Current Commercial Trends in SBSP

The reduction in launch costs and the increasing global demand for energy have accelerated international interest in Space-Based Solar Power. Several modern studies and commercial initiatives have identified multiple SBSP architectures with potential commercial viability. Recent startups and private companies have also managed to raise investment capital for SBSP-related technologies, reflecting renewed worldwide interest in the concept.

Modern SBSP companies largely approach the problem from a terrestrial energy perspective. Their business models resemble those of utility companies, where SBSP is treated as a large-scale power generation system intended to supply energy to Earth. The primary challenges identified by these companies include launch costs, technology readiness levels, orbital assembly complexity, and regulatory uncertainty.

Current business models generally assume that reductions in launch costs, combined with technological demonstrations and incremental deployment strategies, will eventually make

SBSP commercially profitable. Most modern architectures rely on manufacturing the solar power satellites on Earth and launching them into orbit using reusable launch systems.

4. O’Neill’s Space Industrialization Paradigm

Gerard O’Neill proposed a fundamentally different approach to Space-Based Solar Power. In his vision, SBSP was not merely an energy-generation project but part of a broader strategy for human expansion into space. O’Neill proposed large rotating space habitats capable of supporting permanent human settlements with populations reaching hundreds of thousands of inhabitants.

The proposed settlements relied heavily on lunar and asteroid resources to sustain industrial activity in space. O’Neill envisioned the use of mass drivers to transport raw materials from the Moon into space, where orbital manufacturing facilities could fabricate large infrastructure systems. Within this framework, solar power satellites become commercially attractive products manufactured by space settlers rather than isolated infrastructure systems launched from Earth.

Unlike modern SBSP concepts, O’Neill’s approach reduces dependence on Earth-based manufacturing and launch systems over time. The broader objective is not only energy production but also the development of a self-expanding industrial ecosystem capable of supporting long-term human civilization beyond Earth.

5. Comparative Analysis Between the Two Paradigms

5.1 Economic Philosophy

Modern SBSP companies operate using economic models similar to terrestrial utility companies. The systems are evaluated based on launch costs, manufacturing costs, insurance, energy prices, operational costs, and return on investment. The central assumption is that launch costs will decline significantly in the future while technology readiness levels improve through demonstrations and pilot projects.

O’Neill’s economic philosophy is fundamentally different. His vision focuses on reducing pressure on Earth by enabling millions of people to live and work in space settlements. Within this framework, SBSP becomes a major economic product that can support trade between Earth and space settlements. Manufacturing SBSP systems in space using extraterrestrial resources would eliminate thousands of rocket launches while reducing the environmental footprint associated with Earth-based manufacturing and launch activities.

Additionally, large-scale space settlement could redistribute industrial activity away from Earth and create entirely new economic sectors based on orbital manufacturing, resource extraction, and energy export.

5.2 Infrastructure Philosophy

Modern commercial companies generally view SBSP as standalone orbital infrastructure similar to communication satellites. In contrast, O'Neill viewed SBSP as one component within a much larger industrial ecosystem involving settlements, mining operations, transportation infrastructure, and manufacturing facilities in space.

5.3 Scalability

The scalability of Earth-manufactured SBSP systems remains constrained by launch capacity, structural mass limitations, radiation degradation, and replacement requirements. As SBSP systems grow toward gigawatt-scale deployment, launch cadence and manufacturing complexity become major economic bottlenecks.

In contrast, O'Neill's framework allows for exponential industrial growth through in-space manufacturing and extraterrestrial resource utilization. Once orbital manufacturing infrastructure is established, the dependence on Earth launches decreases significantly, allowing larger systems to be produced directly in space.

5.4 Energy Economics

Launch cost currently dominates the economics of Earth-manufactured SBSP systems. Even with improvements in reusable launch systems, the cost associated with launching extremely large structures into orbit remains a critical challenge.

Manufacturing SBSP systems in space could significantly reduce launch-related emissions, structural constraints, and long-term deployment costs. In addition, orbital manufacturing could create sustainable economic activity capable of supporting large space settlements and reducing environmental pressure on Earth.

5.5 Strategic and Geopolitical Implications

Modern SBSP business models remain highly dependent on reusable launch systems currently being developed by a limited number of countries and companies. This introduces strategic and geopolitical dependencies that may affect future global energy systems.

Furthermore, terrestrial renewable energy systems remain vulnerable to geopolitical instability and conflict. In contrast, large-scale SBSP systems may provide more stable long-term energy access. However, if all SBSP infrastructure continues to rely on Earth-based manufacturing and launch systems, scalability limitations may eventually prevent meaningful global deployment.

The risk associated with maintaining Earth-based manufacturing is that large-scale SBSP may become economically trapped due to launch dependency, structural limitations, and replacement requirements. Energy independency is extremely important for countries in Europe, Japan and other countries with no or limited oil and gas reserves. If some companies create a monopoly to launch from near equator (simplest path to Geostationary orbit), the energy dependency of many countries will be at risk, and therefore, a core advantage motivating launching SBSP from earth becomes unattractive.

6. Transition Path Toward Space Manufacturing

The transition from Earth-manufactured SBSP systems toward orbital manufacturing can be viewed as a multi-phase technological evolution.

6.1 Phase I — Earth-Based Demonstrators

Current commercial efforts focus on microwave beaming demonstrations, modular satellite architectures, and remote power systems. These demonstrations provide critical operational experience for future large-scale systems.

6.2 Phase II — Orbital Assembly

As systems become larger, companies may transition toward modular deployment, robotic assembly, inflatable structures, and orbital servicing technologies. This phase reduces the inefficiencies associated with launching fully assembled systems.

6.3 Phase III — Orbital Manufacturing

The next transition occurs when launching raw materials becomes economically preferable to launching fully assembled satellites. Instead of launching complete structures, companies may launch feedstock materials, robotic systems, and compact manufacturing units capable of fabricating trusses, antennas, radiators, and support structures directly in orbit.

6.4 Phase IV — Extraterrestrial Resource Utilization

In the final phase, lunar and asteroid resources such as aluminum, silicon, oxygen, and metallic materials become economically meaningful for large-scale orbital industry. At this stage, SBSP becomes integrated within a broader space economy rather than functioning as an isolated energy project.

7. Discussion

Modern SBSP companies are unintentionally developing many of the technological foundations required for future space industrialization. Technologies such as autonomous assembly, wireless power transmission, lightweight structures, robotics, and orbital servicing are all directly applicable to orbital manufacturing and large-scale space infrastructure.

Recent advances in reusable launch systems, artificial intelligence, robotics, and additive manufacturing may gradually reduce the barriers that previously prevented O'Neill's vision from becoming technically plausible. Although modern commercial companies currently focus on terrestrial energy applications, their technologies may eventually evolve toward broader industrial activity in space.

From this perspective, modern SBSP architectures may represent transitional systems rather than the final form of large-scale space-based energy infrastructure.

8. Conclusion

This paper compared the modern commercial approach to Space-Based Solar Power with Gerard O'Neill's broader space-industrialization paradigm. Modern commercial companies primarily approach SBSP as a terrestrial energy infrastructure problem dependent on Earth-based manufacturing and launch systems. In contrast, O'Neill viewed SBSP as one component of a larger industrial ecosystem involving space settlements, orbital manufacturing, and extraterrestrial resource utilization.

The analysis highlights the scalability limitations associated with Earth-manufactured SBSP systems and discusses how current commercial developments may eventually transition toward orbital manufacturing and space resource utilization. The paper argues that the long-term viability of large-scale SBSP may depend not only on advances in wireless power transmission and launch economics, but also on the development of sustainable industrial activity in space.