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Development of Space-Based Solar Power

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1. Overview

The potential of space-based solar power (SBSP) as a resource to alleviate world energy needs has not been effective in obtaining the political support for a comprehensive program of evaluation and demonstration. An alternative approach is to emphasize the environmental benefits. Not fully understanding the stability of the Earth System and the specific feedback mechanisms controlling our climate, scientists are unable to effectively predict the course of change to the global environment. Geologic records show a potential rate of change that leaves civilization vulnerable to severe economic effects in a period of significant population growth.

Solar energy as an alternative to fossil fuel reduces stress on the Earth's environmental system. Cost of solar power, particularly from space, is not competitive with current prices of fossil fuels. Collecting the energy in space provides significant advantages in continuity of supply over terrestrial solar, but there is large initial cost prior to getting a return on the investment. The "Fresh Look at Space Solar Power" study shows that concepts needing less investment in an operational system may be feasible. Resources are needed to develop technology and to demonstrate practicality.

2. SBSP Concept Definition

The SBSP concept is to collect energy from the Sun in Earth orbit. The electrical energy is converted to microwave frequency for transmission to the surface of the Earth. There it is converted back in to electricity for use. Possible usages are base-load power, fuel conversion or direct delivery to consumers in isolated locations. The available potential of solar energy is greater than energy in petroleum reserves. The primary issue is defining the path to development of SBSP capability.

No scientific or technological breakthroughs are needed to develop SBSP. Certain technology may require demonstration such as microwave power transmission through the atmosphere. The primary questions relate to beam focus and efficiency. The challenge will to limit the cost of the required hardware. One of the requirements will be a minimum weight for the particular subsystems that make up the orbital system. This is directly related to the cost of launching the total mass into orbit.

Cheap, reliable access to space is a key issue in making SBSP economically viable. The mass to be deployed will mandate a reusable launch system. Trades of the number of stages will be needed to optimize the efficiency. One evaluation may be the air launch concept being developed by Burt Rutan. It enables the launch of the upper stages above much of the sensible atmosphere. This reduces aerodynamic loads, but may be limited by a reasonable takeoff weight.

Current assembly concepts have assumed construction in low earth orbit. After completion, the solar power satellite would be transferred to a higher orbit. Propulsion to accomplish this is a critical issue. One concept that has the specific impulse to make transfer practical is Variable Specific Impulse Magnetoplasma Rocket (VASIMR). NASA spinoff firm, the Ad Astra Rocket Company, has announced a key milestone in ground testing of its prototype plasma drive technology,

The VASIMR "helicon first stage" - which generates the plasma for acceleration by the rest of the drive has achieved its full rated power of 30 kilowatts using Argon propellant, according to the company. This paves the way for further trials in which the ion-cyclotron second stage will get to boost the helicon plasma stream to the target power of 200 kW.

The idea of the plasma drives is to use electric power to blast reaction mass (in this case Argon) from its rocket nozzles at a much higher speed than regular chemical rockets can achieve. This means that the carrying spacecraft gets a lot more acceleration from a given amount of fuel. A potential demonstration for VASIMR is maintaining the orbit of the international space station (ISS) without the need to burn large amounts of chemical rocket fuel. This serves as a demonstration of the transfer large structures between orbits.

Since the solar power satellite was studied in the late 1970’s there have been many advancements in subsystem technology. These advances have included (a) improvements in photo-voltaic efficiency from about 10% (1970s) to more than 40% (2007); (b) increases in robotics capabilities from simple teleoperated manipulators in a few degrees of freedom (1970s) to fully autonomous robotics with insect-class intelligence and 30-100 degrees of freedom (2007); (c) increases in the efficiency of solid-state devices from around 20% (1970s) to as much as 70%-90% (2007); (d) improvements in materials for structures from simple aluminum (1970s) to advanced composites including nanotechnology composites (2007); (e) the application to large space structures; (f) high temperature super-conductors and many other technologies may be integrated into the design.

Microwave beams are constant and conversion efficiencies high. They can be beamed at densities substantially lower than that of sunlight. This delivers more energy per area than terrestrial solar energy. The peak density of the beam can be significantly less than noon sunlight, and at the edge of the rectenna equivalent to the leakage of a microwave oven. This low energy density and choice of wavelength also means that biological effects are likely to be low. The safety of wild life wandering into the beam is not expected to be an issue.

The physics of electromagnetic energy beaming is uncompromising. The size of the antenna makes microwave beaming unsuitable as a “secret” weapon. The distance from the geostationary belt is so great that beams diverge beyond the coherence and power concentration needed for a weapon. The beam is likely to be designed to require a pilot beam transmitted from the rectenna site. Absent the pilot signal, the system can be programmed to go into an incoherent mode. Concerns may also be addressed through an inspection regime. The likelihood of the beam wandering over a city is extremely low. Even if it occurred, it would not be a hazard.

Wireless energy transfer by laser beam represents a different set of requirements. To achieve comparable efficiency, the beam must be more intense. The clouds in the atmosphere will reduce the transfer. The intense beam may produce a hazardous level to be avoided by aircraft and satellites. Still for the application to military power supply, it may be a manageable method.

At present, the United States has very limited capabilities to build large structures, very large aperture antennas or very high power systems in orbit. The capability to control and maneuver these systems in space must be developed and demonstrated. Presently, the ability to translate large mass between Earth orbits will be required for deployment SBSP. Eventually, the capability for in-space manufacturing and construction or in-situ space resource utilization may be developed, but at this point it is a challenge that should not be incorporated into the program. One critical item to be demonstrated is capability for beamed power and application to propulsion of large space systems.

The Thunderstorm Solar Power Satellite (TSPS) is a concept for interacting with thunderstorms to prevent formation of tornadoes. TSPS benefits are saving lives and reducing property. These benefits are not as sensitive to the system economics as the commercial solar power satellite and justify government investment in space solar power. The TSPS can develop and demonstrate the technology and operations critical to understanding the cost of space solar power. Consequently, there is no direct competition with fossil fuel based power supplies until SSP technology and operations have been demonstrated. Before weather modification can be safely attempted, the fine structure of thunderstorms must be simulated and related to tornadogenesis

3. Environmental Benefits

Advocates of space solar power have been presenting the concepts as a means to help meet world energy needs. This argument has not been effective in garnering support for even basic research and technology development. Fossil fuel alternatives have been too cheap and near term effect on the "economy" inhibits action by policy makers. Concern for the environment is greater than the policy makers realize.

The key to getting support for space solar power may be the growing awareness of the threat of rapid global environmental change. Scientists are extending their traditional role of theory and observation to emphasize the risks of global change. The risks provide the context for action by policy makers to move toward sustainable systems. The transition to power from space is responsive to the environmental concerns and the need to stabilize the Global environment and consequently the Earth's economic and social stability.

The "overview effect" from space has played a major role in developing a public sense of the fragile nature of the global environment. Stress on the Earth’s environmental system is increasing due to the buildup of carbon dioxide and other greenhouse gases. Models predicting the response to this buildup have not performed well in projecting the effect on the Earth’s climate because of the complexity of the system and the feed- backs within the system. Even the direction of climate change has not been predictable. An enhanced greenhouse effect has not been detected by temperature measurements. There may be interactions that are not well defined by the computer models, but that are reducing the stability of the Earth system. Because of the potential influence on the stability of the ocean currents that transport heat from the tropics to the higher latitudes, there is even a risk of returning the Earth to a glacial period rather than the global warming that is the present paradigm. Analysis of glacial ice cores indicates that such a shift can take place in less than a few decades.

The likely effects of rapid climate change are increases in storm intensities, flooding, droughts, regional cropping shifts and sea level rise. These effects will have severe social and economic consequences.

The rate of change and it’s direction leave civilization vulnerable to severe economic change in a period of significant population growth. Sustainable development has become the mantra for dealing with the potential global crises that are facing civilization. Clean, renewable energy is a resource that meets the criteria of sustainability. Collecting solar energy is prime candidate. Collecting the energy in space provides significant advantages in continuity of supply, although it’s development represents many challenges. A primary challenge is the issue of large initial cost prior to generating a return on that investment. The NASA Fresh Look at Space Solar Power study shows that concepts needing less initial investment are feasible. Even so, early SSP systems are not likely to be price competitive unless fossil fuel pricing incorporates the long range economic impact.

The risks identified through the rigor of the U. S. Global Change Research Program (USGCRP) must provide the motivation for action toward sustainable systems. The USGCRP is an integrated program documenting the Earth system, understanding Earth system processes and developing computer models to predict the course of changes induced by humans or as the result of natural variations. The program is beginning to analyze the environmental, socioeconomic and health consequences of global change. The obvious next step is to assess means for mitigation of the effects of global change.

The prosperity of future generations is dependent on a stable global environment. To ensure environmental stability, a continued effort to understand the effect of human activities must be a priority. Just understanding may not be sufficient because of the complex relationships of greenhouse gases, wind circulation, ocean currents and atmospheric water vapor. It is undisputed that carbon dioxide in the atmosphere has increased by over twenty percent since the beginning of the industrial age. Fossil fuels are certainly a major contributor to that increase. By replacing fossil fuel use, SSP could reduce the buildup of CO_2 in the atmosphere and the consequent climate changes from an enhanced greenhouse effect. There are economic returns from a space-based power source that will lead to commercial management and operation of the system.

There will continue to be an element of the political community that is committed to the short-term view because of the immediate economic impact. This reality is a factor that will have to be dealt with through facts and risk assessment for the long term view. The anticipated benefit to the Earth's environment is the overarching objective that may provide support for technology development and demonstration toward space solar power for use on Earth.

4. Summary

Space-Based Solar Power is a huge project. It might be considered comparable in scale to the national railroads, highway system, or electrification project rather than the Manhattan or Apollo endeavors. However, unlike such purely national projects, this project also has components that are analogous to the development of the high volume international civil aviation system. Such a large endeavor includes significant international and environmental implications. As such it would require a corresponding amount of political will to realize its benefits.

Most of America's spending in space does not provide any direct monetary revenue. SBSP will create new markets and produce new products. Great powers have historically succeeded by finding or inventing products and services not just to sell to themselves, but to sell to others. Today, investments in space are measured in billions of dollars. The energy market is trillions of dollars and will generate substantial new wealth for our nation and our world. Investments to develop SBSP have significant economic spin-offs. They open up or enable other new industries such as space industrial processes, space tourism, enhanced telecommunications, and use of off-world resources.

After the fundamental technological risks have been defined, shifting SBSP from a research and development project to a financial and production program is needed. Several major challenges will need to be overcome to make SBSP a reality, including the creation of low cost space access and a supporting infrastructure system on Earth and in space. The opportunity to export energy as the first marketable commodity from space will motivate commercial sector solutions to these challenges. The delivered commodity can be used for base load terrestrial electrical power, wide area broadcast power, carbon-neutral synthetic fuels production, military tactical support or as an in-space satellite energy utility.

Solving these space access and operations challenges for SBSP will in turn also open space for space tourism, manufacturing, lunar or asteroid resource utilization, and eventually expansion of human presence and permanent settlement within our solar system.

Space-based geoengineering concepts for environmental countermeasures are a potential supplement to earth-based actions. By defining options and benefits, SBSP may alert decision-makers to the potential of space operations as more than a tool to monitor the course of global change. Within the envelope of environmental protection is the preventing tornadoes concept. It promises early benefits by saving lives and reducing property damage. The principal payoff is projected to be the demonstration of space solar power technology and operations. This can lead to investment by the commercial energy organizations when their technical and operational risk is reduced. Once the potential for clean renewable energy from space is demonstrated, the way will be opened for further exploration and development of space.

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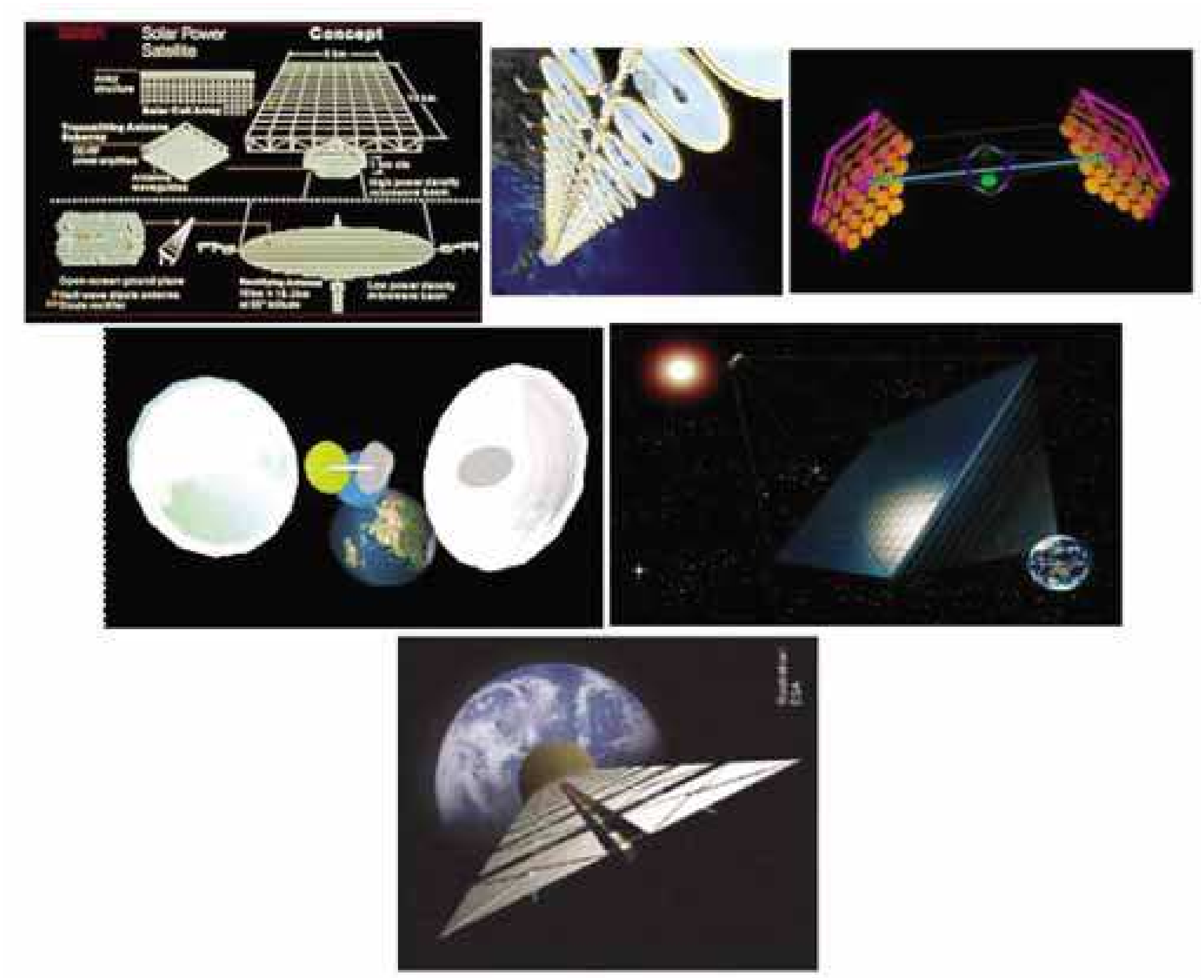

Fig. 1. Top left-NASA/DOE reference 5GW; top center-NASA Sun Tower 200MW; top right-Integrated Symmetrical Concentrator; center left-JAXA Free Flyer Model; center right-USEF Tethered SPS; bottom- ESA Sail Tower 400MW

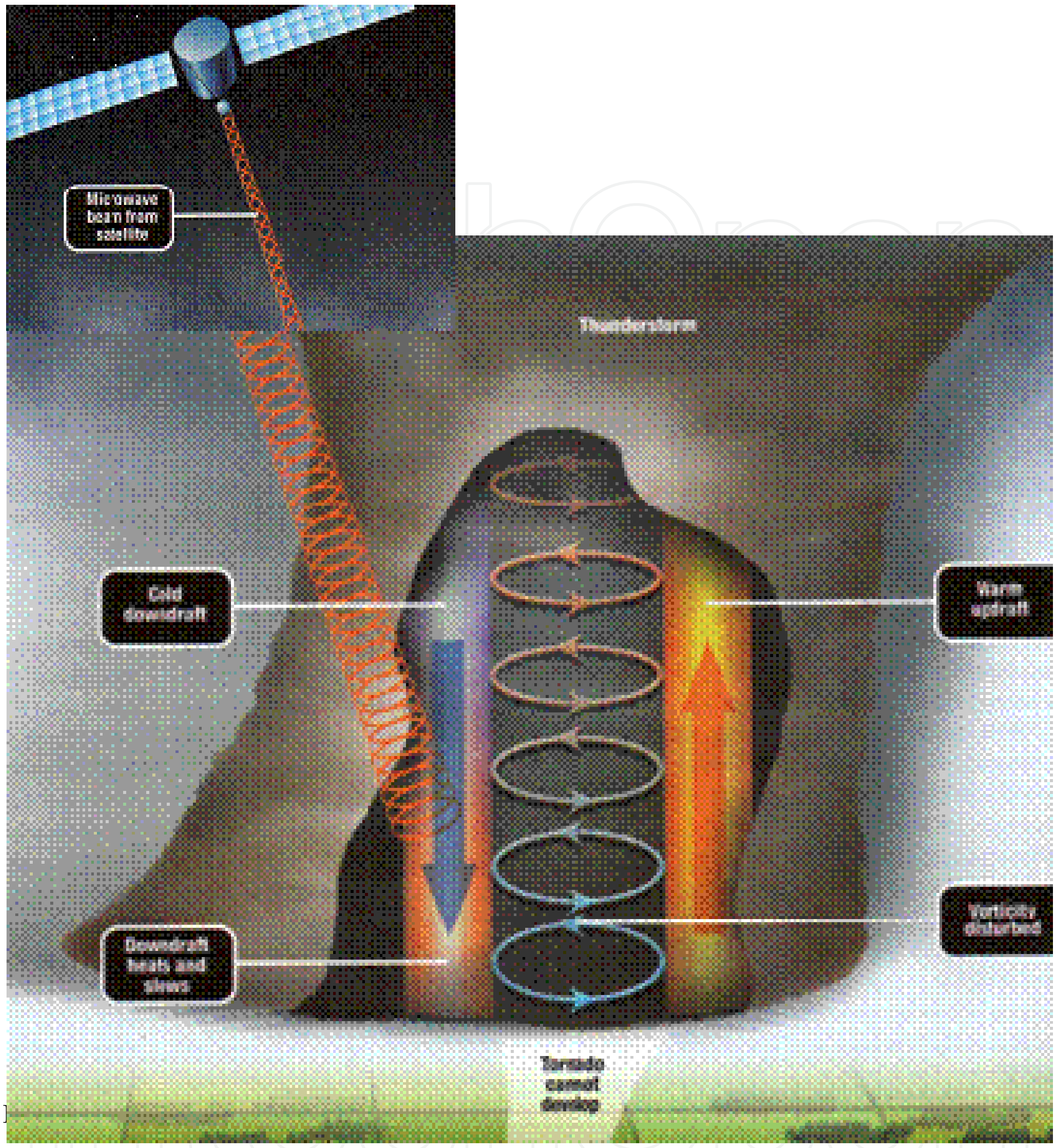

Fig. 2. Thunderstorm Solar Power Satellite Concept for preventing tornadoes.

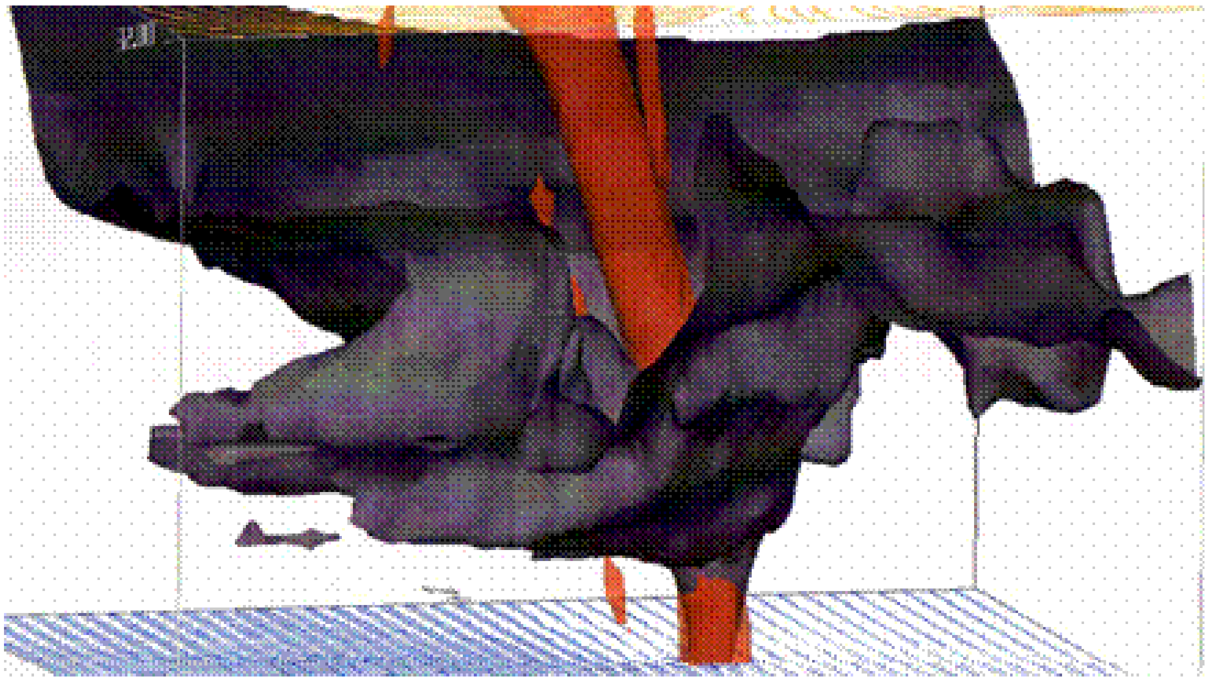

Fig. 3. Computer simulation of tornadogenesis.

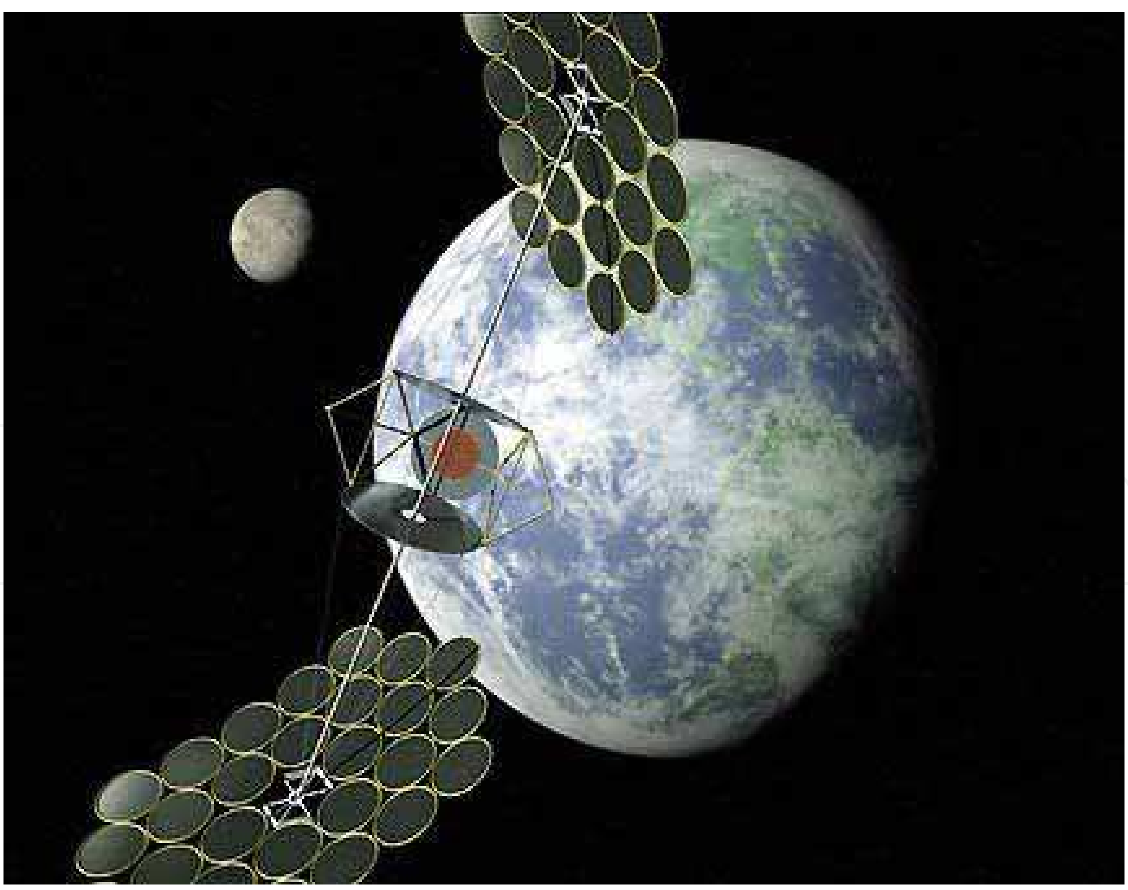

Fig. 4. SBSP concept.

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Renewable Energy is energy generated from natural resources-such as sunlight, wind, rain, tides and geothermal heat-which are naturally replenished. In 2008, about 18% of global final energy consumption came from renewables, with 13% coming from traditional biomass, such as wood burning. Hydroelectricity was the next largest renewable source, providing 3% (15% of global electricity generation), followed by solar hot water/heating, which contributed with 1.3%. Modern technologies, such as geothermal energy, wind power, solar power, and ocean energy together provided some 0.8% of final energy consumption. The book provides a forum for dissemination and exchange of up-to-date scientific information on theoretical, generic and applied areas of knowledge. The topics deal with new devices and circuits for energy systems, photovoltaic and solar thermal, wind energy systems, tidal and wave energy, fuel cell systems, bio energy and geo-energy, sustainable energy resources and systems, energy storage systems, energy market management and economics, off-grid isolated energy systems, energy in transportation systems, energy resources for portable electronics, intelligent energy power transmission, distribution and inter-connectors, energy efficient utilization, environmental issues, energy harvesting, nanotechnology in energy, policy issues on renewable energy, building design, power electronics in energy conversion, new materials for energy resources, and RF and magnetic field energy devices.