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Legal Challenges Facing Solar Power Satellites

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Abstract

This paper addresses some important legal elements that will be involved in implementation of solar power satellites drawing down energy from the sun, a process commonly called space-based solar power (SBSP). This paper outlines the advantages of SBSP and briefly reviews its history and limited development until today. The paper's important contribution is to describe the current regime of international space law. It explains specific ways international regulations help to create a supportive environment for launching, maintenance and removal of solar power satellites, while offering suggestions for future improvements to this regime.

The Context

To address the future energy needs of an expanding population there is a growing need to find clean reliable sources of energy. World population is expected to grow to 8.9 billion by 2050.[1] The world's energy demand is predicted to increase 44% by 2030.[2] In 2010, the U.S. Department of Energy estimated that non-renewable resources such as oil, natural gas, and coal were providing as much as 88% of the world's energy.[3] Ground-based solar, wind, hydropower, and other renewable energy options are currently in place, but provide less than ten percent of the world's power.[4] This percentage should grow but current renewable energy technology is limited and cannot provide enough power to match the growing need. Biomass plantations can produce carbon-neutral fuels for power plants or transportation, but photosynthesis has too low a power density for bio-fuels to contribute significantly to climate stabilization. Nuclear energy can supply power without emitting C02, but problems of waste disposal and weapons proliferation are well known.

There are new technologies being developed having the potential to contribute or even solve to the world's future energy needs.[5] These include fusion reactors, high-altitude wind farms, tidal energy and solar power satellites. These options should all be explored. This paper focuses on one of the most promising of all current options, space-based solar power (SBSP).

SBSP has the potential to fulfill our planet's growing energy needs in the coming centuries. The concept of SBSP is simple. Satellites are sent into space fitted with solar panels that can convert the sun's rays into electricity.[6] This electricity is transmitted via radio waves to one or more receivers on the planet's surface. Upon receipt, these power beams are then converted into alternating current that is compatible with the terrestrial power grid. Any company or country seeking to implement this technology will face certain technical and legal challenges.

Advantages of SBSP

A single solar power satellite can be designed to convey one gigawatt of continuous power to earth, enough to power 500,000 homes, also the equivalent of a large nuclear power plant.[7] Like a nuclear power plant, SBSP would do so without emitting any carbon dioxide into the atmosphere. Unlike a nuclear power plant, SBSP would do so without any radioactive waste by-product or danger of nuclear meltdown. Unlike ground-based solar installations, without the interference of the earth's atmosphere a solar power satellite positioned in space could collect 7-10 times the amount of power.[8]

The two conditions that set SBSP apart from other renewable energy sources are: 1) sun's rays that shine continuously on a solar power satellite and 2) sun's power that can be supplied continuously without interruption.[9] Solar power satellites can transmit their beams to almost anywhere in the world.[10]

Ground-based solar power requires an energy storage system for supplying power when the sun is blocked by bad weather or during the night, which adds to its cost and decreases its efficiency. Wind power is often available only from remote or offshore locations.[11] Even countries with minimal energy infrastructure or people located in remote areas would be able to install receivers to get a continuous power supply from appropriately positioned solar power satellites in space.

The base technology of SBSP is already proven. In 2008, SBSP had a milestone breakthrough.[12] American and Japanese researchers, in only four months and on a budget of only $1 million, successfully transmitted a microwave beam 148 kilometers between two Hawaiian Islands. The distance was chosen because of its equivalence to the thickness of the atmosphere that a microwave beam from space must penetrate to reach the planet's surface.[13] This experiment was significant because it proved that power transmission over large distances at high efficiency rates is possible.

Also, since 1977, the efficiency of solar cells has increased from around 10% to over 40%. The efficiency of solid-state amplifiers has increased from 20% to 80%. Solar power satellites using these new technologies should weigh around 25 tons, much smaller than the 250 ton satellites originally contemplated by Dr. Peter E. Glaser, the scientist who introduced the SBSP concept.[14] Dr. Glaser's 1960's proposal required hundreds of astronauts in space to build solar power satellites.[15] This is no longer the case as advances in computing and robotics will now allow satellites to be self-assembling made up of many small parts. More time and research will help to lower the initial cost and improve efficiency to the scale needed for SBSP implementation, but no new breakthrough discovery or invention is thought to be necessary.

Public health and safety issues with microwave use have been examined extensively. Microwaves used in space solar power have no ionizing effect and there is no danger of cancer or genetic alterations due to microwave radiation.[16] The potential danger of microwaves, like energy from the sun and from artificially light sources, relates directly to the energy's density in a given area. The design of SBSP systems calls for power densities well within safe limits at the planet's surface. For example, the average power density of the sun's rays is about 100 mW/cm2 while the design maximum of satellite solar power systems is 25 mW/cm2 on the planet's surface.[17] Even high flying birds would still remain well within safe limits.[18] Scientist should still plan further safety studies, a necessary precaution for technology on this scale.

Historical Perspective

NASA Studies:Dr. Peter E. Glaser, a NASA consultant, first proposed the idea of SBSP in 1968.[19] His proposal, to launch giant satellites for the purposes of beaming power to the earth from space, seemed extremely unconventional at the time. Various subsequent studies showed its promise, however, including a $19 million 1976-1980 study conducted by the U.S. Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA).[20] The study concluded that no insurmountable technological hurdles stood in the way of solar power satellites as a major alternative energy source. However, the study also estimated that creation of operational SBSP would require several decades with a cost-to-first power at over $280 billion.[21] The study recommended the issue be revisited in ten years to allow technology to catch up and potential costs to decrease.[22] As a result, all serious effort on solar power from space by the U.S. government ceased until the mid-1990s.

The U.S. government revisited the idea of SBSP in 1997 when NASA's "Fresh Look Study"[23] sought to determine whether recent technological advances could deliver SBSP to terrestrial markets at competitive prices. The study found that a huge global market had developed and concerns about greenhouse gas emission were growing. It also found that technological innovations had increased the potential for space-based solutions.

NASA followed the initial positive results of the "Fresh Look Study" by initiating the Space Solar Power Exploratory Research and Technology program in 1999. The SERT program concluded that SBSP no longer required an unimaginably large initial investment before gaining returns.[24] The SERT program also concluded that SBSP possessed many significant environmental advantages when compared to alternative approaches.[25] However, despite SERT program findings and a history of numerous studies, NASA did not commit substantial funds to the development of SBSP. Eventually budget constraints lead NASA to shut down its SBSP research in 2001.[26]

National Security: The most recent study of SBSP occurred in 2007 when the National Security Space Office (NSSO), a division of the Department of Defense (DoD), conducted its own study on the feasibility of SBSP.[27] The NSSO study requested input from numerous experts in the science and solar power community and with their help made a number of key findings. The NSSO study concluded SBSP presented a strategic opportunity that could significantly advance U.S. and partner security, capability, and freedom of action. Most studies up to that point only focused on SBSP as a solution to the power needs of the global community at large. The NSSO study added an additional layer emphasizing the advantages SBSP could offer the U.S. military.

The study concluded that ". . . SBSP and its enabling wireless power transmission technology could facilitate extremely flexible 'energy on demand' for combat units and installations across an entire theater, while significantly reducing dependence on vulnerable over-land fuel deliveries… SBSP could provide the ability to deliver rapid and sustainable humanitarian energy to a disaster area or to a local population undergoing nation-building activities… Perhaps the greatest military benefit of SBSP is to lessen the chances of conflict due to energy scarcity by providing access to a strategically secure energy supply.[28]

Military Interest: The U.S. military was spending over $1 per kilowatt hour for electrical power delivered to troops in forward military positions due to transportation and security costs. This estimate of cost does not include the significant numbers of soldiers killed or injured protecting supply convoys. Unlike the public sector where SBSP would need to cost as low as 8-10 cents per kilowatt to be a viable energy option, for military purposes SBSP could still be viable at a cost closer to $1 per kilowatt .[29]

The NSSO Study proposed that DoD partner with private companies and foreign allies in creating a test model for SBSP. The DoD would agree to be an anchor tenant customer for the initial SBSP systems. The DoD's high energy supply costs could justify the high initial implementation cost of SBSP. Energy companies working with the DoD could also begin to supply SBSP to the public sector as the costs of SBSP lower over time.

Nations and Corporations: While the U.S. government has yet to fully commit to SBSP development, another country and several of its private companies have done so. Japan's Aerospace Exploration Agency (JAXA) has committed to developing SBSP and plans to place a one gigawatt solar power satellite in geostationary orbit by 2030.[30] JAXA hopes to have a working 1-2 megawatt prototype within 10 years. In JAXA's advanced mission research center, some 180 scientists are already working on the scheme. JAXA is willing to develop the technology on its own but believes the ideal arrangement would be to work together with NASA and the European Space Agency.

A few private companies have emerged with the goal of developing viable business plans for SBSP. Space Energy, Inc., a pioneer in commercial SBSP, plans to a have a test satellite in orbit in approximately 10 years.[31] Space Energy, Inc. understands that building a satellite to demonstrate the feasibility of the technology is only the beginning. Peter Sage of Space Energy, Inc. recently stated in an interview, “Once we’ve demonstrated that we can wirelessly beam power accurately to the ground…we will have taken a massive step forward to prove SBSP is a technology of the future that has the potential to really fill a gap in the world’s energy needs.”[32]

Another SBSP company, Solaren, recently signed a power purchase agreement with Pacific Gas & Electric to provide the California-based utility with 200 megawatts of electricity over 15 years beginning in 2016. [33] The Space Island Group says it wants to employ technologies already in use by NASA to build orbiting space stations out of empty fuel tanks discarded by space shuttles as they reach orbit.[34] Space Island’s plan is to rent out these converted fuel tanks for space tourist applications, using the proceeds to finance the startup costs for a large solar powered satellite. Were Space Energy, Solaren, Space Island, or any of their competitors to be successful in creating the first working prototype, they can expect large returns and many more competitors to follow.

Technical and Financial Challenges

The biggest challenge for the potential SBSP operator is the high launch costs of getting its satellites into space. At the current rate, the cost of launching payloads into low-earth orbit is $6,000 to $10,000 per kilogram.[35] At that rate, SBSP start-ups would well exceed the cost of coal powered electricity produced at 8-10 cents per kilowatt. With current technology, to supply power at 8-10 cents per kilowatt, launch costs would need to fall as low as $440 per kilogram. As the private space industry expands, costs are expected to fall significantly in the coming decades.[36] Virgin Galactic, founded by Sir Richard Branson, and SpaceX, founded by Elon Musk, are two such companies working to lower the cost of space travel.

SpaceX’s Falcon 1 rocket successfully reached orbit for the first time in Sept. 2008. The company is developing a much larger rocket, Falcon 9, which will be capable of carrying payloads up to 12 tons into orbit. Mr. Musk estimates the Falcon 9 could bring the launch costs down to $3,000 per kilogram, and with reuse of each launcher eventually down to $1,000 per kilogram.[37]

High initial launch costs could also be alleviated if they were shared amongst a larger group of participants joined by their interest in creating SBSP. Were NASA, ESA, and JAXA to work together, the initial startup costs of SBSP could be distributed and would not place as great a burden on the individual parties. Such cooperation is not unprecedented. The International Space Station, a joint effort of 16 countries, has cost the U.S. and its partners over $100 billion over the past 15 years.[38] A similar effort, for a price tag closer to $10 billion, could see the development of the first prototype of SBSP.[39] If JAXA, or a private company, is able to complete the first working prototype, the argument for SBSP will become even stronger. Prohibitive launch costs remain the number one technical and financial barrier to SBSP though it seems this problem will diminish over time.

A matter of near-equal importance in the eventual realization of SBSP, will be improving the international legal framework governing space law.

Space Law

Solar power satellites automatically raise questions concerning the currently applicable international law, and which laws and processes may need to be in place to accommodate the special requirements of SunSats. These questions include coordination and registration of space objects, property rights in space, rights of private parties, liability for damage, and environmental protection. The general framework to answer these questions already exists, but further development will be needed. The United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) has led the development of this legal framework. Presently there are three treaties relating to outer space significant to SBSP.

The first and most important is the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space (Outer Space Treaty).[40] Second is the Convention on International Liability for Damage Caused by Space Objects (Liability Convention).[41] Third is the Convention on Registration of Objects Launched into Outer Space (Registration Convention).[42]

Outer Space Treaty: The Outer Space Treaty has been accepted and ratified by over 100 countries including all current space faring nations. Ratified in 1967, the Outer Space Treaty created the fundamental base of outer space law under the idea that outer space is the common heritage of mankind. [43] Thus, the exploration and use of outer space shall be free for exploration and use by all states. Article II states outer space, including the moon and other celestial bodies, is not subject to national appropriation by any means. Even for countries that currently lack the resources to reach outer space, the right of exploration and use remains available to them as they become capable of space exploration.

Under Article VII, though a state cannot claim ownership to outer space or any celestial bodies within, a state on whose registry launches an object into outer space retains jurisdiction and control over that object. The ownership of such objects in outer space is also not affected by their presence in outer space or by their return to earth. Thus, countries or companies that launch satellites on their state's registry retain ownership of those satellites. If no such ownership interest existed, there would be no incentive to send a satellite into space that could be appropriated by another country or private party.

The Outer Space Treaty addresses actions taken by states. It does, however, contemplate the actions of private companies in two sections. First, in article VI, parties to the treaty agree to bear international responsibility for their national activities in outer space, whether those activities are carried out by governmental agencies or by non-governmental entities. Second, article IX requires states and their nationals are required to seek international consultation in circumstance that could cause harm to other states. Though space exploration in 1968 was dominated by states, the Outer Space Treaty still contemplated private companies joining the states in space travel.

For the purposes of SBSP, the Outer Space Treaty contains several other key provisions. Article V of the Outer Space Treaty specifically prohibits the placement of any objects in space carrying nuclear weapons or weapons of mass destruction. Further, testing of any military weapons is strictly forbidden. An example might be an attempt to transform a solar power satellite into a death ray using microwaves or laser beams.[44] Such an action would be in strict violation of the Outer Space Treaty.

Article XII of the Outer Space Treaty requires that any station, installation or equipment on the moon, asteroid or other celestial body must be open to inspection on a basis of reciprocity. This provision, though limited to objects on celestial bodies, allows countries to ensure that others are within the terms of the treaty. The Outer Space treaty answers questions concerning the right of private ownership and the role of private companies in outer space. The following two treaties answer questions relating to liability and registration of objects in space.

The Liability Convention: Ratified in 1972, the Liability Convention helped clarify the liability of states and private parties for damage in space. The guidelines, under article II, that affirmed that launching states will be absolutely liable for damage caused by their space objects on the surface of the Earth and to aircraft in flight have now been approved and ratified by 91 countries including all current space faring nations.

Under article II, for damage occurring to objects in outer space, the party causing the damage will only be liable only if the damage is due to its fault or the fault of persons for whom it is responsible. Article VII of the Liability Convention specifically excludes nationals of a launching state from liability for damage caused.

Countries have to create their own laws regulating private companies to protect themselves in the case that a company causes damage. If such regulations are not created, it could discourage a country from allowing a private company to go to space for fear of international liability. The U.S. and Japan offer two similar but significant solutions to this problem.

The U.S. passed the Commercial Space Launch Act of 2004 granting the Federal Aviation Administration the authority to regulate commercial space flights with the interest of promoting private space development while shielding itself from liability.[45] Prior to launching an object into space, a private company has to apply for a license from the FAA.[46] The CSLA requires all license applicants to demonstrate financial responsibility through liability insurance or independent means. The U.S. requires evidence of insurance to compensate another party for damages or itself for losses stemming from an activity carried out under the license.[47]

In the U.S., a licensee is required to obtain sufficient insurance to cover maximum probable loss, but the total amount of insurance need not exceed $500 million.[48] If the damage exceeds $500 million, the U.S. will cover the remainder up to $1.5 billion but only "to the extent provided in an appropriation [bill]."[49] Thus, anything over $1.5 billion would need to be covered by the company. If not enough money is allocated in an appropriations bill the company will be liable for all damages.

It is important to note the CSLA does not require insurance for loss of the private company's property, only for liability of damage caused to another. However, CSLA helps to protect the U.S. from liability from private accidents, while still giving private companies a potential cushion from liability in the case of damages exceeding $500 million. The CSLA helps resolve the potential liability problem of private companies seeking to launch commercial spacecraft.

Japan has taken a similar approach but its law seems friendlier to private companies. As in the U.S., private companies have to secure liability insurance for an amount determined by the government.[50] Unlike the U.S., the government average liability insurance requirement is around $200 million.[51] More importantly, the Japanese government will cover any amount over the liability insurance without limit.[52] Though Japan protects itself from potential liability, it makes it easier for private companies to enter into space.

As for solar power satellites, countries should continue to develop laws encouraging commercial space companies to enter this market. Commercial space companies can help reduce development costs while bringing fresh ideas to the marketplace. Countries could further incentivize commercial space companies to develop SBSP applications by lowering or eliminating a company's liability in exchange for the company's help.

The Liability Convention could be improved by further clarifying when a party would be liable to another for damages. For example, the Liability Convention fails to define the term "fault" in the context of liability for damage caused in outer space. Because fault is not well defined it is difficult for countries or companies to determine when another party is at fault for damage to their property in space. A narrow definition of fault could see a country escape liability for damage caused in space, when liability could have been found under a broader definition. This could be especially troubling for a company that invests billions of dollars into SBSP only to have its satellite destroyed by space debris left behind by an old satellite.

The U.N. and member states should work to clarify more precisely the meaning of “fault” so that countries and companies will be able to more easily predict their potential liability. Thus, the international regime should continue to develop the framework used to determine liability for damages to protect the property and investments of countries and companies around the world. This could include requiring countries to cleanup after broken satellites and retrieve satellites that have been decommissioned, or face strict liability for the damages they caused. Steps could also be taken to improve dispute mechanisms between countries and the assessing of penalties on those refusing to pay proper judgments. Penalties for refusal to pay for damages could help ensure compliance for damage awards, incentivizing countries and companies to promote safe practices, while lowering the risk of catastrophic losses.

The Registration Convention: As more satellites entered orbits around the Earth, the U.N. and its members recognized the necessity of registering all space objects in a single registry to help prevent accidental collisions in space. This Convention has been approved and ratified by 53 countries, including all current space faring nations. Ratified in 1974, the Registration Convention, under article II, requires all countries to create and maintain a registry of all objects they or their nationals have launched into space. Article IV then requires countries to give this information to the U.N., including the objects’ orbital parameters, from which the U.N. builds its global registry. Countries can then consult with the registry to ensure future satellites will not interfere with current ones. Private companies seeking to send up a satellite are expected to consult with their country registries to ensure the vehicle is noted domestically and that that information is submitted to the U.N.

Though the U.N. maintains a general registry, as more satellites are sent into space a simple registry may not be sufficient. The international regime will likely need to develop a mechanism for space traffic control with the ability to track satellites in orbit and the authority to assign orbital slots equitably, while establishing transit corridors for new satellites to safely reach orbit. Without such, space travel could become more dangerous. An increase in the frequency of collisions could also add to the costs and threaten the security of solar power satellites.

Environmental Concerns

Space debris is the largest environmental problem for satellites in outer space. There are over 19,000 pieces of trackable debris in Earth orbit; the number of un-trackable pieces is much higher.[53] Collisions with even small orbital debris can cause catastrophic damage. The global community has taken steps to deal with this growing problem. The Inter-agency Space Debris Coordination Committee (IADC) is one of the most important international sources of space debris policy. Domestically, the U.S. also has its own standards to control space debris. These standards offer initial guidance but further improvements will be needed to fully address this problem.

The IADC is an international organization, made up of all major space faring countries, responsible for proposing solutions and researching problems posed by space debris. It has created guidelines to help minimize debris-creating events and avoid debris-caused hazards. The guidelines are not binding, however states can use these guidelines to formulate their own mitigation standards. The IADC guidelines focus mainly on mitigation measures for spacecraft operators. These include limiting debris released during normal operations, minimizing the potential for orbital break-ups, refraining from intentionally destroying space objects, and prevention of on-orbit collisions.[54]

The Orbital Debris Mitigation Standard Practices (Standard Practices) of the U.S. Government incorporates guidelines offered by the IADC while adding its own provisions. Like the IADC guidelines, the Standard Practices seek to avoid releasing debris during normal operations, especially debris larger than 5mm that will remain in orbit over 25 years.[55] The Standard Practices also offer guidelines for post mission disposal of space structures including:

1. Atmospheric reentry: for objects in LEO, where atmospheric drag should limit the lifetime of the object to no longer than 25 years;
2. Maneuvering the device to a storage orbit: structures would be moved or have the capability of moving themselves to different "storage" orbital levels; or
3. Direct Retrieval: retrieving and removing the structure from orbit after completion of its mission.[56]

Such guidelines as Standard Practices can help lessen the problem of orbital debris but it is not clear that private actors or states will have the necessary incentives to follow them. Were domestic and international standards made legally binding it would better ensure compliance by both public and private entities. As space transport technologies improve, the methods for preventing and retrieving orbital debris should improve as well. States should also continue developing their ability to track orbital debris. With better data, states should also work toward creating a global database for orbital debris, as proposed by COPOUS. Such a database would help prevent possible collisions and promote a heightened understanding of the orbital debris problem.

Conclusion:

Space energy is not the only option for solving the world's future energy needs, but it is one of the most promising. The idea of satellites sending clean continuous power from the sun may still sound like science fiction, but many of today's technological marvels had a similar history. The realization of solar power satellites will not happen overnight; in fact it has been an idea over 40 years in the making. Launch costs need to be lowered. The international legal regime needs further development to accommodate to space solar power implementation. SBSP will require substantial international between and among countries and their private companies. All are difficult challenges but will be rewarded with a worthy prize.

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