Chapter 5
How Will Sunsat Power Be Captured on Earth?

Abstract This chapter addresses both potential opportunities and expressed concerns relating to wireless transmission of space solar energy to Earth in baseload and related electrical power applications. Safety protections associated with the design, location and redistribution of energy on the ground are also discussed.

Future Prospects

A small group of students and faculty at the Georgia Institute of Technology is framing a "space power grid" architecture that will position solar installations in orbit around the globe as a means of exchanging power between terrestrial power plants located in different parts of the world. Building on the revenue from this market, the intent is to then proceed in the construction of the large space power stations that can generate solar electric power for all nations.

This approach, they say, will set up an evolutionary, low-risk, revenue-generating path to "realize the global dream of space solar power." The strategy is incremental, concentrating on helping terrestrial power plants become viable, and then working to align public policy priorities with the goal of a sustainable supply of energy from space.

The team's focus is to help establish a working relationship between the space and energy industries of India and the United States. "Much of humanity today does not enjoy the $0.10/kWhe, uninterrupted delivery of electric power that is taken for granted in urban industrialized societies," the group from Georgia Tech wrote in a paper they presented to the Solar Power Symposium of the 2011 International Space Development Conference held in Huntsville, Alabama (Dessanti et al. 2011, p. 1).

"In regions that are not wired for power, residents pay exorbitant costs for a few watts or watt-hours and suffer lack of basic amenities and opportunities. Thus the first point to make is that competing with the efficient, reliable terrestrial utility and power grid is not the principal purpose of a space-based electric power resource."

D.M. Flournoy, *Solar Power Satellites*, SpringerBriefs in Space Development,
DOI 10.1007/978-1-4614-2000-2_5,

"The ability to reach all parts of the world at any time is a very significant characteristic, beyond being worth a high price. On the other hand, it is entirely possible that the price commanded by terrestrial utilities will keep rising beyond the level where we can make SSP viable even in this market" (Dessanti et al. 2011, p. 1).

Narayanan Komerath, professor at the Daniel Guggenheim School of Aerospace Engineering at Georgia Tech, has been engaged with the idea of a global space power grid since 2006. In a personal communication he wrote, "The notion of exchanging terrestrial power through space is still a complex one for most people to digest, but that is because they are not used to the idea that collaborating with the terrestrial energy community is smarter than trying to articulate why the government should choose one over the other." He thinks a U.S.-India space-based power exchange demonstration would constitute a rational first step toward establishing a space-based power grid to complement and interconnect power grids on the ground (Komerath 2011, Space power grid, personal communication to the author, 19 May 2011).

In the paper, the group anticipates that building an orbiting solar power production and exchange system will enable "a real-time power exchange through space to help locate new plants at ideal but remote sites, smooth supply fluctuations, reach high-valued markets, and achieve baseload status.

"Demand for power can vary with the time of day or the season of the year. The amount of electricity consumed on a hot summer evening can be 2–3 times greater than the amount consumed in the middle of the night during temperate weather. Because wind and terrestrial solar power sources are intermittent, auxiliary generators, which are expensive and fossil-burning, are needed at these plants to guarantee a steady baseload power flow. One advantage of nuclear power plants is that they can reliably meet baseload demand. Once these plants are up and running, they can be expected to supply consistent levels of energy 24/7, and they usually achieve nearly 90% or more of their rated power output year-round, compared to only 30–50% for wind and solar power farms" (Dessanti et al. 2011).

The Georgia Institute of Technology proposal takes a 50-year perspective, foreseeing a constellation of power-generating satellites capable of converting sunlight into as much as 4 terawatts of usable energy. This energy will be beamed to widely dispersed wholesale and retail markets on the ground. The first step toward this type of space power grid, according to the team, is a U.S.-India space-based power exchange demonstration that provides baseload energy across national boundaries. Two possible approaches to the first constellation achieving a near-24-h power exchange demo across countries are (1) four to six satellites at 5,500 km near-equatorial orbits, with ground stations in the United States, India, Australia and Egypt and (2) six satellites in 5,500 km orbits, with ground stations only in the United States and India.

"We argue for a strategy where SSP helps, rather than competes with, terrestrial renewable energy initiatives, as a way to establish the technology and the infrastructure to exchange power between markets."

"In other words, space is a venue for power exchange rather than just generation, and as such we call our architecture the Space Power Grid (SPG). This approach

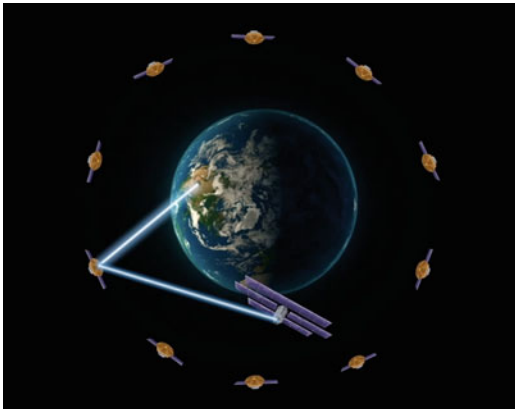

Fig. 5.1 Artistic conception of a network of reflector satellites in equatorial orbit, relaying energy from a power sats in a Sun-synchronous orbit (Lightbourne 2011)

will also buy time to develop the best technological options for the gw-level SSP satellites that will replace the first-generation relay satellites. [Such a strategy] can lead to an economically viable infrastructure with a continuing revenue stream. This will help develop the massive satellites needed to expand SSP to the 4 terawatt level of today's fossil-based primary power supply" (Dessanti et al. 2011) (Fig. 5.1).

Historical Perspective

The scale and the potential impact of solar power satellite designs are much greater in 2011 than they were when the U.S. House Committee on Science and Technology asked for a study of the concept in 1978.

Responding to interest by NASA and the newly created Department of Energy, the House Committee sent a letter to the U.S. Office of Technology Assessment (OTA), asking that it undertake an independent look at "the potential of the SPS system as an alternative source of energy" and to assess its benefits and drawbacks as an energy system (Gibbons 1981, p. 18).

That report, entitled "Solar Power Satellites," was filed in August 1981. John Gibbons served as chair of the SPS Study Committee consisting of a distinguished advisory panel that included Peter G. Glaser, the widely acknowledged author of the concept.

The OTA Study Committee spent more than 2 years evaluating the prospects for solar power satellites. In a final summary, it wrote, "Along with other electric-generating technologies, SPS has the potential to supply several hundred gigawatts of baseload electrical power to the U.S. grid by the mid-twenty-first century. However, the ultimate need for SPS and its rate of development will depend on the rate of increase in demand for electricity, and the ability of other energy supply options to meet ultimate demand more competitively. SPS would be needed most if coal and/or conventional nuclear options are constrained and if demand for electricity is high."

The OTA study concluded, “SPS has potential for supplying a portion of U.S. electrical needs, but current knowledge about SPS, whether technical, environmental, or sociopolitical is still too tentative or uncertain to decide whether SPS would be a wise investment of the nation’s resources” (Gibbons 1981, p. 55).

Public Policy Concerns

In the process of carrying out its research and deliberations, the OTA conducted an assessment of the potential environmental and human impacts of solar power satellites. This was perhaps the most thorough examination of such public policy issues as environment and health risks, land-use and receiver siting and military implications ever to have been done. It is because so many of the issues raised by the OTA study are the big “social impact” issues of today—many of which have yet to be fully addressed—that the author has chosen to highlight and quote at length from this 30-year-old source.[1]

Environment and Health

The OTA study reported, “Many of the environmental impacts associated with SPS are comparable in nature and magnitude to those resulting from other large-scale terrestrial energy technologies. A possible exception is coal, particularly if CO_2 concerns are proven justified. While these effects have not been quantified adequately, it is thought that conventional corrective measures could be prescribed to minimize their impacts” (Gibbons 1981, p. 10).

The study identified several health and environmental effects thought to be unique to SPS but whose severity and likelihood were uncertain. These included effects on the upper atmosphere from launch effluents and power transmission, human health hazards associated with non-ionizing radiation, radiation exposure for space workers and electromagnetic interference with other systems and with astronomy.

The authors understood that more research in these areas was needed before decisions about the deployment or development of SPS could be made, noting, “Little information is currently available on the environmental impacts of SPS designs other than the reference system. Clearly, environmental assessments of the alternative systems will be needed if choices are to be made between SPS designs” (Gibbons 1981, p. 11). “Reference system” refers to NASA’s solar power satellite designs developed prior to the OTA study.

[1] In this section on early social concerns, the author trusts readers will see the value of an approach in which more questions are raised than solutions given when first introducing new and untested technologies. Current day research and expert opinion on most of these topics are addressed in Chap. 9.

The study team acknowledged that too little was known about the biological effects of long-term exposure to low-level microwave radiation to assess the health risks associated with SPS microwave systems. "The information that is available is incomplete and not directly relevant to SPS. Further research is critically needed in order to set human-health exposure limits. Currently, no microwave population exposure standard exists in the United States" (Gibbons 1981, p. 11).

The report continues, "More stringent microwave standards could increase land requirements and system cost or alter system design and feasibility. In light of the widespread proliferation of electromagnetic devices and the current controversy surrounding the use of microwave technologies, it is clear that increased understanding of the effects of microwaves on living things is vitally needed even if SPS is never deployed."

There was concern related to the bio-effects of exposure to SPS power transmission and high voltage transmission lines on humans, animals and plants. "While the thermal effects of microwave radiation (i.e., heating) are well understood, research is critically needed to study the consequences of chronic exposure to low-level microwaves such as might be experienced by workers or the public outside of the receiver site."

"For SPS systems other than the microwave designs," the study leaders observed, "very little assessment of the health and safety effects has been conducted. The power density of a focused laser system beam could be sufficiently great to incinerate some biological matter. Outside the beam, scattered laser light could constitute an ocular and skin hazard." More study would be needed to quantify risks, define possible safety measures and explore the effects of long-term exposure to low-level laser light.

> The light delivered to Earth by the mirror system, even in combination with the ambient daylight, would never exceed that in the desert at high noon. The health impacts that might be adverse include psychological and physiological effects of 24-h-per-day sunlight and possible ocular damage from viewing the mirrors, especially through binoculars (Gibbons 1981, pp. 45–46).

Upper Atmosphere Effects

"Atmospheric effects result from two sources: heating by the power transmission beam and the emission of launch vehicle effluents. While the most significant effect of the laser and mirror systems is probably weather modification due to tropospheric heating, ionospheric heating is most important for the microwave systems operating at 2.45 GHz. Of most concern is disruption of telecommunications and surveillance systems from perturbations of the ionosphere" (Gibbons 1981, p. 45). The report explains further:

> Experiments indicate that the effects on telecommunications of heating the lower ionosphere are negligible for the systems tested.
>
> The injection of rocket exhaust, particularly water vapor, into the ionosphere could lead to the depletion of large areas of the ionosphere. These "ionospheric holes" could degrade telecommunications systems that rely on the ionosphere. While the uncertainties are greatest for the lower ionosphere, experiments are needed to test more adequately telecommunications impacts and to improve our theoretical understanding of chemical-electrical interactions throughout the ionosphere.

In the troposphere, ground clouds generated during liftoff could modify local weather and air quality on a short-term basis. Additional experiments and improved atmospheric theory are needed to understand and quantify the above impacts under SPS conditions. In addition, mitigating steps such as trajectory control, alternate space vehicle design, and the mining of lunar materials need to be assessed. Atmospheric studies would play a major role in the choice of frequency for power transmission (Gibbons 1981, p. 45).

Land Use

The OTA study noted, "Receiver siting could be a major issue for each of the land-based SPS systems. Offshore siting and multiple use siting might each alleviate some of the difficulties associated with dedicated land-based receivers, but require further study. There are two components to the siting issue: technical and political. Tradeoffs must be made between a number of technical criteria:

- Finding geographically and meteorologically suitable areas.
- Finding sparsely populated areas.
- Keeping down the cost of power transmission lines and transportation to the construction site.
- Siting as close to the equator as possible (for GEO systems) so as to keep the north–south dimension of the receiver reasonably small.
- Coordinating receiver sites with utility grids and the regional need for electricity.
- The cost of land.
- Ensuring that the receivers are sited away from critical and sensitive facilities that might suffer from electromagnetic interference from SPS, e.g., military, communications, and nuclear power installations" (Gibbons 1981, p. 46).

It is clear that the choice of frequency, ionospheric heating limits, and radiation standards could have an impact on the land requirements. Further study is needed to understand fully the environmental and economic impacts of a receiver system on candidate sites and to determine if enough sites can be located to satisfy the technical requirements (Gibbons 1981, p. 46).

The earlier NASA technical (reference) designs had suggested the need for large contiguous plots of land dedicated to one use. The study's authors note that laser options might require less land area per site, but a greater number of sites to deliver the comparable amount of power.

The plausibility of multiple uses (e.g., agriculture or aquaculture), offshore siting (especially for such land-scarce areas as the northeastern United States, Europe and Japan) and possible receiver siting in other nations, with their particular environmental constraints, also need to be explored.

The report concluded that the regional political problems may be more severe than the technical ones, especially in light of past controversies over the siting of power plants, power lines, and military radar and other facilities. Although the construction and operation of receivers might be welcomed by some communities on the basis of economic benefit, others might oppose nearby receiver siting for a number of reasons, including: environmental, health and safety risks; fear that the receiver would be a target for nuclear attack; fear of decreased land values; preference for an alternate use of the land; objection to the receiver's visibility; and, for rural Americans, resistance to the intrusion of urban life (Gibbons 1981, p. 46).

Space Communications

An assumption of the writers of the OTA report was that all artificial Earth satellites would be using some portion of the electromagnetic spectrum for communication. Some would also use spectrum for remote sensing. All would be affected in one way or another by SPS (Gibbons 1981, p. 48).

Study members thought that geosynchronous satellites would be most strongly affected by the microwave systems, experiencing interference from noise at the 2.45 GHz frequency suggested in the reference design. "All radio frequency transmitters generate such noise and receivers are designed to filter out unwanted effects. However, the magnitude of the power level at the central frequency and in harmonic frequencies for a microwave SPS is so great that the possibility of degrading the performance of satellite receivers and transmitters from these spurious effects is high." The study continues:

> In addition to the direct effects from microwave power transmissions, geosynchronous satellites could also experience "multipath interference" from geostationary power satellites due to their sheer size. In this effect, microwave signals traveling in a straight line between (GEO) communications satellites would experience interference from the same signal reflected from the surface of the power satellite.
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> The sum of all these effects would result in a limit on the distance that a geosynchronous satellite must have from the SPS in order to operate effectively. The minimum necessary spacing would depend directly on the physical design of the satellite, the wavelength at which it operated and the type of transmission device used (i.e., klystron, magnetron, solid-state device).

The study acknowledges that "There are numerous military and civilian satellites in various low-Earth orbits that might pass through an SPS microwave beam. Such satellites could in principle protect themselves from adverse interference from the SPS beam by shutting down uplink communications for that period, and improving shielding for data and attitude sensors, computer modules, and control functions" (Gibbons 1981, p. 50). The laser and mirror systems might also interfere with non-geosynchronous satellites by causing reflected sunlight to blind their optical sensors or by passing through communications beams.

Concluding Thoughts

The size of space/Earth antennas will certainly be a point of comparative difference between Sunsats and comsats, and so will the power levels of their transmissions to Earth. The footprints of early communications satellites—the spot on Earth illuminated by its power beams—were often as wide as one-third of Earth. In the case of today's comsats, their power beams are shaped so that the footprint conforms to specified coverage areas. Using spot beam technologies, such satellites can target areas of 100 square miles or less.

An estimated 300 currently active comsats are positioned in geosynchronous orbit (GEO). An even larger number of communications satellites are in MEO and LEO, including those collecting and using power for remote sensing, surveillance, weather, geo-positioning, satphone and military applications. According to a NASA website, that number might be as high as 3,100. Although their power ratings may be somewhat less, the total energy gathered and transmitted to Earth as microwaves is likely to be 10 times greater than those in the higher fixed orbit.

Orbiting comsats obviously collect and transmit less energy than is proposed for the new Sunsats. While the antennas of communications satellites are measured in meters and millimeters, those of solar power satellites will be measured in kilometers. Sunsat antennas will be sized to correspond to the total amount of the Sun's energy collected in space in ratio to the amount of usable energy needed for a specific purpose on the ground; thus, its receiving stations will be scaled to fit the need.

For siting and permitting, the U.S. government may have made Sunsat rectenna placement easier when it announced in late 2010 that it had established "solar energy zones" on public land in six western states and that other sites were under consideration. Large-scale solar energy projects within these zones were to receive streamlined authorization and preferential treatment. The announcement followed a report by the Departments of Interior and Energy of a 2-year environmental analysis of millions of acres of public land assessing environmental and other impacts of solar energy development.

"We think it provides a common-sense and flexible framework through which to grow our nation's renewable energy economy," Interior Secretary Ken Salazar said in a prepared statement. "Our country has incredible renewable resources, innovative entrepreneurs, a skilled workforce, and manufacturing know-how," Energy Secretary Steven Chu was quoted as saying, "It's time to harness these resources and lead in the global clean energy economy" (Environment 2010). Sunsat providers, in partnership with terrestrial solar businesses, may find future rectenna siting, and health, environmental and other public concerns easier to address as nations take steps to create more of their own energy.

References

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