Chapter 9
What Is Worrisome About Solar Power Satellites?

Abstract This chapter addresses some technological constraints, implementation costs and other challenges facing space solar power satellite systems.

Launch to Space

Hearing space scientists say, "The science behind space-based solar power is sound," and "Solar power satellites are technically feasible," must not be interpreted to mean, "The hard work is all done." As energy-generating satellites are being positioned for launch, informed professionals readily acknowledge the multiple technical and non-technical issues yet to be resolved, many of which can ultimately be addressed only in practice.

The biggest obstacle to space-based solar power is the difficulty and expense of putting satellites into orbit using today's technology and business models. The lack of a regularized transportation system is widely thought to be the single most significant factor holding back near-term implementation of space solar power. The current high cost is attributed to the small number of satellites destined for space each year, the limited number of launch vehicles available to do this work and the fact that almost none of the launch vehicles is reusable, which underscores the reality that space is not yet taken seriously as a commercial destination.

China for the first time in 2010 surpassed the United States in number of launches when it transported only 15 satellites. Taken together, our spacefaring nations launch only about 100–120 satellites of any type each year, and these are launched by a handful of countries—principally the United States, China, European Union, Russia, Japan, India and Israel.

No matter how impressive the designs for space-based solar power systems, these concepts and business plans will go nowhere until there is economical, reliable and frequent access to space. Lowering the cost to orbit is expected to prompt entirely new commercial enterprises, some of which will be transformative for the

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countries and businesses that pursue them. Proponents of energy from space argue that the new solar power satellite market alone will be big enough to bring down launch costs.

Assembly in Space

A second concern relates to assembling, managing and maintaining solar power satellite operations in space orbit. Like the ocean depths, outer space is not conducive to human survival; thus, once rockets lift the basic material components into orbit, robots will most likely be the hands-on managers of these operations, extending human sight, reach and intelligence by means of electromagnetic communications and control.

The Mars exploration rovers Spirit and Opportunity—examples of this kind of interface—have been followed on TV as if they were NASA rock stars. Launched in 2003 and landing on Mars in 2004, these two robotic extensions of humankind have been searching for answers about the history of water on this distant planet some 60 million km from Earth (NASA 2011).

Equipped with wheels, these rovers were expected to spend their life traveling over a distance of 1 km in different parts of the Martian terrain, performing on-site geological investigations. Each carried a panoramic camera for taking pictures of the local terrain and a spectrometer for close-ups of rocks and soils. A robotic arm, capable of moving like a human arm with an elbow and wrist, could place instruments directly up against rock and soil targets of interest. Eventually, one rover became stuck and was turned off in 2011, but both traveled farther and remained responsive to human command far longer than expected. And the full-color images relayed to Earth on a daily basis were followed with interest by the media and audiences everywhere.

The Mars rover experience lends credence to the idea that space structures of considerable mass and complexity can be remotely assembled, monitored and managed by human controllers safely on the ground.

Wireless Transfer of Energy

Possible negative health and environmental effects of beaming energy from space satellites to Earth antennas are a matter of public concern. Anticipating and preventing such effects, if any, is a necessary priority for the emerging space solar power industry.

A typical reference design, circa 2003, involves a satellite in geosynchronous orbit, with photovoltaic arrays of several kilometers continuously pointed toward the Sun. Energy collected is converted into radio frequencies of 2.45 or 5.8 GHz, which is considered most suitable for transmission through Earth's atmosphere. Targeting a pilot signal on Earth, these frequencies are beamed via a wireless power transmitter to a designated antenna—also several kilometers in size—on the ground. The rectifying antenna converts the energy into electricity compatible for distribution on the terrestrial grid. Such an installation can deliver as much as 5–10 gw of electrical power. At the location where the beam encounters the ground, intensities are expected to be about 1/16 of noon sunlight (SBSP Study Group 2007, pp. 7–8).

In 2007, a space-based solar power study group was commissioned by the National Security Space Office of the U. S. government to update NASA's 1997 "Fresh Look" study on energy from space. The office was concerned about potential political conflicts (wars) arising as a result of increasing global population and declining energy resources. In addition to energy security, the group was asked to consider environmental, economic, intellectual and space security as well. The group found that "when people are first introduced to this subject, the key expressed concerns are centered on safety, possible weaponization of the beam and vulnerability of the satellite, all of which must be addressed with education."

> Because the microwave beams are constant and conversion efficiencies high, they can be beamed at densities substantially lower than that of sunlight and still deliver more energy per area of land usage than terrestrial solar energy. The peak density of the beam is likely to be significantly less than noon sunlight, and at the edge of the rectenna equivalent to the leakage allowed and accepted by hundreds of millions in their microwave ovens. This low-energy density and choice of wavelength also means that biological effects are likely extremely small, comparable to the heating one might feel if sitting some distance from a campfire (SBSP Study Group 2007, p. 26).

Land Use

Ground positions are becoming scarce for new wind and solar farms, as well as for highways, gas pipelines, airports, hospitals and prisons. Thus, the question arises, "Where can one find 5 square miles of protected Earth on which to put a space solar power rectenna?"

Locating a good site may not be as challenging as one would first assume. A unique characteristic of microwave-transmitted energy from space is that agriculture can coincide with the rectenna site to the advantage of both. A rectenna can be erected directly above a terrestrial solar farm, doubling and perhaps tripling its capacity, or above a coal or gas-fired power plant to reduce its dependency on fossil fuels.

How is this possible? Microwave receiving rectennas are designed to absorb almost all of the beamed energy but allow the larger percentage of ambient light to pass through. In rejecting excess heat, these space solar antennas can retain sufficient warmth and light to power large greenhouse complexes for year-round flower and vegetable production, to support an ongoing feedlot operation for raising livestock or to sustain the atmosphere needed to keep farm ponds active 12 months a year for the production of fish or algae.

At the International Space Development Conference in 2011, Ohio University students presented a digital visualization of a space solar power application that converted 5 square miles of abandoned strip mine land in southeastern Ohio into a working rectenna. According to the technical brief and business plan associated with the design, this site would be sufficient to supplement and eventually replace the productive capability of a coal-fired plant owned by American Electric Power rated at 1 gw.

Another of the Ohio University student designs employed abandoned oil well drilling platforms off the coast of southern California for use as rectennas for powering saltwater desalination units pumping fresh water to shore. This same system was also sized to transmit wireless electric power sufficient to power a city of 45,000.[1]

Satellite Collisions

Some observers, fearing that space is getting crowded, worry that satellites will start crashing into one another. Although these incidents are rare, they do happen.

The Space Data Center, established on the Isle of Man by the Space Data Association in 2009, maintains an automated space situational awareness facility that works to reduce the chance of satellite collisions and frequency interference on a global basis. The need for such a facility was prompted in part by events that occurred in space in 2007 and 2009. The first was a Chinese military demonstration of a "kinetic kill vehicle" that destroyed one of its own retired weather satellites, the Fengyun-1C. The impact exploded the satellite into 3,000 separate pieces of debris 10 cm or larger. The second occurred when an orbiting Iridium 33 (satellite telephone) spacecraft collided with a defunct and wandering Soviet-era Cosmos 2251 satellite. The collision created 2,100 additional pieces, all of which are moving at high speeds in orbital space (Schrtz 2010, pp. 172–180).

Prevention requires two different types of preparedness. The first is to assure that no satellite crash is intentional, i.e., a human-directed event. In such a case, the recommended solution is nation-to-nation or corporation-to-corporation diplomacy. For accidental collisions, monitoring and managing the space environment and data sharing are the recommended preventive measures. In both cases, liability conventions should be in place (or at least there should be a process for adjudication of differences).

It may be helpful to explain why satellite collisions rarely happen: one of the most crowded satellite orbits is the geosynchronous arc located 36,000 km above

[1] To view these and other space solar power designs see http://spacejournal.ohio.edu/issue17/main.html. Other visualizations are being solicited in the 2011–2014 SunSat Design Competition being sponsored by the Society of Satellite Professionals International, the National Space Society and the *Online Journal of Space Communication* hosted at Ohio University. Click on http://sunsat.gridlab.ohio.edu/.

Earth's equator. Within the 360° orbit, the ITU makes no satellite assignment that is less than one degree apart, which means that spacecraft placed in GEO will be no closer than 773 km, the approximate distance between east and west coasts of Panama. With such a separation, satellites orbiting with Earth each 24 hours at comparable approximate speeds of 11,000 kph are not likely to bump into one another. Satellite spacing within other orbits receives similar monitoring.

Space Debris

A much bigger concern are the 5,100 pieces of debris caused by the Chinese A-Sat and Cosmos/Iridium events (and others released by humans and by nature) that are still orbiting in a place where numerous Earth observation, meteorological and other satellites are located.

According to Nicholas Johnson, NASA's chief scientist for orbital debris, the Department of Defense is responsible for tracking materials larger than 10 cm, while NASA is responsible for anything smaller. By using ground-based telescopes and radar, NASA is tracking as many as 300,000 particles from the two collisions (and others), yet has no capability to remove them.

Interviewed by *Space News*, Johnson said, "I've been the U. S. technical expert on orbital debris at the United Nations for the last 14 years…. We have guidelines. If everybody follows the guidelines, the change in the environment will be very, very modest. One of the good things about debris is that by and large debris has characteristics that allow it to come back to Earth more quickly than satellites" (Werner 2010, p. 18).

Solar Storms and Flares

In April 2011, a commercial satellite fleet operator in Thailand announced that its Thaicom 5 satellite had suffered a 4-hour service outage due to an apparent electrostatic discharge. The satellite, located in GEO at 78.5° east longitude, had automatically placed itself into safe mode and pointed itself toward the Sun to maintain electrical power. A company spokesman explained, "[A]n electrostatic discharge cannot be predicted in advance, and its occurrence is quite rare" (de Selding 2011b, p. 3). The satellite was not damaged.

An earlier in-orbit failure of the Galaxy 15 satellite owned by Intelsat was initially blamed on an electrostatic discharge. In that case, the satellite was unable to respond to commands and began a 6-month uncontrolled drift along the geostationary arc before it was brought back under ground control. Intelsat reported in January 2011, following a complete checkup, that Galaxy 15 appeared to be in good health. *Aviation Week & Space Technology* noted, "Of the 120 potential root causes identified, only two remain. Solar flares, the long-rumored culprit, are not one of them" (Taverna & Morring 2011, p. 38).

In brief, solar flares trigger the ejection of coronal mass (an eruption of gas) from the face of the Sun that is propelled through space. Our Sun follows an approximate 12-year cycle of such activity but is thought to now be entering a period of relative quiet (perhaps the least activity in 80 years). These flares can disturb Earth's ionosphere, the uppermost part of the atmosphere, and have led to radio blackouts. Such flares can also create static electricity that can discharge and short circuit vital electrical components on spacecraft.

Solar storms can be responsible for the magnetic fields and charged particles that have washed over power lines on the ground, melting transformers and cutting power to those connected to electrical utility grids (Clark 2009, pp. 27–31). These, too, are rare events that cannot be easily predicted and even less easily protected against.

Signal Interference

Communication providers are protective of the electromagnetic frequencies assigned to them and watchful of any applications or events that might compromise their signals. A 2011 example is the case of hybrid satellite/terrestrial broadband wireless provider Light Squared, a telecommunications company that ran into a storm of protest when the L-band (2 GHz) radio spectrum it proposed to use was thought to cause interference in an adjacent spectrum assigned to global positioning systems. When both government and industry users of GPS aired concerns, the company was sent scrambling for an alternative frequency plan (de Selding 2011a, p. 5).

Communications satellites transmit electromagnetic waves that convey voice, data, video, navigation and timing signals. Solar satellites transmit electromagnetic beams that convey energy and electrical power. Research has not determined whether communications signals and energy beams are compatible. The author put the question to Dr. Paul Werbos, IEEE Fellow and member of the National Science Foundation Energy, Power and Adaptive Systems (EPAS) group and a number of other informed professionals. A search of IEEE's *Journal on Microwave Theory and Techniques* led to an inconclusive answer.

The compatibility (or incompatibility) of energy and communication is an example of an unanswered question that could make a big economic and political difference for solar power satellites. If space power and space communications services can originate from the same space platform, the comsat industry will more readily embrace energy as its next new market. If not, launching an energy-from-space program will be a greater challenge because of all the interference issues that could arise.

Concluding Thoughts

Whether it relates to communications and media, imaging and remote sensing or geo-positioning and location services, launching a new space business is never going to be easy. As with launch of any global enterprise on Earth or space, there will always be causes for worry. The energy-from-space initiative will have to find its place and address its challenges as it moves forward. Since its product is greatly needed, this development will have lots of encouragement and help along the way.

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