Chapter 1
What Is a Solar Power Satellite?

Abstract This introductory chapter explains how the new Sunsats—sometimes called powersats or solarsats—will differ from comsats in terms of purpose, operations, market, regulation and design.

What Is a Sunsat?

A solar power satellite is a space-based vehicle for gathering quantities of sunlight in space and delivering it to Earth as electrical power. Such satellites are poised to become the next-generation equivalent of communication satellites, and energy services will be their new market.

No solar power satellites are yet in operation. While all satellites in Earth orbit host some type of solar collector to generate the energy for power and control, no such satellites are there for the primary purpose of gathering energy from the Sun and delivering it to Earth. Because an abundant and sustainable new source of energy is desperately needed on Earth and the current level of technological development will now permit it, a huge new satellite sector is about to emerge that will relay energy from space to antennas on the ground, where it will be used on-site or plugged into our electrical power grids.

The logical path forward for those intending to develop solar power generation plants in space is in partnership with the commercial satellite (comsat) industry, a well established ($200 billion per year) sector with 40-plus years of expertise in designing, manufacturing, launching and operating spacecraft in orbit above Earth.

The future is never very clear, but once it becomes clear that communication satellites can be repurposed to safely and profitably deliver energy as well as video, voice and data signals, the author predicts it will be the comsat stakeholders taking the lead in new Sunsat ventures. This is logical; near-space is their home territory. They will enter into the field with the global perspective, the venture capital, the regulatory clout, the managerial experience and the marketing skills to turn such an enterprise into multiple viable businesses.

D.M. Flournoy, *Solar Power Satellites*, SpringerBriefs in Space Development,
DOI 10.1007/978-1-4614-2000-2_1,

Power Plants in Space

The idea that the Sun's rays can be collected in space and beamed to Earth as an energy source from a space-based platform has been around even longer than the idea of communications satellites. The entrepreneurs in communications sectors were the first to commit to space because they were quicker to see the advantages in having transmission towers located high above Earth for widest reach, coverage and mobility, while the power industry stayed Earthbound, feeling assured that it could meet future demand by scrapping for fossil fuels on the ground.

In the 1970s, Earth-based energy was still readily available and very cheap. But some 40 years later, oil and gas reserves are harder to find and a lot more expensive to retrieve. Coal and nuclear fission material are perceived as "dirty energy" sources. Also, by the twenty-first century, all the unaccounted for costs of environmental desecration and atmospheric pollution associated with fossil fuels have finally come due just when long-term energy security for many nations is in doubt.

Those scenarios, along with some prominent disasters in the energy business, have created the context for a more favorable reconsideration of the Sunsat option. Although initial investment costs are still considered high, the attractiveness of clean, abundant and instantly useful energy drawn down from strategically placed solar stations above Earth is now too compelling to ignore (Fig. 1.1).

Since comsats and Sunsats have many similar technological and operational requirements, it is worth considering how their business plans might converge. These in-orbit satellites perform a variety of functions, the most significant being communication (audio and video broadcasting, mobile telephony, broadband data and Internet); remote sensing (weather, environmental surveillance, mapping); and geo-positioning

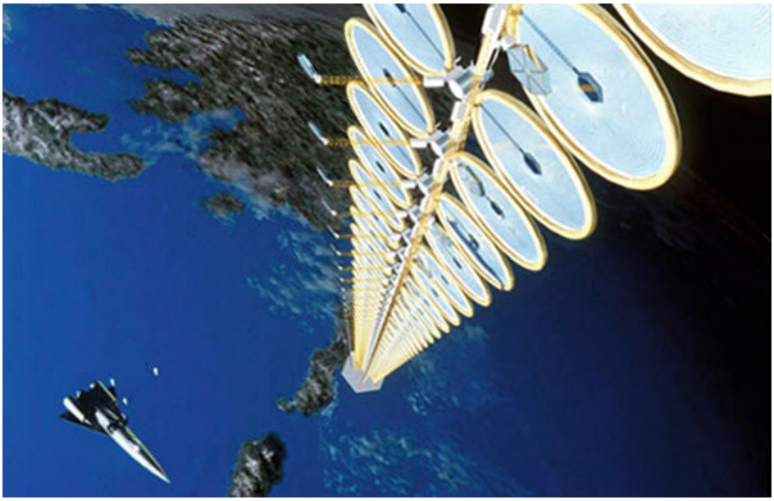

Fig. 1.1 The Sun Tower is a conceptual design based on NASA's 1997 Fresh Look study in which the transmitter diameter is 500 m and the vertical "backbone" length is 15.3 km. An equally large rectenna receiver provides for power production on the ground (Potter et al. 2009)

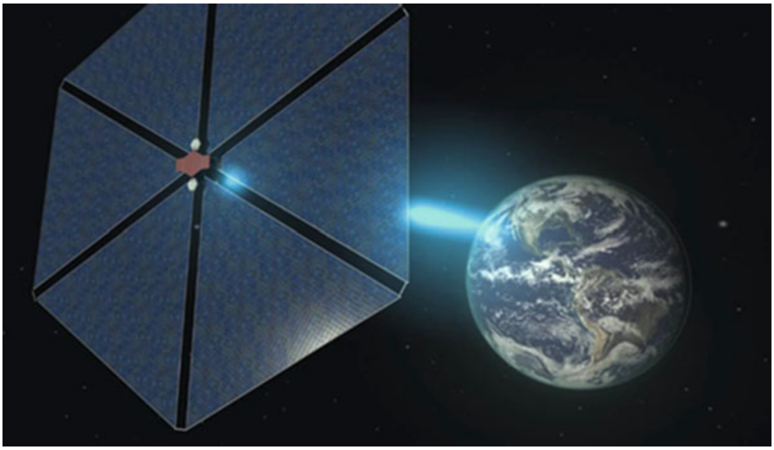

Fig. 1.2 Solar power satellite design created by Ohio University students affiliated with the Game Research and Immersive Design Laboratory (GRID Lab), commissioned by the Online Journal of Space Communication for the 2011–2014 Sunsat Design Competition (Ohio 2011)

and navigation. As a platform for performing work beyond Earth's atmosphere, the International Space Station (ISS) is also a multipurpose satellite, conducting research while testing the opportunities and challenges of living and working in space.

Will solar power satellites differ radically from those operating in space today? The answer is yes—and no. If one considers the three basic structural elements of communication satellites—that is, the space segment, the Earth segment and the transport segment, one can see that they have much in common.

The Space Segment

The new solar power satellite industry will position above Earth a new type of energy infrastructure hosting many of the features of communications platforms, including a satellite bus (physical structure), solar arrays, onboard processing, telemetry control and wireless transmission systems. Unlike the comsats that gather a small portion of the Sun's radiation to power their spacecraft, the Sunsat antennas would be designed to collect and concentrate solar thermal or photovoltaic energy for the principal purpose of relaying it to Earth, where it will be converted into electricity (Fig. 1.2).

While development of the thinner, lighter, cheaper photovoltaic (PV) cells that make terrestrial power production increasingly more efficient currently benefits communications systems in space, the benefits will be much greater for solar power producers looking to reduce the size and increase the productivity of their antennas while holding down the costs of launching their much larger solar collection arrays into space. Also benefitting the Sunsat and comsat industries will be promising new developments in remote construction, assembly, repair and replacement.

Sunsats will need bigger, more efficient solar panels than are currently in use since the principal purpose of their onboard power conversion and transmission systems will be to convert the Sun's energy into low-density radio or light frequency waves capable of providing many times more electrical power than we use today. To increase efficiency, large-scale reflectors will be used to concentrate photons from the Sun such in a way that the PV cells see the equivalent of not just one Sun but many suns.

Among the more innovative Sunsat designs are architectures that network more than one satellite together within a common space orbit, creating a photovoltaic area of 20 km or more. Multiple clusters of such satellites may one day be operating in space orbit, and these will be linked for global electric power service. While building, launching and assembling such structures in space will be a massive undertaking, past space achievements (such as the International Space Station, the Hubble Telescope, the Mars rovers and the many spacecraft that operate safely and productively in Earth orbit) give proponents of space solar power increased confidence that locating solar stations in space is within our reach.

Comsat architectures in the digital age have greatly improved functionality and performance as a result of onboard computer processing and control, and effective use of spot beam technologies. These advanced technology spacecraft can direct communications transmissions to more narrowly defined regions and increase power levels through cloud cover. Such beams can be moved from one receiver to another on command from Earth. While transmitting a communication signal requires significantly different operations from those required in wireless power transmission, these more advanced comsat designs will help to solve some of the challenges faced by Sunsat engineers.

The Launch Segment

Launch systems are key to space-based solar power implementation. Every piece of infrastructure destined for space must be shoved out of Earth's gravitational field using one or more of the principal launch vehicle types. These include a wide variety of reusable launch vehicles (RLV). Some are of these are of the "vertical takeoff vertical landing" and "horizontal takeoff horizontal landing" types; some are "single stage to orbit" or "two-stage to orbit," with the first stage from the ground. Other options are in development (Bienhoff 2008, p. 2).

At least in the beginning, Sunsats will employ the same private, commercial and government rockets used to lift communications satellite structures from Earth to space. Some plans involve assembling solar satellites and their antennas from components lifted by medium power rockets into a low-Earth orbit (LEO), possibly using the International Space Station as a staging area, later transferring the assembled unit into its final position in a geosynchronous, Sun-synchronous or other suitable orbit. Other plans call for inserting solar spacecraft and their large arrays directly into the designated orbit using more powerful thrusters.

Launching satellites safely and economically into space is among the greatest challenges of the satellite industry. But after many years of successes and failures, the industry is consistently delivering 90% of its payloads into designated orbits. This level of predictability will give the energy providers, as well as the insurance business, a high level of confidence that the launch providers can do what they say they can do.

The communications industry is now—and the solar power industry will soon be—the beneficiary of an ongoing global effort to regularize space transport, making it a viable business enterprise in the way that aerospace is today. To avoid the high costs of launching workers and material into space, some visionaries see space-based infrastructures being built from materials found on the Moon (and on near-Earth asteroids), with robotic manufacturing and assembly managed from Earth via virtual systems of communications and control. The orbits above the Van Allen radiation belts, where the Sunsats will operate, are too intense as a radiation environment for long-term workers, so most Sunsat construction and maintenance is expected to be done tele-robotically—by operators on the ground.

The Ground Segment

Rectifying antennas—Earth receiving stations—will capture the transmitted signals of the solar satellites and convert them into electrical power. In this respect, Sunsat receivers will resemble the passive early TVRO (receive only) Earth antennas of radio and television, capturing not information but energy to be relayed to clients and consumers. Except for telemetry (and the low power guide beam originating with the ground receiver that insures the satellite transmitter is focusing its main power beam accurately), no uplink is needed. The Sunsat on-ground receivers will also be substantially larger than those of radio/TV, lowering the energy density to acceptable levels.

Were the power levels to be too focused, there could be dangerous effects. Highly concentrated transmissions from space could harm airline passengers flying through the RF (radio frequency) beam. Reflections from the reception antennas could interfere with or disable the communications of other application satellites. The answer is to create low-density RF energy beams and spread them more broadly. With networked arrays capable of producing electrical rating equivalents of coal fired or nuclear power plants at 1 gw or larger, solar power rectennas can be expected to stretch 1–10 kilometers (km) across. Such collection points will require a protected area similar to that established with coal and nuclear plants; their advantage, however, is that agricultural crops can be grown and fish farms and greenhouses can be situated on Sunsat sites. The fuel they use will not have been extracted from Earth; the power they will generate will be non-polluting and there will be no toxic waste to be disposed of.

Just as satellite communication teleports and antenna farms are connected into the broadband fiber optic networks distributing signals terrestrially, Sunsat antenna farms will be connected into a terrestrial grid that distributes electrical power. While comsats are networked with data centers for information storage and retrieval, the Sunsats will be networked into power distribution centers that will ensure balanced energy transmissions within regions served by their multiple electricity sources.

Challenges That Sunsats Face

As with communication satellites, solar power satellites must be lifted into designated orbits, where they will be expected to provide service to specified regions. No matter the orbit, such satellites must go through a nation-by-nation approval process that will ultimately involve the International Telecommunications Union, an agency of the United Nations, to decide upon a particular location and type of service.

World satellite communications is strictly regulated in terms of orbital registration and position, frequency allocations and levels of power transmission. Since the solar power satellite industry will be arriving late in the process, it will encounter some resistance on such matters as orbital slots and frequency assignments, as these are by nature scarce. The commonly discussed orbital location for Sunsat placement is the geosynchronous Earth orbit, a 36,000-km-high "sweet spot" heavily used by communications satellite services.

Minimizing interference with electromagnetic spectrum assignments of other space users and with those on the ground is the principal reason for such controls. Although none of the existing players in space will be conducting businesses in direct competition with Sunsat products and services, some resistance to sharing positions and spectrum is to be expected from incumbents protecting performance (and future) of their communications, navigation, remote sensing and other systems.

In January 2008, the Space Solar Power Institute of Atlanta, Ga., approached the U.S. House Committee on Science and Technology with a proposal to form "a congressionally chartered public/private corporation" patterned after the highly successful model provided by the COMSAT Act of 1962. That model led to the creation of the Intelsat (international satellite) consortium that now provides satellite communication to all world regions (Preble 2008). The purpose of the proposed Sun Satellite Corporation would be "to build commercial power satellites to collect and transmit energy to electric power grids under contract to wholesale (utility) customers on Earth." The strategy was offered as a concrete step forward in improving U.S. energy security.

News about this initiative made few headlines and has all but disappeared from view, but the idea of private/public corporations focusing on new energy resources is very much alive. It now appears that development of space solar power in the United States will be a lot more private sector than government driven. Private/public collaborations are also the most likely approaches to be taken by such space-faring nations as Canada, China, India, Japan, Russia and the European Union, where solar power satellite systems will be launched by collaborators as often as by competitors in the race to space for energy. The idea of Sunsat corporations is not going away in the United States or elsewhere.

The most significant barriers to realizing a new satellite business based on energy from space are not technological. Certainly there are many technical challenges to be met. These include easier and cheaper access to space, greater efficiencies and capacities of solar cells, wireless power transmission and receiver networks, and energy conversion, storage and distribution systems.

Space visionaries have always looked to governments to get ambitious projects off the ground. In the building of Sunsat infrastructures, governments can help with research and development funding, assist with demonstration projects and agree to be the anchor tenant purchasing the first products produced. But today, countries around the world are expecting their commercial sectors to be involved, and involved early, for creative design as well as for long-run implementation and management.

Progress in raising capital for Sunsat businesses will inevitably be tied to progress in space commercialization overall, and the development of plausible business plans related to alternative energy markets in particular. The fact that the U.S. demand for electricity is expected to increase by as much as 40% in the next two decades, and assumptions that lesser developed nations will wish to grow even faster, is a key incentive. The rising cost of conventional carbon-based energy sources, coupled with the increasing cost of overcoming greenhouse gas pollution and safety concerns associated with nuclear energy, are helping to move up the timetable.

A Perfect Storm

The world is facing a perfect storm in which an energy crisis and an environmental crisis are occurring simultaneously. Earth's population continues to grow. Oil, gas and coal, the principal energy basis for the steadily improving standards of living among the more developed societies—and coveted by lesser developed societies—are now shown to be contaminating Earth's atmosphere. Atmospheric pollution and climate change occur as carbon-based fuels are mined, processed and consumed. At the same time, those nonrenewable fossil fuels are rapidly being used up. Experts predict that, within the next generation, fossil fuels—plus all known alternative energy sources on Earth—will fall far short of projected need.

Several government commissions, think tanks, energy companies and utilities in more than one country investigating the potential of space-based solar power have concluded that satellite delivery must be a part of the long-term solution. Such studies note that the solar energy available in space is several billion times greater than any amount human societies could ever use on Earth. The Sun's energy, always available, is virtually inexhaustible. Unlike fossil fuels, space solar power does not emit greenhouse gases. Moving to solar energy can also reduce competition for the limited supplies of Earth-based energy, predicted to be the basis for future wars.

Prior to its 2011 nuclear disaster, Japan had already made a financial commitment to go into space for one of its long-term alternative energy solutions. In September 2009, a research group representing 16 companies, including Mitsubishi Electric and Mitsubishi Heavy Industries, announced a 2 trillion yen ($21 billion) effort to build and launch into GEO a 1 gw solar station, to be in operation by 2025 (Sato and Okada 2009). As proposed, the satellite was to be fitted with 4 km^2 of solar panels. In 2015, a smaller demonstration satellite fitted with wireless power transmission equipment was to be used to test power beaming to Earth (Yomiuri Shimbun 2011). Since its March 2011 nuclear disaster, Japan's resolve to build SSP has apparently escalated, although not scheduled to become available until significantly more R & D is done.

Solaren, a U.S.-based entrepreneurial company, has indicated its plan to deploy an alternative design on a more accelerated schedule. This innovative design consists of several components. One is a series of concentrator reflectors that would focus power from the Sun so that the solar array would see the equivalent of many suns. The second is a solar array that would be of higher efficiency and have longer life that would convert the solar energy into power. The third is a transmission system that would relay the energy to Earth as RF (microwave) power. This company has signed contracts to deliver energy to U.S. West Coast public utilities starting as early as 2016. These contracts, however, are non-binding and go into effect only when Solaren is actually able to start delivering space solar power at a commercially viable rate (Bullis 2009).

Concluding Thoughts

Figuring out how to collect energy in space and transmit it on demand to anywhere on Earth will be an undertaking of far greater significance than placing a man on the Moon or building a human habitat on Mars. Such an accomplishment—ready access to energy on Earth (and elsewhere)—is key to all space exploration. Because Sunsats can tap the one energy supply that cannot be depleted, any corporation or country in the space energy business will have a perpetual competitive advantage.

In practical terms, building international businesses around solar energy from space may be the only way we can keep alive our individual and collective dreams for a better life. Having abundant, safe, non-polluting energy could represent a tipping point for human productivity and creativity—that one essential ingredient enabling the human race not just to survive but to live up to its potential. If indeed solar energy can make that difference, let us work toward the possibility, as there are no other sustainable solutions currently available to meet our seemingly unending demands for power.

References

Bienhoff, D. 2008. Space infrastructure options for space based solar power. 6th International Energy Conversion Engineering Conference (IECEC). 28–30 July 2008. Cleveland, Ohio.

Bullis, K. 2009. Startup to beam power from space. *Technology Review*, April 15. http://www.technologyreview.com/blog/energy/23381/. Accessed 5 July 2011.

Ohio University GRID Lab. 2011. http://sunsat.gridlab.ohio.edu.

Potter, S., M. Bayer, D. Davis, A. Born, D. McCormick, L. Dorazio, & P. Patel. Space solar power satellite alternatives and architectures. AIAA Aerospace Sciences Meeting. Orlando, Florida, 5–8 January 2009.

Preble, D. 2008. How to build a space solar power system: The Sunsat Incorporation Act. Space Solar Power Workshop. http://www.sspi.gatech.edu. Accessed 23 January 2008.

Sato, S. & Y. Okada. 2009. Mitsubishi, IHI to join $21 billion space solar project. *Bloomberg*. http://www.bloomberg.com. Accessed 15 September 2009.

Yomiuri Shimbun. 2011. Space-based solar power set for 1st test. http://www.yomiuri.co.jp/ 23 January 2011.