Chapter 2
What Are the Principal Sunsat Services and Markets?

Abstract This chapter describes some of the challenges facing the planet as a result of burning fossil fuels, and the opportunities presented to the satellite industry in response to world demand for cleaner and more abundant energy. Among the Sunsat uses discussed are the production of baseload electrical power—not just an intermittent source of power—supporting agriculture, saltwater desalination, disaster relief, military operations and related applications.

The Energy Picture

Gordon Woodcock, a space scientist for the Boeing Company who has worked on SPS solutions for more than 30 years, defines fossil fuels as "solar energy stored in chemical form by natural processes over hundreds of millions of years." He observes that we are depleting this stored energy in a timeframe measured in decades rather than millennia. Present methods of fossil fuel consumption are also extremely dirty, polluting our Earth's biosphere. It's a race between resource depletion and destruction of the environment. Either way, he says, the world economy collapses (Woodcock 2010).

Alternative terrestrial energy is not the complete answer, either. According to Woodcock, the limitation of Earth-based renewable energy sources is that they are not "demand" sources; that is, they are only intermittently available. Terrestrial solar power works when the Sun shines. Terrestrial wind power works when the wind blows.

Terrestrial hydroelectric power is a way of storing water energy until users demand it. This process can include hydroelectric pumped storage, which is the lifting of water uphill where it is held until released to create electricity as it flows through turbines. But there is little capacity remaining on the planet for hydroelectric installations. Geothermal energy is also way to tap stored energy in the Earth itself. Batteries, water electrolysis and hydrogen storage in fuel cells are other ways to provide storage. But to run a modern power grid exclusively (or even largely) on terrestrial renewable energy, he says, would require enormous amounts of storage, and storage is expensive.

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Woodcock concludes that solar power satellites are a potential solution because they can be positioned in space over a particular location to which they can stream continuous sunlight. Supplying power around the clock, such an energy system can serve as a demand source with very little storage required. He also suggests, given constant solar pointing, the photovoltaic area could probably be reduced by a factor of 10–100 by using concentrators. Land designated for receiving sites might also serve dual or multiple purposes.

The National Space Society (NSS) hosts annual conferences that include sessions on space solar power. The organization's website includes one of the most complete archives on space solar research. It also has taken positions of advocacy, stating that "all viable energy options should be pursued with vigor, [but that] Sun/Sat power (SSP) has a number of substantial advantages over other energy sources." The NSS lists several of these advantages:

- Unlike oil, gas, ethanol and coal, SSP does not emit greenhouse gases.
- Unlike nuclear power plants, SSP does not produce hazardous waste that needs to be stored and guarded for hundreds of years.
- Unlike terrestrial solar and wind power plants, SSP can be available in huge quantities 24-hours-a-day, 7 days a week. It produces regardless of cloud cover, daylight, or wind speed.
- Unlike coal and nuclear fuels, SSP does not require environmentally problematic mining operations.
- Unlike nuclear power plants, SSP does not provide potential targets for terrorists (National Space Society 2008).

The National Space Society notes that "SSP will provide true energy independence for the nations that develop it, thereby eliminating a major source of national competition for limited Earth-based energy resources." The society acknowledges that "SSP development costs will be large, although significantly smaller than that of the American military presence in the Persian Gulf or those associated with the impacts of global warming" (National Space Society 2008).

Climate Change

In the *Online Journal of Space Communication*, Dr. Feng Hsu, a NASA scientist at Goddard Space Flight Center, a research center in the forefront of science of space and Earth, writes, "The evidence of global warming is alarming," noting the potential for a catastrophic planetary climate change is real and troubling (Hsu 2010).

Hsu and his NASA colleagues were engaged in monitoring and analyzing climate changes on a global scale, through which they received first-hand scientific information and data relating to global warming issues, including the dynamics of polar ice cap melting. After discussing this research with colleagues who were world experts on the subject, he wrote:

> I now have no doubt global temperatures are rising, and that global warming is a serious problem confronting all of humanity. No matter whether these trends are due to human

Fig. 2.1 As an indicator of global warming, the glaciers on the South Island of New Zealand are observed melting (Photo by the author)

> interference or to the cosmic cycling of our solar system, there are two basic facts that are crystal clear: (a) there is overwhelming scientific evidence showing positive correlations between the level of CO_2 concentrations in Earth's atmosphere with respect to the historical fluctuations of global temperature changes; and (b) the overwhelming majority of the world's scientific community is in agreement about the risks of a potential catastrophic global climate change. That is, if we humans continue to ignore this problem and do nothing, if we continue dumping huge quantities of greenhouse gases into Earth's biosphere, humanity will be at dire risk (Hsu 2010).

As a technology risk assessment expert, Hsu says he can show with some confidence that the planet will face more risk doing nothing to curb its fossil-based energy addictions than it will in making a fundamental shift in its energy supply. "This," he writes, "is because the risks of a catastrophic anthropogenic climate change can be potentially the extinction of human species, a risk that is simply too high for us to take any chances" (Hsu 2010).

It was this NASA scientist's conclusion that humankind must now embark on the next era of "sustainable energy consumption and re-supply, the most obvious source of which is the mighty energy resource of our Sun" (Hsu 2010) (Fig. 2.1).

Satellite Power Markets

This new energy market will have lots of stakeholders. Those who contribute to the energy supply and those who receive benefits from an on-demand power resource will represent all sectors in all nations, including business and commerce, government and military and the public at large.

Energy is a $1 trillion-plus global industry, and demand is expected to double every 20 years (Mankins 1997, p. 8), making this market attractive enough to bring it to the attention of the global satellite industry. From their inception, space satellites have collected and used the Sun's rays as a power source for communication and related services. Were satellite services to extend their range of offerings to include energy production, baseload electrical power (and other applications) could conceivably become a major new product line. Here are some illustrative examples.

Power-to-Power Utilities

One of the obvious opportunities for solar power satellites is to become an on-demand source of electric power for terrestrial utilities. Once Sunsat providers can demonstrate the capability to direct continuous radio or light frequency power beams to production sites, the owners of coal-fired generation stations will quickly discover the value of this service. The same will also be true of nuclear, gas-fired, biomass and other such plants.

With electrical power production ratings of 1 gw or more, solar satellite systems can be designed to meet the short- and long-term needs of the terrestrial power plants at their existing locations, at first to complement but eventually to replace their current fuel feedstocks. An attractive feature of this approach for space solar power investors is that the utilities have a predictable need for energy in great quantities. Since the power utilities are already connected to an electrical power grid, often covering regions larger than a single state or nation, the Sunsat people won't have to also be in the terrestrial distribution business.

Whether producing power from coal, nuclear, gas, biomass or other sources, power utilities can be expected to step forward as early users of this new space asset to begin reducing their mining and transportation costs. The use of scrubbers and filters will be greatly reduced, if needed at all. Problems related to spent fuel disposal and toxic waste management should be fewer. But mainly the utilities will become clients (and possibly investors) in the Sunsat business to guarantee a sustainable night-and-day fuel source.

Power-to-Agriculture

In many places on Earth, the climate, soil and terrain does not permit cultivation. With innovative applications of space solar power, it may be possible to establish multipurpose greenhouses and other agricultural facilities above which space-pointing Earth antennas have been installed for the purposes of producing heat along with electricity.

An example is reclaimed strip mine land brought back to productive use with the cultivation of local vegetables, flowers and other high-value crops underneath a several kilometer space solar power antenna. In this scenario, the SPS rectenna is a wire mesh energy receiver positioned above the greenhouses. The constant temperatures and light created in the generation of energy make for a 12-month growing season. The wire mesh energy receiver produces electricity that can be used to operate machinery and supply the local power grid. This approach creates a business circle: an environmentally friendly energy production operation that can take advantage of seemingly worthless land to produce cash crops and have access to readily usable energy to stimulate the creation of new businesses, thereby improving the rural economy.

Power-to-Terrestrial Solar

A slight modification of the power-to-agriculture approach will be the design and installation of an SPS rectenna that covers a terrestrial solar generation site, as in the case of solar farms. Energy beaming from space would be coordinated to operate in sync with photovoltaic stations on the ground where Earth solar and space solar antennas are co-located, taking maximum advantage of the sunlight that makes its way through Earth's atmospheric filter and also using the microwaved energy, beamed from space, on the same unit.

Engineers have already figured out that photovoltaic arrays can be designed with an integral antenna built-in, thereby maximizing efficiency, or such systems can be constructed with the space solar collectors working overhead. In such cases, the dual-use installation assures 24-h power production (Landis 2004).

The Boeing Company sponsored space solar power research that looked at the matter of "synergy with other energy sources." In addition to finding that SSP required lower land use per unit power compared to other renewables, the team learned that "space solar power microwave antennas can be designed to let light pass through, so the same land area can be used for conventional solar power—or possibly agriculture" (Potter et al. 2009, p. 36).

Such installations do not yet exist, but the technical design and business plan for one of these could easily be modeled upon a project in Appalachian Ohio, where some 500 acres of reclaimed land, mined by the Central Ohio Coal Co. between 1969 and 1991, is expected to become the site of the largest solar farm in the eastern part of the United States.

Turning Point Solar's 49.9 mw solar array is to be built adjacent to The Wilds nature conservancy in Muskingum County, Ohio. In October 2010, American Electric Power signed a memorandum of understanding with project developers to enter into a 20-year purchase agreement for the facility's power. This project is aided by a 2008 energy reform bill that calls for 25% of all energy consumed by Ohioans to come from advanced energy sources by 2025 (Athens Messenger 2010).

Power-to-Fresh Water

One resource that has been negatively affected by the increasing accumulation of carbon dioxide and methane greenhouse gases in Earth's lower atmosphere is clean water. Kent Tobiska, a space environment scientist, says that one effect of adverse climate change is flooding and fresh water contamination. Population growth has also reduced water supplies while increasing demand.

Tobiska, in a paper written for the American Institute of Aeronautics and Astronautics (AAIA), notes that continued population growth in coastal areas makes it economically feasible to begin considering seawater desalination as a larger source for metropolitan water supplies. He also notes that the process of desalination is, however, energy intensive, which has discouraged its widespread use. (Tobiska 2009, p. 1)

In a later paper, written for the *Online Journal of Space Communication*, he made public an unusual proposition and proposal to the State of California, one that could help not only solve the state's energy problems but also allow coastal areas access to a continuous supply of fresh water. He writes:

> California offshore oil and gas platforms already use seawater desalination to produce fresh water for platform personnel and equipment. It is proposed that as California coastal oil and gas platforms come to the end of their productive lives, they be re-commissioned for use as large-scale fresh water production facilities.
>
> Solar arrays, mounted on the platforms, are able to provide some of the power needed for seawater desalination during the daytime. However, for efficient fresh water production, a facility must be operated 24 h a day. The use of solar power transmitted from orbiting satellites (Solar Power Satellites—SPS) to substantially augment the solar array power generated from natural sunlight is a feasible concept.
>
> The architecture of using an SPS in geosynchronous orbit (will) enable 24 h a day operations for fresh water production through seawater desalination. Production of industrial quantities of fresh water on re-commissioned oil and gas platforms, using energy transmitted from solar power satellites, is a breakthrough concept for addressing the pressing climate, water, and economic issues of the twenty-first century using space assets (Tobiska 2011) (Fig. 2.2).

Power-to-Cities

It is predicted that by 2020 there will be 26 mega-cities—defined as a population area of ten million or more—in the world, primarily in the newly industrialized third world (Landis 2004, p. 16). Almost all of these high population areas will be scrambling to find the energy resources to meet even basic needs, with the more prosperous cities already having teams of planners trying to find answers.

Here again, California can be used as illustration. In December 2009, the California Public Utilities Commission unanimously approved a power purchase agreement that its utility Pacific Gas and Electric (PG&E) had negotiated with a space solar power provider. The 15-year contract with Solaren Corp., a Manhattan

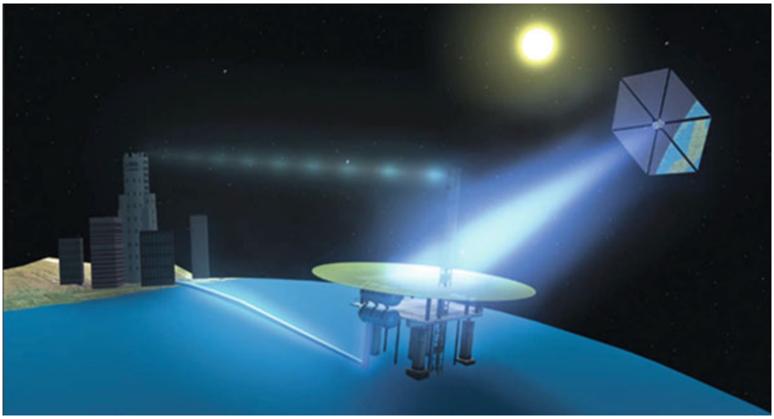

Fig. 2.2 The production of fresh water using space power is illustrated in this visualization created by Ohio University GRID Lab students (Ohio 2010). For animation and related content see http://spacejournal.ohio.edu/issue17/present.html

and California-based company, set the goal to begin beaming from space 1.7 gw of electricity by 2016 to a receiver antenna in Fresno.

In 2010, Solaren was looking to raise more than $100 million to develop its orbiting solar farm in space. The project would require billions of dollars, including rockets that are likely to cost $150 million each (Wang 2009).

As part of PG&E's commitment to providing more renewable energy to its customers, the utility was supporting a wide range of technologies, including wind, geothermal, biomass, wave and tidal, and at least a half dozen types of solar thermal and photovoltaic power. With the Solaren agreement, PG&E extended that approach to renewable energy from space. A PG&E in-house report states that, while the concept of space solar power makes sense, making it all work at an affordable cost is a major challenge, which Solaren says it can solve. Solaren's team includes satellite engineers and scientists, primarily from the U.S. Air Force and Hughes Aircraft Company, with decades of experience in the space industry. Its CEO, Gary Spirnak, was a spacecraft project engineer in the U.S. Air Force and director of advanced digital applications at Boeing Satellite Systems, among other positions (Marshall 2009).

Among the arguments given was that the energy available in space is eight to ten times greater than on Earth. There's no atmospheric or cloud interference, no loss of Sun at night, and no seasons, which means that delivered energy from space is a continuous baseload resource, not an intermittent source of power. Even if hard to reach, real estate in space is still free. Solaren would need to acquire land only for the receiving station, which it can locate near existing transmission lines. Where the rectenna is located can make some difference in reducing delays.

Power-to-Disaster Sites

SSP disaster relief was one of the visualizations created for the fall 2011 issue of the *Online Journal of Space Communication* by students affiliated with the Ohio University GRID (Game Research and Immersive Design) Lab. The technology imaging and animation project was also used in the journal's launch of its 2011–2014 SunSat Design Competition, sponsored by the Society of Satellite Professionals International and the National Space Society.

The concept for a future-oriented solar power satellite solution to disaster recovery came from the team mentor Dean E. Davis, aerospace systems engineer, Lockheed Martin Corporation (Davis 2011). From the team's technical brief, the following explanations were given, prefaced by this: "When a disaster strikes an area, rescue teams fly in from all over to give aid. But destruction to the local infrastructure greatly slows rescue efforts, wasting precious recovery time. Finding ways to quickly recover from power outages and to restore communications in large-scale disasters can help to ameliorate its devastating results. This technical brief explains some of the problems encountered in a disaster relief effort and illustrates how space solar power might help in the recovery" (Power 2011).

Illumination: In the context of natural or man-made disasters, rescue workers need to be able to work around the clock. Due to the absence of lighting, they are often limited to working full force only during the day. The lack of illumination can be addressed, in part, by satellites orbiting Earth. Networked in constellations, specially designed satellites will act as mirrors to reflect sunlight upon the spot facing a disaster situation. Each of these satellites will host a 100-m-thin film solar-reflecting mirror orbiting in a Sun-synchronous orbit. This orbit will be 600 km above Earth, inclining 98°. Potentially, these satellites could focus between 10,000 and 20,000 lumens of light, or about as much light as the Sun gives off in the daytime. This space-based asset will enable rescue workers to continue working at nighttime, thus making it possible to save time and lives.

Power: Light alone will not be sufficient, as areas struck by disaster will also likely need electrical power. Terrestrial power can be replaced by space solar power. Although the first constellation of Sun-synchronous (SEO) Earth-orbiting satellites provides light, imagine a second set of orbiting satellites. These satellites will convert the Sun's energy into electricity and beam it to Earth via laser-focused light beams operating at safe IR (infrared) or microwave frequencies. With giant solar collectors onboard, the satellites will collect energy via their solar cells and convert the energy into electrical power, to be wirelessly transmitted to the ground. In large-scale emergencies, it can be expected that terrestrial sources of electrical energy will also be damaged; thus an intermediate power source is needed, which can be supplied with the help of a high-flying airship.

Navigable airship: In this design, power in the form of laser energy will be sent from SEO solar power satellites to an intermediate platform hovering high in the stratosphere. These dirigible-type airships, powered by solar power, are designed to continuously operate at 60,000–100,000 ft above the disaster area for weeks to months as needed, with the capability to receive laser power energy from space and relay up to 1 gw (one billion watts) of energy to Earth's surface via laser power or cloud-penetrating microwave beams. The 1 gw is sufficient to power a million homes during a crisis, matching the capacity of a coal or nuclear power plant. Portable, expanding receptor antennas can be erected on site to receive this energy with the purpose of running generators or beefing up the existing electrical grid.

Emergency communications: When a devastating hurricane hits, one of the greatest constraints in providing relief will be the lack of communications. Phone towers for mobile telephony will often be knocked out, slowing the local team's ability to coordinate relief efforts. In this design, the same airship providing power will be equipped to serve as a tall multi-purpose telecommunications tower, filling in as a relay and hub for telecommunication services.

Search and rescue sensors: Such airships can also be equipped with passive electro-optical (EO) and active radar sensors allowing rescue managers to quickly scan the debris and locate people trapped in the aftermath of the disaster. This task can be accomplished in a fraction of the time it would take to find them in other ways.

The brief concludes that, in the event of a disaster, solar power satellites have an important role to play in saving lives as well as restoring order.

With access to space-based solar power produced by Sun-synchronous satellite networks, rescue agencies will be able to direct electrical power to any location on the planet. Although still in the planning stages, this technology is paving the way for an alternative power grid that can be used to the benefit of all (Power 2011).

Concluding Thoughts

There is no way to foresee precisely the areas in which Sunsat products/services will be in greatest demand, for some space energy applications will be as broad as charging the batteries of cell phones, laptops and other new media devices while providing roaming connectivity to the Internet in all parts of the globe day or night; or they will be as narrowly targeted as servicing an advance guard of a military operation where access to electrical power is unavailable. All of these are possibilities.

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