Chapter 3

ISSUES AND FINDINGS

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ISSUES AND FINDINGS

TECHNICAL OPTIONS

What technical options might be available for SPS?*

A number of technical options for the solar power satellite (SPS) have been proposed. Because SPS is a developing technology, the specific design parameters of each of these approaches are evolving rapidly as research continues. Hence no single option is completely defined, nor are there detailed systems studies of any designs other than the National Aeronautics and Space Administration/Department of Energy (NASA/DOE) "reference system" that uses microwaves for transmitting energy from space to Earth. The reference design is the basis for the NASA/DOE environmental, societal, and comparative assessments. The two other major SPS variants depend on laser transmission of power from space and on reflected sunlight.

Microwave Transmission

The Reference System Design

The reference system satellite conceptual design consists of a 55 square kilometer (km^2)** flat array of photovoltaic solar cells located in the geostationary orbit 35,800 km above the Earth's Equator (fig. 1). The cells convert solar energy into direct-current (de) electricity that is conducted to a 1-km diameter microwave transmitting antenna mounted at one end of the photovoltaic array. Microwave transmitting tubes (klystrons) convert the electrical current to radio-frequency power at 2.45 gigaHertz (GHZ), and transmit it to Earth. A ground antenna receives the electromagnetic radiation and rectifies it back to direct current; hence its designation "rectenna." The direct-current (de) power can be inverted to alternating-current (ac) and "stepped up" to high voltage. It would then be either rectified to dc and delivered directly to a dc transmission network in the terrestrial utility grid or used as conventional ac power. The rectenna covers a ground area of 102 km^2 and would require an "exclusion area" around it of an additional 72 km^2 to protect against exposure to low-level microwaves. The beam density at the center of the rectenna is 23 milliwatts per square centimeter (mW/cm^2). The beam is shaped in such a way that at the edge of the exclusion area it reaches 0.1 mW/cm^2.

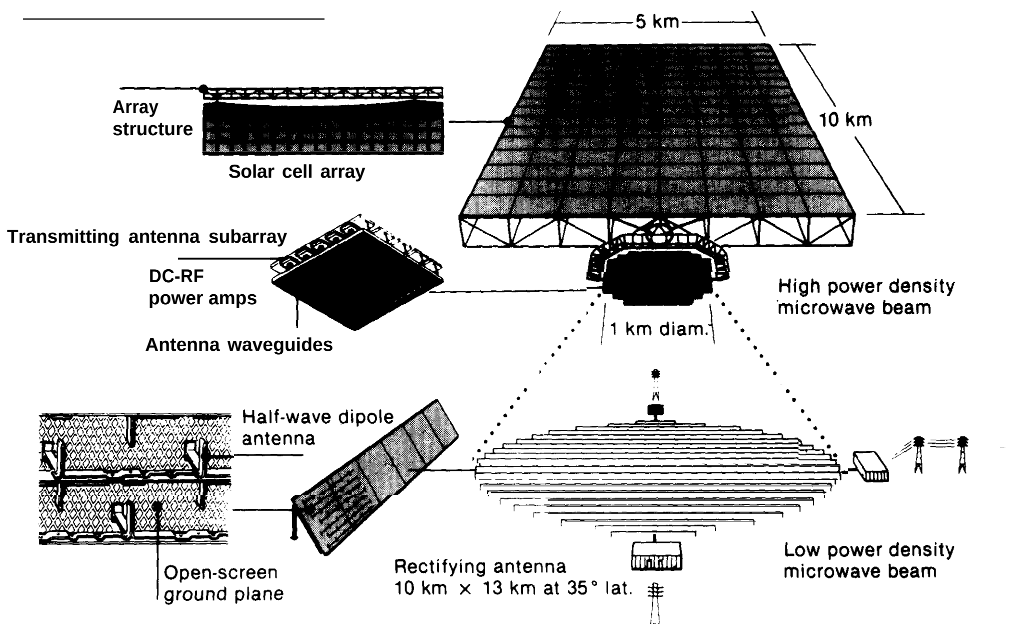
For the given set of design assumptions for the reference system, i.e., beam density, taper, and frequency, the maximum power per transmitter-receiver combination would be 5,000 MW. Except for a small seasonal variation in output due to the variation of the Sun's distance from the Earth, and short periods of shadowing by the Earth near the time of the spring and fall equinoxes, each reference system satellite could be expected to deliver the maximum amount of power to the grid approximately 90 percent of the time. This power level was selected by NASA/DOE for the reference system in the belief that it would provide energy at the lowest cost. 1 n subsequent discussions it is used to consider the impact of the reference system design on utilities and their systems; however, the power level could be set at any value permitted by the design constraints.

The reference system, which was developed to provide a base for further studies and is now several years old, is far from an optimum microwave system and could be substantially improved. In addition, alternative concepts that depend on laser transmission or passive reflection of sunlight each offer certain specific benefits over the microwave designs. Because none of these alternatives are as well defined as the reference system, they are discussed here in more general terms.

*See ch. 5.

**Equivalent to about 13,600 acres

Figure 1 .—The Reference System



SOURCE: C. C. Kraft, "The Solar Power Satellite Concept," NASA publication No. JSCp14898, July 1979.

The Solid-State Variant

Using solid-state devices that convert electricity from the satellite's solar array directly to microwave power would be a possible alternative to the reference system's klystrons. Such devices might have a longer working lifetime and require less mass in orbit; when coupled with photovoltaic cells in a "sandwich" design, they would also allow for a much larger transmitting antenna (the entire surface area of the solar cells would, in effect, be the antenna), smaller earthside antennas, and lower power delivered to Earth per satellite (i.e., about 1,000 MW per rectenna). In combination, these effects would make it possible to position rectennas closer to the cities, which would be the major users of SPS generated power, than would the reference system design.

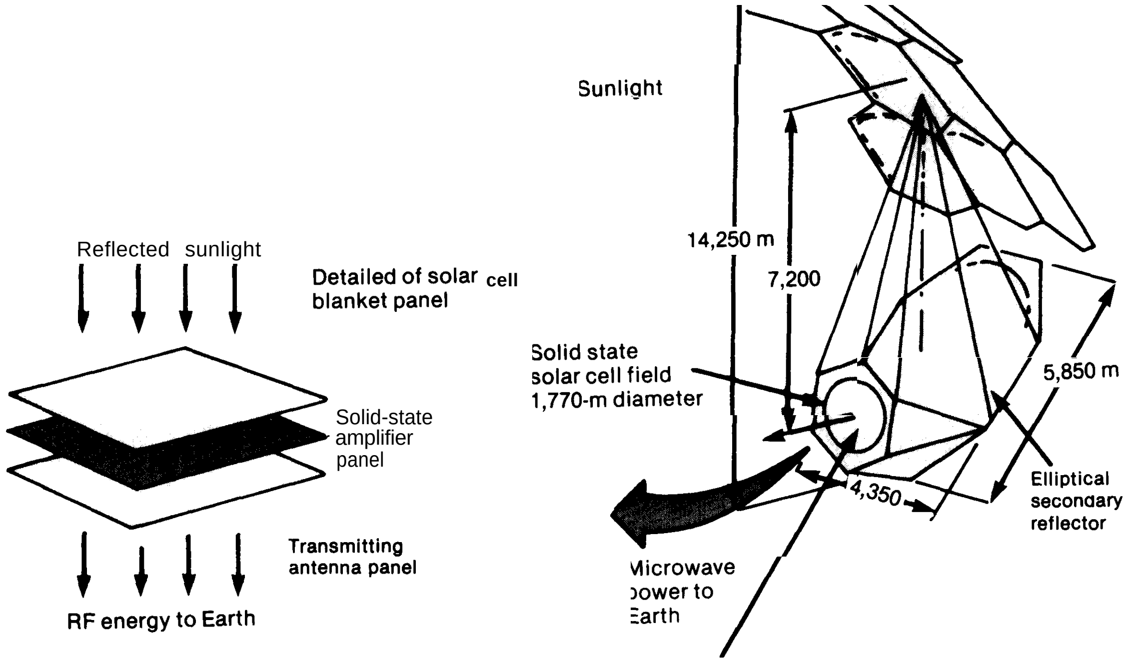
Solid-state devices are now in the very early stages of being evaluated for SPS application. It is still unclear whether they would be able to reach the efficiency and cost goals that would be necessary for SPS.

Laser Transmission

Lasers constitute an obvious alternative to microwaves for the transmission of power over long distances. Compared with microwaves, lasers have a much smaller beam diameter; since the aperture area of both transmitting and receiving antennas decreases as the square of the wavelength, light from an infrared wavelength laser can be transmitted and received by apertures over 100 times smaller in diameter than a microwave beam. This reduces the size and mass of the space segment and the area of the ground segment. Perhaps even more important, the great reduction in aperture area permits consideration of fundamentally different systems. For example:

- It would become possible to use low Sun-synchronous rather than high geostationary orbits for the massive space power conversion subsystem (a Sun-synchronous orbit is a near-polar low Earth orbit that keeps the satellite in full sunlight all the time while the Earth rotates beneath it). The primary laser would then beam its

Figure 2.—The Solid-State Variation of the Reference System



SOURCE: G. M. Hanley, et al., "Satellite Power Systems (SPS) Concept Definition Study First Performance report No. SS D 79-0163, NASA MSFC contract No. NAS8-32475, Oct. 10, 1979.

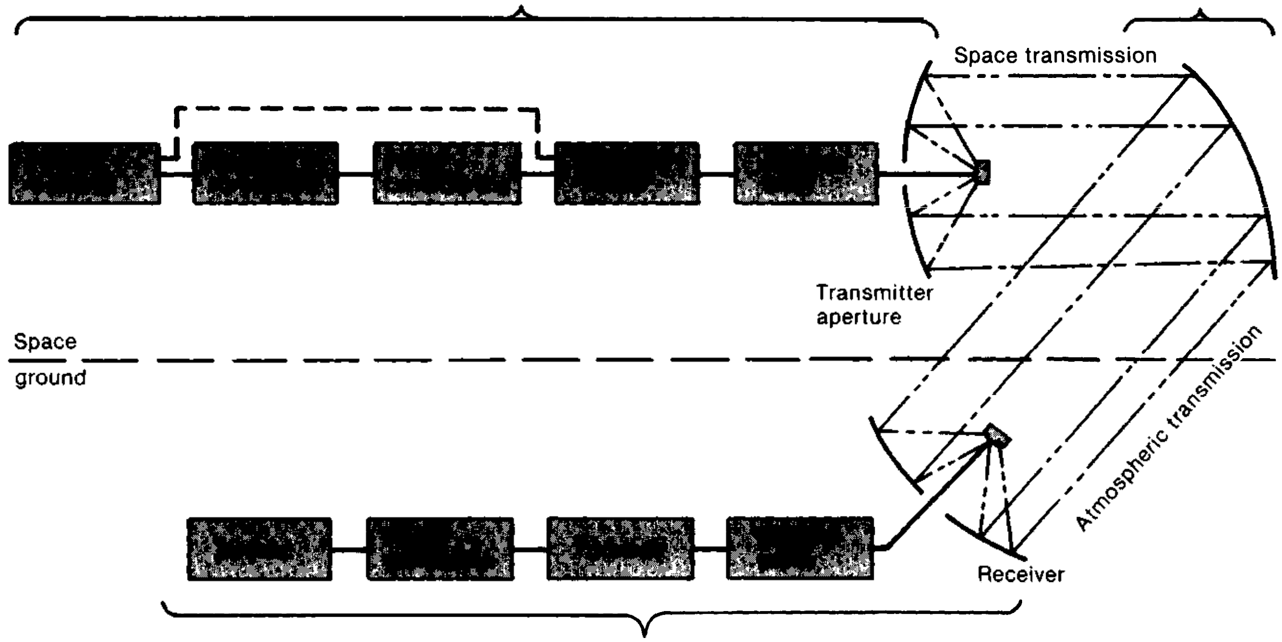
power up to low-mass laser mirror relays in geostationary orbit for reflection down to the Earth receiver. This arrangement, while complex, would considerably reduce the cost of transportation, since the bulk of the system would be in low Earth orbit rather than in geostationary orbit. It also could be built with smaller transportation vehicles than the reference system's planned heavy lift launch vehicle (HLLV).

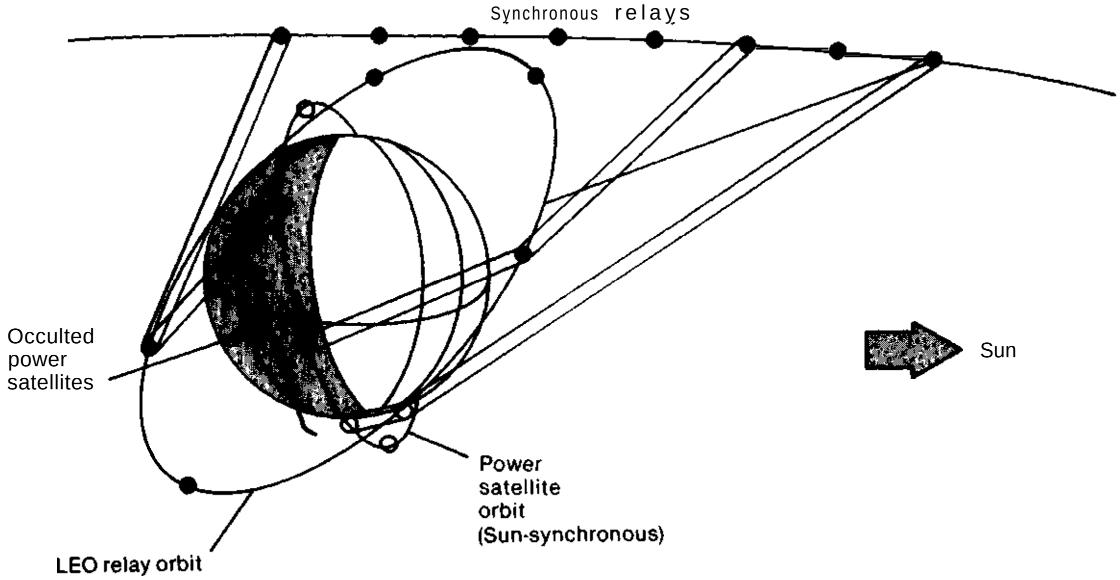
- A laser system might be able to operate efficiently and economically on a smaller scale (100 to 1,000 MW). Thus, it would offer the flexibility of power demand matching on the ground, making possible higher degrees of redundancy and a smaller and therefore less costly system demonstration project.
- The potentially small size of the receiving station would make it possible to employ multiple locations close to the points of use, thereby simplifying the entire ground distribution and transmission system.
- Laser power transmission would avoid the problem of microwave biological effects and would reduce overall interference with other users of the electromagnetic spectrum.

A laser SPS would suffer from three important disadvantages:

- *Absorption of laser radiation.* Infrared radiation is subject to severe degradation or absorption by clouds. A baseload system, unlike the microwave option, would require considerable storage capacity to make up for interruptions. Multiple re-

Figure 3.—The Laser Concept (One Possible Version)





SOURCE: W. S. Jones, L. L. Morgan, J. B. Forsyth, and J. Skratt, "Laser Power Conversion System Analysis: Final Report, Vol. II," Lockheed Missiles and Space Co., report No. LMSC-D673466, NASA report No. CR-159523, contract No. NAS3-21137, Mar. 15, 1979.

ceivers at different locations to achieve some redundancy are also possible, but expensive (seeUtilities, ch. 9).

- *Efficiency.* Current high-power, continuous-wave lasers are only capable of very low overall power conversion efficiencies (less than 25 percent). Converting the beam back into electricity is also inefficient, though progress in this area has been rapid. The relatively undeveloped status of laser generation and conversion means that considerable basic and applied research would be needed to determine the feasibility of a laser SPS.
- *Health and safety hazard.* The beam intensity would be great enough to constitute a health and safety hazard. Preventive measures could include a tall perimeter wall, and/or a warning and defocusing system.

Several types of continuous wave lasers currently exist. Of these, the most highly developed and most appropriate laser for SPS would be the electric discharge laser (EDL). At present, EDL models have achieved only modest power levels and relatively low efficiencies when operated in a continuous mode.

Another future option that has been considered is the solar-pumped laser. In this device, concentrated sunlight is used directly as the exciting agent for the laser gases. Although a solar-pumped laser has been built and operated successfully at NASA Langley, it would require considerable basic research, development, and testing before it could be a realistic prospect for SPS.

Free electron lasers (FELs) offer another possible means of transmitting power from space. These new devices are powered by a beam of high-energy electrons which oscillate in a magnetic field in such a way that they radiate energy in a single direction. Although the FEL has been demonstrated experimentally, it is too early to predict whether it would reach the efficiencies and reliability necessary for an SPS.

Reflected Sunlight

Instead of placing the solar energy conversion system in orbit, large orbiting mirrors could be used to reflect sunlight to ground-based solar conversion systems. Thus, the system's space segment could be much simpler and therefore cheaper and more reliable.

One such system would consist of a number of roughly circular plane mirrors in various nonintersecting Earth orbits, each of which directs sunlight to the collectors of a number of ground-based solar-electric powerplants as it passes over them. Conversion from sunlight to electricity would occur on the surface of the Earth.

In one approach, (the so-called "SOLARES baseline" concept) about 916 mirrors, each 50 km^2 in area, would be required for a global power system projected to produce a total of 810 gigawatts (GW) (more than three times current U S. production) from six individual sites. This is not necessarily the optimum SOLARES system. It was selected here to demonstrate the magnitude of power that might be achieved with such a system. However, a number of different mirror sizes, orbits, and ground station sizes are possible. A more feasible option would be a lower orbit system (2,100 km) to supply 10 to 13 GW per terrestrial site. One of the principal features of the SOLARES concept is that it could be used for either solar-thermal or solar photovoltaic terrestrial plants. The fact that energy conversion would take place on the surface of the Earth keeps the mass in orbit small, thereby reducing transportation costs.

However, a major disadvantage of such a mirror system would be that the entire system would require an extremely large contiguous land area for the terrestrial segment (see table 4, p. 47). As with the laser designs, transmission through the atmosphere would be subject to

Figure 4.–The Mirror Concept (SOLARES)

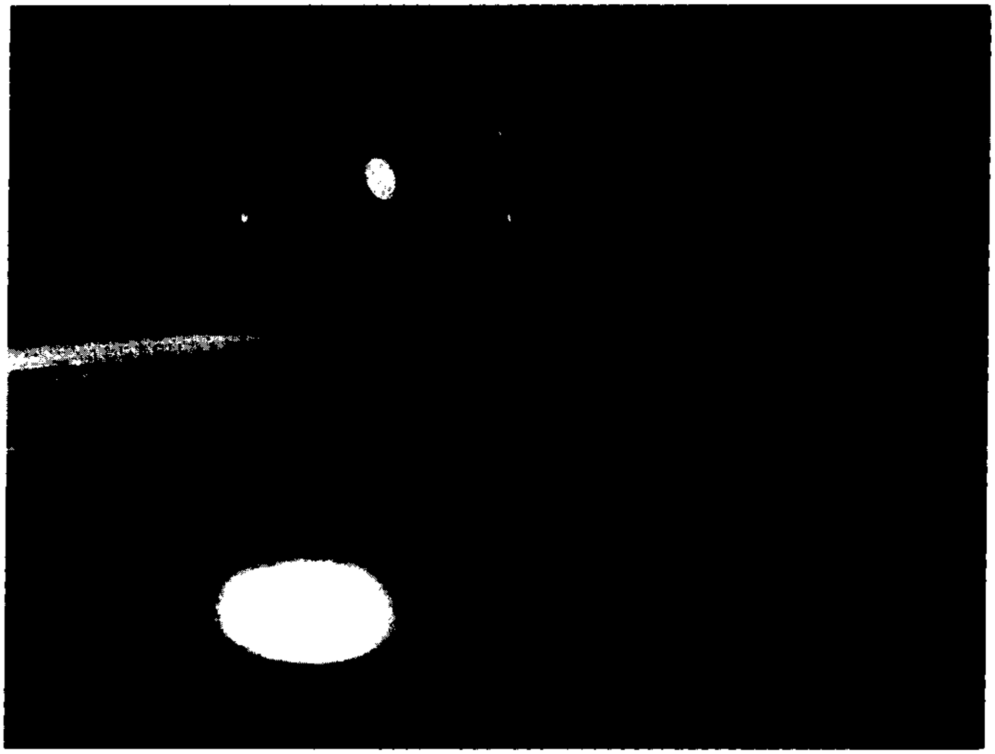
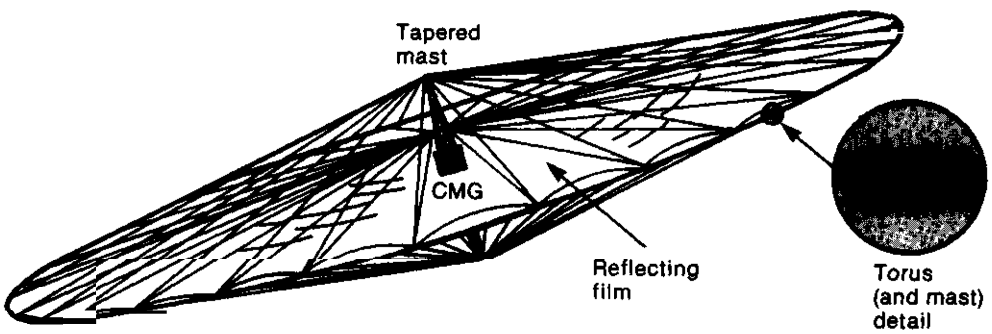


Photo credit National Aeronautics and Space Administration



SOURCE: K. W. Billman, "Space Orbiting Light Augmentation Reflector Energy System: A Look at Alternative Systems," SPS Program Review, June 1979.

reduction or elimination by cloud cover. It would also illuminate much of the night sky (see issue on electromagnetic interference) as seen by observers within a 150-km radius of the groundsite center.

SPS Scale

As presently conceived, the reference system is a large-scale project that has the potential of delivering hundreds of gigawatts of electrical power to the United States or to other countries. However, its very scale is seen by many as a serious drawback to deployment. The utilities here and abroad would find it hard to accommodate power in 5,000 MW blocks (see Utilities, ch. 9), and the space transportation system needed to build and maintain such a massive system would be very expensive. Thus, it is of considerable interest to investigate ways in which the scale of the various components, and of the system itself, could be reduced to a more manageable size.

The laser system would offer the potential for the most substantial reductions, both in overall system size and in the size of the first demonstration project. This reduction in scale might also bring with it a concomitant reduction of costs. There are also a number of possible ways in which to reduce the physical scale of portions of the microwave system. However, economies of scale tend to drive microwave systems to sizes of 1,000 MW output or more.

SPS would require a massive industrial infrastructure for space transportation and construction and for related terrestrial construction, comparable in scale to that developed for existing ground-based coal and nuclear systems.

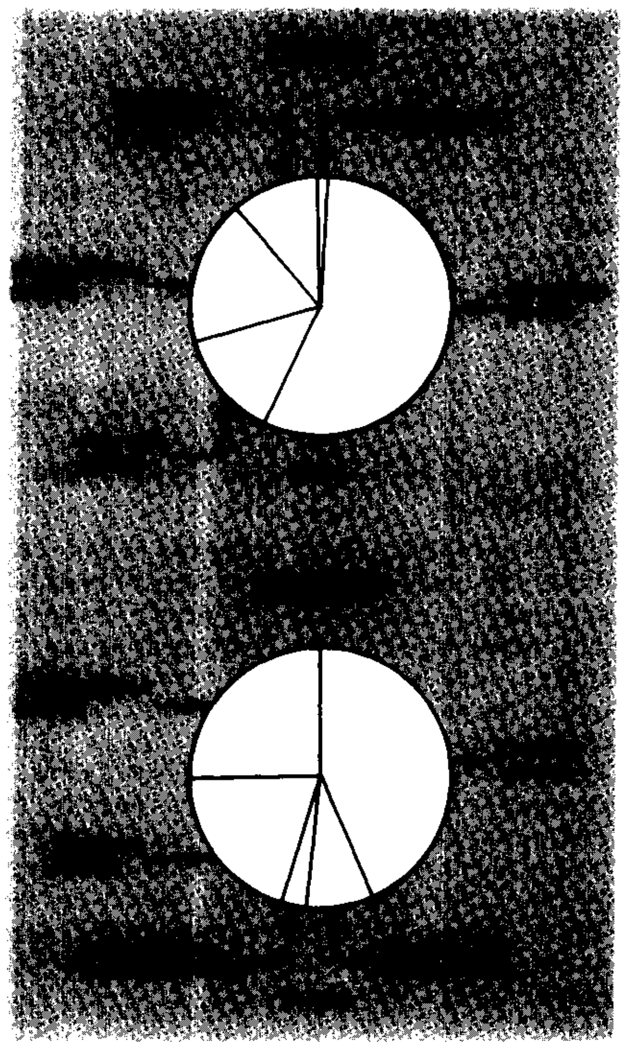
- Space transportation. The reference system assumes the construction and use of a large third-generation, shuttle-type transportation system. Construction of a single reference system satellite (silicon photovoltaics) would require approximately 190 flights of an HLLV. However, launch vehicles somewhat larger than the current shuttle, but smaller than the HLLV, are capable of operating with less load per flight but with many more flights and might be more economical. I n addition, an intermediate size vehicle would be more appropriate for other uses in space. No other currently planned space project envisions using vehicles the size of an HLLV.
- *Space construction.* SPS would require construction bases in low Earth orbit and, for some designs, at geostationary orbit. It might be possible to achieve substantial cost reductions by constructing the satellites in low Earth orbit and transporting them to geostationary orbit, rather than by constructing them in geostationary orbit.

costs

Although the costs of many SPS components have been estimated by a number of different agencies, it is not yet possible to establish them with any reasonable level of confidence. The most detailed cost estimates have been made by NASA for the reference system (fig. 5): $102.4 billion to achieve the first complete reference system satellite, and $11.3 billion to construct each satellite thereafter.

These estimates included the costs of the entire transportation system, the costs of establishing the launch sites and construction facilities in low-Earth and geosynchronous orbits, as well as all of the component development

Figure 5.—Reference System Costs[a]
(dollars in billions)



[a]NASA estimates— 1977 dollars.

SOURCE: National Aeronautics and Space Administration costs. However, they do not include interest on the invested capital or the potential use of SPS facilities for other space or terrestrial projects. According to one possible development scenario generated by NASA (see fig. 24, p. 93), including interest of 10 percent per year more than doubles the development cost of SPS.

By using a smaller capacity transportation system (assuming more flights per satellite), and apportioning the development costs of generic space technology among all the space programs that benefit from it, it might well be possible to deploy a single reference satellite for $40 billion to $50 billion, or roughly one-half of the above estimate.

Other systems might cost more or less than the reference system, depending on the state of development of the alternative technologies (see table 1). For example, since lasers would need considerable development before they would be suitable for use in a laser-powered SPS, they would be likely to be more expensive to develop than the microwave transmitter of the reference system; however, some of the development cost could conceivably be borne by other laser applications, e.g., directed energy weapons or inertial fusion. The cost of a laser demonstration satellite might well be less than the reference system demonstrator. Because of the relatively low mass and ease of construction and operation of a SOLARES system, it may prove to be much more attractive than other alternatives. Cost estimates suggest that if the cost of terrestrial photovoltaics can reach the goals implied by reference system estimates, the costs of a total SOLARES system would be less than the reference system. More exact costs for the SPS await further information on the details of the preferred system. Whatever system might be chosen, it is clear that the startup costs would be in the tens of billions. How much of this cost would have to be borne by the U.S. taxpayer depends on the breadth and depth of industrial and international interest in the development of SPS (see ch. 7).

SPS AND THE ENERGY FUTURE

How could SPS flt into the U.S. energy future (2000-30)?*

SPS will ultimately be accepted or rejected in the full context of future electrical demand and supply technologies. It would compete with other renewable or inexhaustible energy sources such as hydro, wind, terrestrial solar, ocean thermal energy conversion, fusion, fission breeder, and geothermal. Their technologies are all quite different; some serve a demand for baseload, some for peaking or intermediate needs. Together, they would constitute a mix of technologies designed to supply the full range of electrical needs for the United States. SPS must be considered in light of its potential contribution to this mix, as well as of future electrical demand.

*See ch. 6, *Energy* section.

SPS Is Not Likely To Be Commercially Available Before 2005-15

Experience with other new electric generating technologies indicates that new technologies take from 30 to 45 years to become a significant source of electrical capacity in the utility grid. SPS is unlikely to constitute a major exception to this rule of thumb. If a decision to develop SPS were made, some 15 to 25 years of development, engineering, and demonstration would be needed to reach a commercial SPS. However, because of the many uncertainties surrounding SPS, it is not yet possible to make a development decision. If, after considerable further research a decision is made in the next decade to proceed with SPS, then it could be commercially available in the period between 2005 and 2015. Several years of operational testing beyond that would

Table 1.—Characterization of Four Alternative SPS Systems

Information matrix	Reference design	Solid state	Laser system	SOLARES ("baseline")a
costs				
R&D	$400 million	More R&D needed than reference system	More R&D needed than reference system	Relatively simple technical lower cost
Demonstration	$102 billion DDT&E (one sateilite)[b]		Smaller, demonstration with shuttle?	$44 billion, demonstration with shuttle?
Construction	$11,5 billion/satellite	Unit cost lower, smaller rectenna	$3 billion satellite (0,5 GW)	$1,300 billion for 810 GW total system
Operation	$200 million/yr-5GW	Greater reliability, long lifetime	25 million/yr-satellite (0.5GW)	Higher ground conversion cost
Dollars/kW	$2,900 -19,000/kW[c]	$1 ,800 -3,000/kW (probably low)	$6,000/kW probably low)	$1,500/kW (probably low)
Scale				
Satellite size	55 km^2	18 km^2	5 km^2	50 km^2
Number of satellites	60 (300 GW total)	Not projected	Not projected	916 (810 GW total)
Power/satellite	5,000 MW	1,500 MW	500 MW	135,000 MW
Mass	5 X10^4 tonnes/satellite, O 1 kW/kg	Less mass than reference/O 1 kW/kg	Less mass than reference/O .05 kW/kg	2 x 10^5 tonnes mirror system 2 kW/kg
Land use rectenna site	174 km^2 (including buffer) x 60=10,440 km^2	50 km^2	0.6 km^2	1,000 km^2
km^2 1,000 MW	35	33	1,2	7.4
Energy	Electricity Fairly centralized 23 mW/cm^2 Gaussian distribution	Electricity Less centralized Unknown	Electricity, onsite generation. Less centralized Unknown (10 mW/cm^2 at edge)	Electricity, light Highly centralized 1.15 kW/m^2 (1 Sun)
Atmosphere				
Transmission	Ionosphere heating might affect telecommunications		Tropospheric heating might modify weather over smaller area; problems with clouds?	
Effluents	Possible effects include alteration of magnetosphere (AR+); increased water content; formation of noctilucent clouds; ionosphere depletion		LEO orbit, smaller size; smaller launch vehicles	
Electromagnetic interference	RFI from direct coupling, spurious noise, and harmonics: impacts on communications, satellites etc from 245 GHz Problem for radio astronomers (GEO obscures portion of sky always) optical reflections from satellites and LEO stations Will change the night sky		If visible light is used there may be problems for optical astronomy; if Infrared is used may Increase airglow optical reflection from LEO satellite	Problem for optical astronomy, optical reflections and interference from beam; change night sky in vicin of sites
Bioeffects	Microwave bioeffects midbeam could cause thermal heating unknown effects of long-term exposure to low-level microwaves, Ecosystem alteration? Birds avoid/attracted to beam?		Direct beam ocular and skin damage ocular damage from reflections? Other effects? Birds flying through Will burn up? If visible will birds avoid? Ecosystem alterations?	Psychological and physiological effects of 24-hour illumination not known Possible ocular hazard if viewed with binoculars? Ecosystem alteration
National security weapons potential	GEO gives a good vantage point over hemisphere –Provides a lot of power in space platform for surveillance, jamming– –Requires developement of large space fleet with/militarv potential–		Direct weapon: as ABM, antisatellite, aimed at terrestrial targets Indirect: power killer satellite, planes space platform Laser defend self, best, LEO more accessible	Indirect: night illumination psychological–possible weather modification
Vulnerability	Satellites may need self defense system to protect against attack Size and distance strong defenses—			Less ground sites; a lot of mirrors-redundancy; individual mirrors fragile; ground sites still produce power in absence of space system
International	Will require radio frequency allocation and orbit assignment	Smaller parcels of energy make system more flexible Meet environmental and health standards?	LEO more accessible to U.S.S.R. and high-lahtude countries, smaller parcels of energy make system more flexible	

aSmaller SOLARES systems, e g 10 GW/site would be possible and probably more desirable
b$102 billion—NASA estimate–mcludes Investment costs
cEstimates b, Argonne National Laboratory, Office of Technology Assessment, US Congress

SOURCE Office of Technology Assessment

be needed before utilities developed enough confidence in SPS to invest in it for their use (see ch. 9).

SPS Would Not Reduce U.S. Dependence on Imported Oil

Currently the biggest energy problem facing the Nation is dependence on unreliable sources for imported oil. This dependence will persist for the next two decades, since our domestic supplies will continue to decline. We now produce about 10 million barrels per day (bbl/d) of petroleum liquids and this will likely fall to 4 million to 7 million bbl/d by 2000. The supply of abundant domestic energy resources such as coal, solar, uranium, and natural gas can increase but not enough to offset the decline in oil. Over this period our best opportunity for reducing dependence on imports will be conservation, which has the potential of cutting current dependence by more than 50 percent. However, the real problem will be the substantial reduction in availability of world oil for export to the United States. The total amount of oil available is not likely to exceed the current level of 52 million bbl/d and may be as much as 15 percent below this level. Further, overall world demand will likely be higher because of increased needs by less developed countries (LDCS), including oil producing countries. As a result, the United States will find it necessary to reduce imported oil dependence considerably by 2000. This reduction will be even more marked past 2000, when we can expect synthetic fuels from all sources to make a substantial contribution. Since the SPS will not be able to make a significant contribution until well past 2000, it cannot be expected to substitute for foreign oil. However, the satellite could eventually begin to substitute for coal-fired powerplants since coal, too, is a finite fuel, and regardless of the outcome of the CO_2 controversy, use of it for electric production will eventually (though probably not for the next 100 years) be reduced and reserved for nonenergy needs, i.e., for plastics, synthetic fiber, etc.

Potential Scale of Electrical Power

The reference system is designed to deliver 5 GW (5,000 MW) of power to each rectenna. If a 60-satellite U.S. fleet were completed, the SPS could deliver a total of 300 GW, an amount nearly one-half the current total U.S. generating capacity. Converted to energy at a capacity factor of 90 percent, a 60-satellite system would produce about 8 Qe/yr, more electrical energy than we currently consume from all supply sources (7.5 Qe). An international fleet of satellites could achieve a much greater capacity than this by placing more satellites in geostationary orbit. A SOLARES-type system could achieve an even greater generating capacity on an international scale.

other proposals, such as the laser system and variants of the microwave system might be economical in somewhat smaller unit sizes (500 to 1,000 MW). Precisely how much total energy they might supply is less clear, however. For example, a laser system supplying power in 1,000 MW units would need 300 such satellites and ground receivers in order to equal the capacity of a 60-satellite reference system.

Electricity Demand Would Affect the Need for Solar Power Satellites

The level of electricity demand in the United States and the world will greatly affect the time that new centralized electric generating technologies, such as SPS, might be needed. The demand for electricity could vary considerably over the next several decades. For the United States, current forecasts show a range in possible electrical demand from less than today's level of 7.5 Qe end-use to more than 30 Qe by 2030. The demand level will be a major determinant of the rate at which new electric generating technologies need to be introduced. At the lowest levels, all of our baseload capacity could easily be supplied by hydro and coal or nuclear for well into the 21st century provided CO_2 buildup does not preclude increased coal use. At high demand levels, however, it is unlikely that any one technology could provide all the needed baseload capacity and several possibilities would be needed. In this case, development of SPS may be attractive, even assuming successful development of fusion or breeder reactors.

An emerging factor that will strongly affect electricity demand is the success in developing demand technologies that use electricity very efficiently. It is likely over the next several decades that the price of electricity will come close enough to other forms of energy (synthetic fuels, direct solar, etc.) that the relative efficiencies of the end-use equipment will determine which energy form is the cheapest. Therefore, electricity demand could grow considerably if such things as very efficient space and water heat pumps, electrochemical industrial processes, and high-capacity storage batteries are developed. If these are not forthcoming and the conventional ways of using energy–direct combustion of liquid and gaseous fuels–continue to be most prevalent, then electricity demand in the United States will not increase rapidly if at al 1. Therefore, the eventual need for solar power satellites and other central electric technologies would be determined as much by the development of efficient electric demand technologies as by its economics relative to other electric energy technologies.

Comparison to Other Renewable Options

Ultimately the United States and the world will choose or reject SPS as an energy supply option on the basis of comparative costs as well as environmental and social impacts. OTA has generated a number of criteria for the choice of energy technologies and compared SPS with other renewable or inexhaustible options (fusion, nuclear breeder, terrestrial solar thermal, and solar photovoltaic) on the basis of those criteria (see table 16, p. 11 6). What emerges from such comparisons is that if the research, development, demonstration, and testing (RDD&T) costs and the estimated cost per installed kilowatt can be lowered significantly, SPS could compete with the alternatives on an economic basis. SOLARES, for instance, might already be economical compared to conventional nuclear. SPS technical uncertainties are much higher than for the breeder, but lower than for fusion. Social costs are extremely difficult to determine, but if research demonstrated the microwave and lonizing radiation hazards to be low, SPS could substitute low-risk environmental hazards for the high risks of coal or nuclear as well as contribute to an expanded space program. It would take longer to commercialize than terrestrial solar or breeder, but less than fusion. In competition with other technologies, overall demand for electricity, and the timing of the commercial introduction of SPS vis-a-vis other options will be crucial.

UTILITIES

Would SPS be acceptable to the utilities?*

The major factors that would affect the utilities' decision about SPS technology are cost, reliability, unfamiliarity with space systems, and institutional questions. Only demonstration, and successful experience with an operational SPS over several years, would assure the utilities that it is a viable technology for their use. If the microwave systems were as reliable and available as their designers suggest they could be (90 percent or more), the utilities would welcome them for baseload generation, assuming their size and costs were also appropriate. The laser system might be of interest to the utilities if it could be used to repower existing thermal facilities. The suggested unit size of the laser system (500 to 1,000 MW) would fit well into the present size mix of terrestrial powerplants. A mirror system with its highly centralized, energy producing facility (10 to

*See ch 9, *The Implications for the Utility Industry* section

100 GW) would be too large for the present size mix, but would offer the potential for some flexibility in energy production. Direct electricity and hydrogen generation are both possible in a SOLARES-type energy park. However, because the SPS would be an integral part of the utility grid, it would impose certain constraints on grid dispatch management. The physical requirements of the rest of the utility grid would in turn impose constraints on the design of SPS. Integrating SPS into the grid involves several difficult system problems.

Microwave Transmission. —

- Stability. Because a microwave SPS is an electronic system, not a mechanical one, any power fluctuations due to beam-pointing errors or to large-scale component failure would be rapid (the order of a second or less). The rest of the grid would only be able to respond relatively slowly (minutes), creating difficulties in controlling the frequency of current and overall power levels in the grid. The importance of this difficulty is directly dependent on the size of the SPS contribution. The smaller the output from a satellite-rectenna combination, the easier it will be to control. Some, if not all of this drawback of the microwave system could be alleviated by including short-term battery storage to act as a buffer between the SPS rectenna output and the grid. The stability of the grid would not then depend on the stability of the microwave mode of transmission. However, buffer storage would increase system costs. The optimum amount of storage that might be needed has not been determined, but cost estimates range from 0.5 to 5 percent of the total system costs.
- *Load following and variations of SPS power.* The rectenna output would vary seasonally depending on the distance of the Earth from the Sun. The amount of the variation, and the rate at which SPS power changes, would in principle pose no technical problem for the grid.

  Because any satellite that lies in a geostationary orbit experiences eclipses (1 to 72 minutes) around the equinoxes (March 21 and September 21) when the Earth's shadow falls across the satellite, a reference system satellite would suffer power interruption. A number of satellites would be eclipsed at one time. The rate at which the eclipsing occurs would cause the SPS power to fall at a rate of about 20 percent per minute, much faster than the utility grids are expected to be able to respond. This could be alleviated by shutting the satellite down slowly in advance of the shadow, with a consequent extra small loss of SPS power for the period, or by including buffer storage as suggested above. If daily load curves maintain their current shape, the eclipse would occur near the daily minimum (local midnight), necessitating less backup capacity than would otherwise be the case.

  In principle, SPS could be designed to follow the daily load, but because of its high capital costs it would be uneconomical to do so. It is designed to deliver continuous, baseload power. Hence the burden of following any shifts in load would be placed on conventional terrestrial intermediate load units in the utility system.
- *Microwave beam positional errors.* The beam could be centered on the rectenna by means of a pilot beam directed towards the satellite antenna from the center of the rectenna. Because the signal would take about 0.2 seconds to sense a position error and correct the pointing of the beam, the antenna output would be subject to a potential frequency variation of about 5Hz (5 cycles/see). Power variations of tens of megawatts from this source could make utility grid manage ment extremely difficult. Weather fronts could adversely affect the position of the beam, but the resultant power variation would be slow. Again, buffer storage could be used to alleviate these difficulties.

Because the difficulties posed by each of the above factors increase with size, the utilities might not find the single 5,000-MW unit proposed by the reference system acceptable even in the future. Although nuclear, fusion, or coal energy parks having about 5,000 MW total capacity have been proposed, they would be composed of several smaller units, each of which are only about 1,000-MW capacity. In addition, in planning for overall system reliability, utilities generally use the criterion that no single unit in the system can account for more than 10 to 15 percent of the total system. Thus, in order to place a 5,000-MW unit in the grid, the grid should have a total system capacity of 33,000 to 50,000 MW. At current rates of electrical growth (3.2 percent per year), only the Tennessee Valley Authority (TVA), the country's largest utility, will have a grid large enough to accommodate a 5,000-MW SPS in 2000. TVA currently has a capacity of 23,000 MW, but it has stopped construction on several new powerplants because of slower demand growth. A national power grid might alleviate the problem of utility grids being too small to accommodate a 5,000-MW SPS.

Laser Transmission.— From the utilities' perspective, the most serious difficulty facing laser transmission is absorption by clouds. Although in a few locations in the country it appears to be technically possible to switch from a cloud covered area to one that is cloud-free, utilities would have little incentive to construct the extra facilities to accommodate such switching unless the economic benefits were commensurate with the expense of the extra facilities. In general, the various sites are unlikely to be all in the same service area, further complicating the ability of the utility to follow the load.

Mirror Reflection. —

- Reflection of sunlight from space suffers from the same disadvantage as that of the laser option: the reflected beam could easily be degraded or occluded by cloud cover. it has been suggested that the additional radiant energy might be enough to dissipate clouds, but this might have detrimental environmental effects and alter weather patterns over a wide region around the energy park.
- As conceived in the "baseline" case, the mirror system would require large energy parks capable of producing more than 100 GW. Smaller parks of 10 GW might also be possible. Even the relatively smaller parks would necessitate major changes in current utility operation and load management. Among other changes, such parks would necessitate building an extensive new network of major transmission lines to distribute electrical power from remote receiving areas to end-users.

In principle, all of the technical problems for the different systems are resolvable at some cost. However, they would require considerable further study and testing as well as a close look at the system economics.

Nontechnical Considerations

In addition to the technical difficulties that SPS can be expected to face, there are a number of potential institutional barriers to SPS acceptance by U.S. utilities:

- SP5 as a *space system.* The current utility management and regulatory infrastructure is much more receptive to the terrestrial renewable or inexhaustible options— breeder reactor and fusion for baseload, and solar thermal and solar photovoltaic for intermediate and peaking loads.
- *Regulatory framework.* Utilities are currently regulated on a State or local basis. SPS could be expected to hasten the move towards greater centralization of the regulatory process (i.e. Federal level). A SOLARES-type SPS, because of its large centralized energy parks, would make a high degree of centralization mandatory. However, other SPS modes may also lead to more centralized regulation, particularly if the SPS were constructed and managed by a federally chartered monopoly (see Ownership *and Finance)* or Government agency.

  Nuclear powerplants are currently regulated at the Federal and State level for health, safety, and environmental impacts. However, their effect on the rate structure is regulated at the State and local level. An SPS corporation might lead to Federal involvement in setting rates for power as well as regulating SPS technology. The utilities and local regulatory agencies could be expected to resist any pressures toward greater Federal involvement in what has traditionally been their province.

Ownership and Finance

Electric utilities currently face a serious problem raising the capital necessary to install new generating capacity. Because of this, and because they lack launch and space construction capability, they are unlikely to own or operate the space segment of an SPS system directly; they could more easily be responsible for the ground receivers. This raises the question of how domestic SPSs would be financed and managed.

The central issues are: 1) the degree and kind of government involvement; and 2) how to differentiate between the R&D and construction/operation phases.

- Government involvement. The arguments for Government financing and ownership would be that the high fronnt-end costs and high-risk long pay-back times inhibit private sector investment, and that lack of competition would necessitate Government ownership. Certain aspects of TVA or NASA could provide possible guidance for SPS ownership and operation.

  On the other hand, it can be argued that direct Government involvement is contrary to American preference for private enterprise, that centralized control would lead to inefficiencies, and that U.S. Government ownership would make military participation far more likely. Furthermore, it is feared that Government investment in SPS would drain resources from other energy technologies that need Federal support. A Government-chartered but privately owned and operated company similar to Comsat, or a regulated private monopoly such as AT&T, might be preferred. Since the United States is party to international law that requires national governments to bear the responsibility for space activities, even when carried out by nongovernmental entities, some degree of Federal supervision and involvement will be required in any case.
- R&D and operating phases. Raising private capital would be especially difficult during the research, development, and demonstration phase. A successful prototype demonstration would probably be necessary to attract private investment. If SPS is judged to be a feasible energy option, prototype development is likely to require Federal funding, perhaps via taxes, similar to the Interstate Highway System trust fund, or through "Space Bonds." After that, it is likely that Government loans or guarantees would be required, at a minimum. At some stage the technology could be turned over to the private sector. Instances of such practices have included nuclear reactors, first developed for military use in submarines; and telecommunications technology, funded by NASA and then turned over to Comsat and commercial carriers. Clarification of current patent provisions for NASA and other Government research contracts would facilitate such transfers. Upcoming examples that should be examined for their applicability to SPS are the Space Shuttle, which has been developed by NASA but may eventually be turned over to private enterprise, due to restrictions on NASA operation of commercial ventures; the newly established U.S. Synfuels Corp., which is intended to provide money for a variety of private synthetic fuels ventures; and the European Space Agency's (ESA) Ariane launcher, which will be operated by a private consortium called Arianespace. Private joint ventures, such as Satellite Business Systems or the Alaska pipeline consortium, are another possible way to establish a "Solarsat" Corp. for the construction and operating phases.

  A combination of the suggested models, involving different degrees of Government and private financing, may be more feasible than any of the specific models mentioned. Providing for a smooth transition between public and private investment phases would be an important concern. A critical consideration should be the ability of an SPS organization to attract foreign capital and to involve foreign participants at early stages of development. (See International Implications.)

INTERNATIONAL IMPLICATIONS

What are the international implications of solar power satellites?*

Development and construction of an SPS system would necessarily involve a number of international dimensions. At a minimum, current and future international treaties and agreements, especially those dealing with the allocation of the electromagnetic spectrum, would require consultation with foreign states and multinational organizations. Beyond this, there may be good reasons to consider an active multilateral regime to regulate, build, and/or operate the SPS.

International organizations, multinational corporations, and domestic interest groups will all be involved in SPS decisions. However, due to the SPS's cost, benefits, and military/foreign policy impacts, which would directly affect the vital national interests of other nations involved, such decisions will ultimately be made at the national level by political leaders.

Economic Impact.– If successful, the SPS promises to deliver significant amounts of electricity. Estimates of future global electricity demand by the International Institute for Applied Systems Analysis (IIASA) indicate that, even with low rates of economic growth, electricity usage will increase by a factor of 4 over the next 50 years. Regional variations in growth rates will be considerable, with developed countries increasing at a much slower rate than developing ones. Recent studies for the United States that take into account marked reductions in usage rates, such as the National Academy of Sciences' Energy in Transition 1985-2010 indicate that demand in the developed countries may remain constant or rise only Slightly over the next 30 years. On a global scale, this might indicate a rise less than that predicted by IIASA. Meeting this demand will be particularly difficult in energy-scarce areas such as Western Europe, Japan, and much of Latin America, Africa, and South Asia. Countries in these regions will be especially interested in SPS development.

Noneconomic Impact. -The noneconomic effects of SPS would influence the decisions of the major space powers, the United States and the U.S.S.R. The prestige of such a major space and energy accomplishment would be considerable. The military advantages of high-capacity launch vehicles and a large energy-producing platform in high orbit would be significant, even if SPS were not used for direct military purposes.

The United States and the U.S.S.R. both have extensive conventional energy sources–oil, coal, oil shale, and uranium. Thus, neither country can be expected to develop an SPS unilaterally unless unpredictable obstacles to the use of coal and/or nuclear power develop. SPS is therefore likely to be pursued in conjunction with foreign partners who contribute capital and expertise and buy completed satellites. Both Western Europe and Japan, who have extensive space programs and a history of cooperation with the United States, would be probable partners. Soviet secrecy and military domination of their space program makes international cooperation on their part unlikely.

International Cooperation.– Experience with multilateral organizations suggests that estab-

*See ch. 7.

1 The global estimates cited in *Energy in Transition,* however, are similar to IIASA's; a rise of three to five times in electricity consumption by 2010. See *Energy in Transition,* National Academy of Sciences, 1979, p. 626.

lishing and running a successful international venture would be difficult. Reconciling the different interests of the participants regarding overall system design, decision making, and allocation of contracts and financial returns would be time-consuming and might compromise timely and efficient results. The example of Intelsat suggests the importance of strong national support by interested parties, of independent corporate management, and a profit-incentive. However, it is unlikely that an agency modeled on Intel sat could be duplicated today for SPS. In particular, the role of LDCs would be greater and could be disruptive unless North-South conflicts can be kept from dominating day-to-day decisions. Strong leadership by the United States and the Organization of Economic Cooperative Development partners would be required to maintain an effective program.

International Law.– International law currently requires allocation of satellite frequencies and geostationary positions by the international Telecommunication Union (ITU). If SPS were to interfere with global communications, this could be a major obstacle to gaining ITU approval. ownership and control of the geostationary orbit has not been completely resolved, and attempts by equatorial states to claim sovereignty over it could hamper development of any geostationary SPS. The proposed Moon Treaty, which calls for an international regime based on the principle of the Common Heritage of Mankind, provides a precedent for international control over space resources, and may affect plans to construct SPS from lunar materials. In each of these cases it can be expected that future LDCs will seek to gain leverage over any SPS regime by controlling access to space. Accommodating LDC interests in a manner compatible with SPS development may be difficult or politically impossible; the precedent set by the uncompleted Law of the Sea negotiations should be carefully considered.

Military Impact. – The military uses of an SPS, especially for directed-energy weaponry, would be restricted by the 1972 Anti-Ballistic Missile (ABM) Treaty and by provisions in the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space banning weapons of "mass destruction" in orbit. Although SPS would not lend itself to efficient use as a weapons-system,* objections to the SPS on military grounds, and demands for inspection and/or redesign to preclude military uses, can be expected. Multilateral development would alleviate many such problems.

Foreign Interests.—To date, space agencies and private firms in foreign countries such as England, France, West Germany, and Japan, along with ESA, have expressed interest in SPS. Most foreign studies have focused on regional applications; technical and operational studies have been done almost exclusively in the United States. Soviet interest has been expressed for several years, with several technical papers published, but no details are known. Third World interest has been informal and cautiously favorable. Future discussion at the United Nation's Committee on the Peaceful Uses of Outer Space and other international bodies will be forthcoming. Any further U.S.-sponsored study of SPSs must take into account international participation in SPS development, and demand for SPS power, in order to evaluate properly the feasibility of SPS programs.

*See ch 7, *Military Uses of SPS* section

NATIONAL SECURITY IMPLICATIONS

What are the national security implications of SPS?*

The military importance of SPS would derive from its very large size, its geostationary orbital position (for certain designs), and its ability to provide tremendous amounts of power. Aside from the important result of reducing

*For extended discussion see ch, 7

the user state's dependence on imported energy, SPS would be strategically significant as a target, as the catalyst for new space transportation and construction capabilities, and as a possible weapons-system.

Vulnerability. –A full-scale SPS system would constitute a high-value target for enemy action. Whether an SPS would in fact be targeted in the event of hostilities will depend above all on how crucial it is to a country's electrical supply. Can SPS power be made up from other sources? Is the attacker vulnerable to a counter-attack in kind? Best estimates are that an SPS system would be unlikely to constitute more than 10 to 20 percent of total generating capacity, in the countries that use SPS, over the next 50 years. Holding SPS to this percent would make it possible to replace SPS power from conventional reserve capacity. However, usage could be much higher in specific regions or industries. A widespread national grid could alleviate the threat of SPS outages. In general, SPS would be no more Vulnerable than other major energy systems.

SPSs could be attacked in a number of ways: 1) by ground-launched missiles carrying nuclear or conventional warheads, 2) by orbiting antisatellite platforms, 3) by ground- or space-based directed-energy weapons, 4) by strewing debris in the satellite's path, and 5) by interfering with or redirecting the SPS's energy transmission beam.

The large size of most SPS options would make it difficult for conventional explosives to do serious damage. Lasers would likely be more effective. Strewing debris in geosynchronous orbit would destroy a reference system SPS, but also affect many other targets, including friendly and neutral spacecraft. Beam interference would be less damaging and would require special preparation to protect against. Nuclear weapons could damage SPSs by direct blast, and also by the electromagnetic pulse (EMP) effect, which might overload the satellite's electrical systems — a large (1 megaton or more) nuclear explosion could damage a photovoltaic SPS at ranges up to hundreds of kilometers.

The use of nuclear weapons outside of a major nuclear exchange would carry great dangers of escalation. Any attack, nuclear or conventional, would depend on perceptions of whether SPS is considered part of national territory and how leaders would react to such a provocation. The analogy to ships on the high sea suggests that an SPS in orbit might be considered fair game even short of full-scale war. Attacks on SPS would also be affected by whether the SPS was manned; destroying an unmanned craft might be undertaken as a relatively unprovocative demonstration of will. At present, neither the United States nor the U.S.S.R. has the ability to attack objects in geosynchronous orbit, but both are working on various antisatellite devices and there appear to be no insurmountable obstacles to their development.

Defense of space craft is possible through: 1) maneuverability, 2) hardening, and 3) antimissile defenses.

The SPS would be too large and fragile to evade attack. Hardening against explosives or EMP bursts would add significantly to weight and costs, and could not be effective against a determined attack. Stationing missile or satellite defenses on a geostationary SPS, whether directed-energy weapons or antimissile missiles, would be feasible due to the power generated by the SPS and its position at the top of a 35,800-km "gravity well". However, such weapons would have unavoidable offensive capabilities and would therefore invite attack. Defense of civilian SPSs could probably be best done by independent military forces, on the ground or in space, rather than by turning the SPS itself into a space-fortress.

Receiving antennas or (for the mirror-system) PV 'parks' would make unattractive targets due to their large size and redundancy; they would certainly be no more vulnerable than other generating facilities. It should be noted that the SOLARES system could continue to produce power, albeit at approximately one-fifth rated capacity, by operating on ambient sunlight even if the space mirror system were destroyed.

Military Uses. –The military usefulness of an SPS stems from: 1) the launchers and other facilities used to construct the satellite portion; 2) the energy beams used by the SPS to transmit power; and 3) its strategic orbital location.

HLLVS or other transportation and construction systems would be perhaps the most direct military benefit of SPS. These could be used by the military to build large space platforms for communications, surveillance, or weaponry. Such activities might be disguised by being carried out during SPS construction, but it is unlikely that they could escape detection by interested parties. Development of such systems would be most important, and destabilizing, in providing a "break-out" capacity for rapid emergency deployment of military satellites by fleets of SPS construction vehicles.

Laser beams built as part of SPS, or more militarily efficient weapons placed on the SPS but not used in transmitting electricity, could be used as strategic weapons. In recent years both the United States and the U.S.S.R. have undertaken large programs to develop directed-energy weapons for use against satellites and/or international ballistic missiles (ICBMs). However, a geostationary SPS is 35,800 kilometers distant from low-flying ICBMs. This distance complicates tracking and requires very high beam intensities. Much greater effectiveness can be achieved by weapons placed in lower orbits. However, a geostationary SPS could play a role in supplying power to remotely located directed-energy platforms. A laser SPS in low Sun-synchronous orbit, of course, would represent a much greater military potential than one in geosynchronous orbit.

Use of SPS, even indirectly, for ABM purposes is currently prohibited by the 1972 ABM Treaty. A militarily effective SPS would be a major factor in strategic planning and would likely be a subject of arms-control negotiations between interested states. Provisions for direct inspection, or design specifications to reduce an SPS's military usefulness, could be negotiated to reduce the various threats it poses. Such provisions might be needed even if SPS would not be militarily useful, but was nevertheless perceived to be a military or political threat.

Using an SPS directly against targets on the ground would ease tracking requirements. High-energy lasers (H EL) or particle-beams could conceivably be used to destroy quickly tactical targets such as ships, planes, or oil refineries without jeopardizing one's own personnel or risking the use of nuclear weapons. However, SPS lasers used for energy transmission would probably not make effective weapons without considerable modification. SPS could also be used to supply electrical power to military units in remote areas, and perhaps even directly to ships or planes.

SPS could serve as a platform for certain surveillance and communications needs. Because of its power, it might be especially suited for conducting jamming and electronic warfare operations.

SPS platforms, because of their size and facilities, would be likely to serve as multipurpose space bases similar to major seaports. If military units used SPS for resupply or rest and recreation, it might be difficult to separate military from civilian uses, or to convince outside observers that SPS was not a military threat.

Any such direct uses of SPS would be determined by the way in which future SPSs are built and managed. Construction by an independent multinational enterprise would reduce any state's ability to use an SPS for military purposes; conversely, unilateral development would enhance it. Use of SPSs as weapons platforms by future superpowers would invite considerable foreign criticism, especially if such attempts interfered with their electricity-generation function. A sudden diversion of SPS power to the military in time of crisis could lead to domestic and/or foreign electricity shortages, resulting in legal or diplomatic protests.

PUBLIC ISSUES

The SPS debate: what are the issues arising in the public arena?*

While public awareness of SPS is growing, most discussion has been confined to a small number of public interest groups and professional societies. In general, many of the individuals and groups who support the development of SPS also advocate a vigorous space program. The L-5 Society has been a particularly vocal SPS supporter and views the satellite system as an important stepping-stone in the colonization of space, a goal to which the society is dedicated. The SUNSAT Energy Council, a group formed to promote interest in SPS, believes that it is one of the most promising options available for meeting future global energy and resource needs. Professional associations such as the American Institute of Aeronautics and Astronautics (AIAA) and the Institute of Electrical and Electronics Engineers (1 E E E), have supported continued research and evaluation of the concept.

Many opponents of SPS are concerned that it would drain resources from the development of terrestrial solar technologies. The Solar Lobby and other public interest groups argue that compared to these ground-based solar options, SPS is inordinately large, expensive, and complex, and that it poses greater environmental and military risks while precluding local decisionmaking. Many opponents also maintain that all future energy demand can be easily met with existing and future terrestrial energy technologies; there is little need to develop SPS, especially in view of the formidable costs to initiate the technology and the highly uncertain cost of the product. The Citizen's Energy Project (CEP) has been an active lobbyist against Government funding of SPS and has coordinated the Coalition Against Satellite Power Systems, a network of solar and environmental organizations. Objections to SPS have also been raised by individuals in the professional astronomy and space science communities who see SPS as a threat to the funding and practice of their respective sciences. In the future, it is conceivable that antinuclear, antimilitary and tax groups could also join the opposition.

Public opinion about SPS can be influenced by a multitude of factors; concerns articulated today may not be as important in the future. In addition, in much of the current public discussion, SPS is treated as a U.S. system alone. If SPS were to be developed on an international basis, the flavor of present opinion could change. Currently, debate about SPS focuses on the question of R&D funding. This and other issues are highlighted in table 2.

'See ch 9, Issues Arising in the Public Arena section

ENVIRONMENT AND HEALTH

How would SPS affect human health and the environment?*

As an energy system operating both in space and on Earth, SPS involves some rather diverse and unique environmental issues (see table 3). While one advantage of SPS is that it would avoid many of the environmental risks typically related to conventional energy options such as nuclear and coal, it would also generate some unconventional environmental effects which are poorly understood at present. The resolution of the uncertainties associated with these effects is critical to the assessment of the environmental acceptability of SPS. More research is needed to understand and quantify these impacts and to investigate modified system designs that would minimize environmental risks. At present, there are three major areas of concern.

1. Bioeffects of Electromagnetic Radiation.—The effects of exposure to SPS power transmission and high-voltage transmission lines

*See ch. 8.

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Table 2.—Major Issues Arising in SPS Debate[a]

Pro	Con
R&D funding	
• SPS is a promising energy option • The Nation should keep as many energy options open as possible • An SPS R&D program is the only means of evaluating the merit of SPS relative to other energy technologies • SPS R&D will yield spinoffs to other programs	• SPS is a very high-risk, unattractive technology • Other more viable and preferable energy options exist to meet our future energy demand • SPS would drain resources from other programs, especially terrestrial solar technologies and the space sciences • No matter what the result of R&D, bureaucratic inertia will carry a Government program too far
Cost	
• SPS is likely to be cost competitive in the energy market • Cost to taxpayer is for R&D only and accounts for small portion of total cost; private sector and/or other nations will invest in production and maintenance • SPS will produce economic spinoffs	• SPS is unlikely to be cost competitive without Government subsidy • Like the nuclear industry, SPS would probably require ongoing Government commitment • Projected costs are probably underestimated considerably • The amount of energy supplied by SPS does not justify the cost
***Environment, health* and safety**	
• SPS is potentially less harsh on the environment than other energy technologies, especially coal	• SPS risks to humans and the environment are potentially greater than those associated with terrestrial solar technologies • Major concerns include: health hazards of power transmission and high-voltage transmission lines, land use, electromagnetic interference, upper atmosphere effects, and "skylab syndrome"
Space	
• Space is the optimum place to harvest sunlight and other resources • SPS could be an important component or focus for a space program • SPS could lay the groundwork for space industrialization and/or colonization • SPS would produce spinoffs from R&D and hardware to other space and terrestrial programs	• SPS is an aerospace boondoggle; there are better routes to space industrialization and exploration than SPS • SPS is an energy system and should not be justified on the basis of its applicability to space projects
International ***considerations***	
• One of the most attractive characteristics of SPS is its potential for international cooperation and ownership • SPS can contribute significantly to the global energy supply • SPS is one of the few options for Europe and Japan and is well-suited to meet the energy and resource needs of developing nations • An international SPS would reduce concerns about adverse military implications	• SPS could represent a form of U.S. of industrial nations' "energy imperialism"; it is not suitable for LDCs • Ownership of SPS by multinational corporations would centralize power
Military implications	
• The vulnerability of SPS is comparable to other energy systems • SPS has poor weapons potential • As a civilian program, SPS would create little military spinoffs	• Spinoffs to the military from R&D and hardware would be significant and undesirable • Vulnerability and weapons potential are of concern
Centralization and scale	
• Future energy needs include large as well as small-scale supply technologies; urban centers and industry especially cannot be powered by small-scale systems alone • SPS would fit easily into an already centralized grid	• SPS would augment and necessitate a centralized infrastructure and reduce local control, ownership, and participation in decision-making • The incremental risk of investing in SPS development is unacceptably high
Future energy demand	
• Future electricity demand will be much higher than today • High energy consumption is required for economic growth • SPS as one of a number of future electricity sources can contribute significantly to energy needs • Even if domestic demand for SPS is low, there is a global need for SPS	• Future electricity demand could be comparable to or only slightly higher than today's with conservation • The standard of living can be maintained with a lower rate of energy consumption • There is little need for SPS; demand can be met easily by existing technologies and conservation • By investing in SPS development, we are guaranteeing high energy consumption, because the costs of development would be so great

[a] arguments mainly focus on the SPS reference system

SOURCE: Office of Technology Assessment.

Table 3.—Summary of SPS Environmental Impacts

System component characteristics	Environmental impact	Public health and safety	Occupational health and safety
Power transmission			
Microwave	—[b]Ionospheric heating could disrupt telecommunications. Maximum tolerable power density is not known. Effects in the upper ionosphere are not known. —Tropospheric heating could result in minor weather modification. —[b]Ecosystem: microwave bio-effects (on plants, animals, and airborne biota) largely unknown; reflected light effects unknown. —[b]potential interference with satellite communications, terrestrial communications, radar, radio, and optical astronomy.	—[b]**Effects of low-level chronic exposure to microwaves are unknown.** — **Psychological effects of microwave beam as weapon.** —**Adverse aesthetic effects on appearance of night sky.**	—**Higher risk than for public; protective clothing required for terrestrial worker.** —**Accidental exposure to high-intensity beam in space potentially severe but no data.**
Lasers	—Tropospheric heating could modify weather and spread the beam. —Ecosystem: beam may incinerate birds and vegetation. —[b]potential interference with optical astronomy, some interference with radio astronomy.	—Ocular hazard? —Psychological effects of laser as weapon are possible. —Adverse aesthetic effects on appearance of night sky are possible.	—Ocular and safety hazard?
Mirrors	—[b]Tropospheric heating could modify weather. —Ecosystem: effect of 24-hr light on growing. cycles of plants and circadian rhythms of animals. —[b]potential interference with optical astronomy.	—Ocular hazard? —Psychological effect of 24-hr sunlight. —[b]Adverse aesthetic effects on appearance of night sky are possible.	—Ocular hazard?
Transportation and space operation			
Launch and recovery HLLV PLV COTV POTV	—Ground cloud might pollute air and water and cause possible weather modification; acid rain probably negligible. —[b]Water vapor and other launch effluents could deplete ionosphere and enhance airglow. Resultant disruption of communications and satellite surveillance potentialy important, but uncertain. —[b]possible formation of noctilucent clouds in stratosphere and mesosphere; effects on climate are not known.	—Noise (sonic boom) may exceed EPA guidelines. —Ground cloud might affect air quality; acid rain probably negligible. —Accidents-catastrophic explosion near launch site, vehicle crash, toxic materials.	—[b]Space worker's hazards: ionizing radiation (potentially severe) weightlessness, life support failure, long stay in space, construction accidents psychological stress, acceleration. —Terrestrial worker's hazards: noise, transportation accidents.

Table 3.—Summary of SPS Environmental Impacts—Continued

System component characteristics	Environmental impact	Public health and safety	Occupational health and safety
	—[b]Emission of water vapor could alter natural hydrogen cycle; extent and implications are not well-known. —[b]Effect of COTV argon ions on magnetosphere and plasma-sphere could be great but unknown. —Depletion of ozone layer by effluents expected to be minor but uncertain. —Noise.		
Terrestrial activities			
Mining	—Land disturbance (stripmining, etc.). —Measurable increase of air and water pollution. —Solid waste generation. —Strain on production capacity of gallium arsenide, sapphire, silicon, graphite fiber, tungsten, and mercury.	—Toxic material exposure. — Measurable increase of air and water pollution. — Land-use disturbance.	—Occupational air and water pollution. —Toxic materials exposure. —Noise.
Manufacturing	—Measurable increase of air and water pollution. —Solid wastes.	—Measurable increase of air and water pollution. —Solid wastes. —Exposure to toxic materials.	—Toxic materials exposure. —Noise.
Construction	—Measurable land disturbance. —Measurable local increase of air and water pollution.	—Measurable land disturbance. —Measurable local increase of air and water pollution.	—Noise. —Measurable local increase of air and water pollution. —Accidents.
Receiving antenna	—[b]Land use and siting. —Waste heat and surface roughness could modify weather.	—[b]Land use—reduced property value, aesthetics, vulnerability (less land for solid-state, laser opt ions; more for reference and mirrors).	— Waste heat.
High-voltage transmission lines (not unique to SPS)	—[b]Land use and siting. —[b]Ecosystem: bioeffects Of powerlines uncertain.	—[b]Exposure to high intensity EM fields—effects uncertain.	—[b]Exposure to high intensity EM fields—effects uncertain.

[a]Impacts based on SPS systems as currently defined and do not account for offshore receivers or possible mitigating sYstem modifications.
[b]Research priority.

SOURCE: Office of Technology Assessment.

(HVTL) on humans, animals, and plants are highly uncertain. The existing data base is incomplete, often contradictory and not directly applicable to SPS. 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. The biological systems that may be most susceptible to microwaves include the immunological, hematological (blood), reproductive, and central nervous systems. The DOE SPS assessment has sponsored three studies of the effects of low-level microwaves on bees, birds, and small mammals. No significant effects have been observed, but the experiments are far from complete. More research is vitally needed to expand the experimental and clinical data base, and to improve theories which may facilitate the extrapolation from animal studies to assessments of human health hazards.

It appears that the United States will establish a microwave standard in the near future that is more stringent than the present occupational 10.0 mW/cm^2 voluntary guideline (the new occupational standard at 2.45 GHz will probably be 5.0 mW/cm^2), thereby approaching the standards in other countries (e. g., Canada: population —1.0 mW/cm^2, occupational —5.0 mW/cm^2; U. S. S. R.: population—0.001 mW/cm^2, occupational —0.01 mW/cm^2). This does not have an immediate impact on SPS land use for the reference system, since it is designed to produce less than 1.0 mW/cm^2 at the rectenna boundary and less than 0.1 mW/cm^2 outside the rectenna boundary. Nevertheless, establishing population standards that are more stringent could mean more land for each buffer zone and could affect system design (power density and beam taper) as well as public opinion.

With respect to spaceworkers, exposure to ionizing radiation (including that from the radiation belts, galactic cosmic rays, and solar flares) would be a health hazard unless steps are taken in future planning to minimize dose. Studies are needed to determine acceptable exposure limits. Research is needed to determine more precisely the expected dose rates, the types and energies of ionizing particles, and the effectiveness rate of various types and thicknesses of shielding. The results will determine the number of spaceworkers, the duration of the stay, the mass needed in orbit (for shielding), and space suit and system designs. All of these impacts may strongly affect SPS costs and feasibility.

For SPS systems other than the microwave designs, 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 hour per day sunlight and possible ocular damage from viewing the mirrors, expecially through binoculars.

2. Effects on the Upper Atmosphere.– 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. Experiments indicate that the effects on telecommunications of heating the lower ionosphere are negligible for the systems tested. As a result, a few researchers have suggested that microwave power densities of up to 40 to 50 mW/cm^2, or two times the level assumed for the reference design, could be used before significant heating would occur.

The largest uncertainty is related to heating and nonlinear interactions in the upper ionosphere. To investigate the heating effects in this region, more powerful heating facilities would be required.

The atmospheric effects resulting from the emission of rocket effluents from SPS space vehicles are of concern because of the unprecedented magnitude and frequency of the projected SPS launches. In the magnetosphere, construction of the SPS reference system as presently designed would lead to a dramatic increase in the naturally occurring abundance of argon ions (from the electric propulsion system proposed for orbital transfer) and hydrogen atoms. While several possible effects have been identified, including enhanced airglow and Van Allen belt radiation, and altered atmospheric electricity and weather, the likelihood and severity of these effects are highly uncertain.

The injection of water vapor at lower altitudes would significantly increase the water content relative to natural levels. One possible consequence is an increase in the upward flux of hydrogen atoms through the thermosphere. Another consequence of increasing the concentration of water in the upper atmosphere might be the formation of noctilucent clouds in the mesosphere. While global climatic effects of these clouds appear unlikely, uncertainties remain.

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 telecommunication 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.

3. Land Use and Receiver Siting.– 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: 1) finding geographically and meteorologically suitable areas; 2) finding sparsely populated areas; 3) keeping down the cost of power transmission lines and transportation to the construction site; 4) siting as close to the Equator as possible (for GEO systems) so as to keep the north-south dimension of the receiver reasonably small; 5) coordinating receiver sites with utility grids and the regional need for electricity; 6) the cost of land; and 7) 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. In addition, for the reference and SOLARES systems, as presently designed, large contiguous plots of land would have to be located and totally dedicated to one use (table 4). The laser options might require less land area per site, but a greater number of sites to deliver the comparable amount of power.

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. In addition the plausibility of multiple uses (e.g., agriculture or aquiculture), offshore siting (especially for land-scarce areas such as

Table 4.—SPS Systems Land Use

SPS system	km^2/site	km^2/1,OOOMW	Number of sites for 300,000 MW	Total land area(km^2) for 300,000 MW	m^2/MW-yr
Reference	174	35.0	60	10,400	1,233[b]
Solid state[c]	50	33.0	180	9,000	1,163[b]
Laser I[d]	0	1.2	600	360	42-51[e]
Laser II[d]	40	80.0	600	24,000	2,819-3,382[e]
Mirror I	1,000		-29	***2,200***	***261-313[e]***
Mirror II[f]	100	9.6	30	2,880	338-406[e]
For comparison					
Washington.	174.0				
New York City.	950.0				
Chicago.	518.0				

aRectenna at 34. latitude covers a 117 km^2 ellipitical area. Microwave power density at edge of rectenna is 1.0 mw/cm^2. If an exclusion boundary is set at 0.1 mW/Cm^2, then the total land per site is approximately 174 km^2. J. B. Blackburn, *Sate//ire Power System (SPS) Mapping of Exclusion Areas for Rectenna Sites,* DOE/NASA Report HCP/R-4024-10, October 1978 does not include land for mining or fuel transport.
bThe values for the reference and solid-state designs assume a 30-year lifetime and a capacity factor of 0.9
cThe solid-state sandwich design is described in G. M. Hanley et al., "Satellite Power Systems (SPS) Concept Definition Study, " First Performance Review, Rockwell International Report No. SSD79-0163, NASA MSFC Contract NAS8-32475, October 10, 1979.
dLaser I and Laser II are two laser systems considered by DOE. Both deliver the same amount of power but the beam of Laser I is more narrow (and hence more intenSe) than that of Laser II. See C. Bain, *Potential of Laser for SPS Power Transmission,* October 1978, Department of Energy, HCP/R-4024-07.
eThe values for the laser and mirror systems assume a 30-year lifetime and capacity factors of 0.75-0.9.
fMirror I system parameters are defined by SOLARES "baseline system" and Mirror II system for low (1,100 km) orbit.
gThe SOLARES baseline system is designed to deliver 81O GW to 6 sites; 2 SOLARES baseline sites actually provide 270 GW.

the Northeast United States, Europe, and Japan) and possible receiver siting in other nations, with their particular environmental constraints, need to be explored.

The regional political problems may be more severe than the technical ones, especially in light of past controversies over the siting of powerplants, powerlines, and military radar and other facilities. While 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.

It is essential that many of the environmental uncertainties be diminished and that the effects are shown to be, at worst, comparable to those of alternate inexhaustible energy sources, before commitment to the development of SPS because:

1. **environmental effects may be identified for which there are no acceptable mitigation strategies or for which mitigation is too costly to make SPS competitive; and**
2. **they have a great bearing on the system design, e.g., choice of frequency, power level and distribution may be determined by the results of bioeffect and atmospheric studies and these may in turn control hardware design, cost, and land use.**

If an SPS program is pursued, the assessment of environmental risks should receive the highest research priority. Some studies such as bioeffects research may require substantial time to complete; the resolution of environmental uncertainties could affect the development schedule of SPS. Much of the environmental research needed in the assessment of SPS is applicable to other studies and would be valuable whether or not an SPS program is undertaken. Conversely, many of the environmental questions associated with SPS are also being addressed in other "generic" research programs such as those investigating microwave bioeffects and upper atmosphere physics. The delineation of which environmental risks are most important would, to a large extent, depend on the specific design concepts that showed the greatest promise.

ELECTROMAGNETIC COMPATIBILITY

How would SPS affect other users of the electromagnetic spectrum?*

Whether SPS were to be eventually deployed as a microwave, laser, or mirror system, it would affect some portion of the electromagnetic spectrum. Other users of the spectrum would be concerned about the nature of potential detrimental effects, whether they are amenable to amelioration and, if so, what the costs would be. A microwave system would be the most problematic because communications of all sorts share this general portion of the spectrum. In addition, a wide range of other electronic devices (e. g., sensors, computers) are susceptible to microwave interference.

The Public

Deploying SPS would markedly change the visual appearance of the night sky. A set of reference system satellites equally spaced along the Equator would appear as a set of bright stationary "stars" whose total effect for observers on longitudes near the middle of the set and for all latitudes along these longitude lines would equal the Moon at about quarter phase. Nonstationary satellites such as an LEO deployed laser or mirror system would create the effect of bright moving "stars." The effect of such satellites on the night sky has not been calculated. However, it could be expected to equal the overall effect of the 60-satellite set of reference satellites.

Some observers might well enjoy the sight of manmade "stars" added to the night sky. Many, especially those in countries who failed to benefit from the generated power, might strongly resent the intrusion on the celestial landscape.

Space Communications

All artificial Earth satellites use some portion of the electromagnetic spectrum for communication. Some also use the spectrum for remote sensing. All would be affected in some way by SPS.

Geosynchronous Satellites.– These would be most strongly affected by the microwave systems. They could be expected to experience microwave interference from noise at the fundamental SPS frequency (e.g., 2.45 Ghz for the reference design), spurious emission in nearby bands, harmonics of the fundamental SPS frequency, and from so-called intermodulation products. 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.

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 CEO communications satellites would experience interference from the same signal reflected from the surface of the power satellite.

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 wave length at which it operated, and the type of transmission device used (i.e., klystron, magnetron, solid-state device).

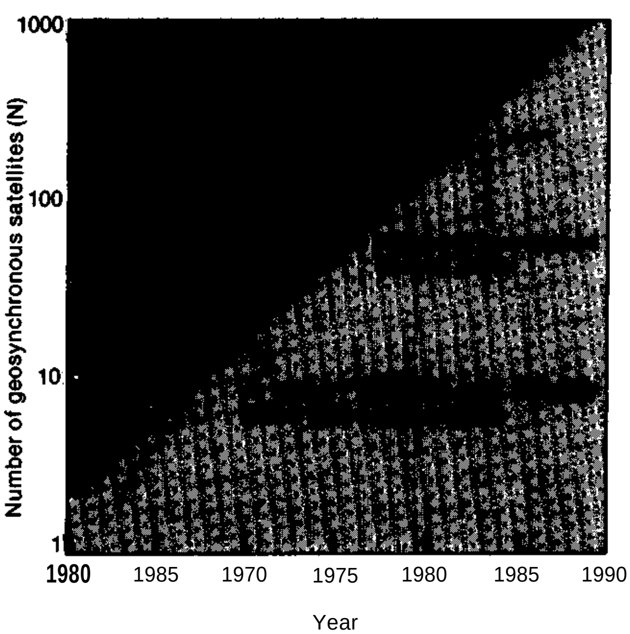
Since a microwave SPS would have to share the limited resource of the geostationary orbit with other satellites, the value of the minimum spacing has emerged as one of the most critical issues facing a geostationary SPS. However, in the absence of a specific design, it is impossible to characterize the exact form and

'See ch. 8

nature of the interference. Additional information is essential to calculate the minimum required spacing. In addition, even if the design parameters were known accurately, the theory of phased arrays is insufficiently developed today to predict the minimum distance. Estimates of the minimum necessary spacing range from 1/2 to 10. The lower limit would probably be acceptable. However, a minimum spacing much greater than 10 would result in too few available geostationary slots to allow both types of users to share the orbit unless many communications functions could be accommodated on a few large space platforms.

At present, some 80 satellites share the geostationary orbit worldwide, and by 1990 that number is expected to increase significantly (fig. 6). Even though improvements in technology will lead to a reduction in the total number of satellites necessary to carry the same volume of communications services, total service is expected to rise dramatically.

Figure 6.—The Number of Geosynchronous Satellites as a Function of Time



SOURCE: W. L. Morgan, *Comsat Technical Review,* 10 vol. 1,1980.

At present the minimum spacing for domestic geostationary satellites is 40 in the 4/6 GHz band and 30 in the 12/14 HGz band. At these spacings, a maximum of 90 4/6 GHz band satellites and 120 12/14 GHz band satellites could theoretically coexist at geostationary altitudes, in the absence of SPS. Current research activity in the 20/30 GHz band is likely to lead to much greater capacity and smaller spacings for that band by the time an SPS might be deployed. But even with these and other unpredictable advances in communications technology in space and on the ground, competition for geostationary orbit slots is likely to be high.

The laser and mirror systems in low-Earth orbit are unlikely to interfere with geosynchronous satellites except in the relatively improbable event that one of the mirrors passes precisely between the geosynchronous satellite and its ground station, and even that interruption would be for so short a time as to pose no serious problem.

Other Satellites. – In addition to geosynchronous satellites operating at the same altitude as the CEO SPS, 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. Whether this action would be feasible depends on the particular mission the satellite is to perform. For some remote sensing satellites, a shutdown could mean loss of significant data. It would not be feasible for the SPS to shut down for the few seconds of satellite passage. It might also be possible for many satellites to fly orbits that will not intersect the SPS beam.

The laser and mirror systems might interfere with nongeosynchronous satellites by causing reflected sunlight to blind their optical sensors or by passing through communications beams. Of the two systems, the mirror system would cause the most problems because of the size of the mirrors and their orbital speed. To date, no one has calculated the possible adverse effects due to this cause.

Deep Space Communications. – Because deep space probes generally travel in the plane of the solar system (known as the ecliptic), they would be especially affected by a geostationary microwave SPS. A microwave SPS would effectively prevent ground communication with the probe when the latter happens to lie near the part of the ecliptic that crosses the Equator. This interference is especially serious for deep space vehicles because it is essential to be able to communicate with them at any time for the purposes of orbit control and for timely retrieval of stored data.

It would be possible to avoid such interference by establishing a communications base for deep space probes in orbit. As we penetrate deeper into space, this may be advisable for other reasons. If not, such a communications station would effectively add to the cost of the SPS.

Terrestrial Communications and Electronic Systems

Both civilian and military terrestrial communications, radar, sensors, and computer components would suffer from a number of possible effects of a microwave beam. Direct interference can occur from the central frequency or the harmonics. In addition, scattered and reflected radiation at these frequencies from the rectenna, and rectenna emissions could cause additional interference problems for terrestrial receivers. At the very least, rectennas would have to be located far enough from critical sites such as airports, nuclear powerplants, and military bases to render potential interference as small as possible. In addition, equipment would have to be redesigned to permit far better rejection of unwanted signals than is now necessary. This appears to be feasible given enough time and funds for the electronics industry to respond.

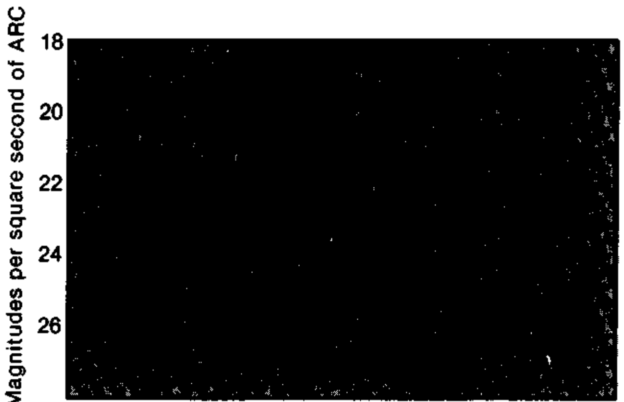
Effect on Terrestrial Astronomy and Aeronomy

None of the proposed SPS systems benefit astronomical research except insofar as they would indirectly provide a transportation system and construction capabilities for placing large astronomical facilities in space. The detrimental effects would vary depending on the system chosen. The impacts of a microwave system are likely to be severe for both optical and radio astronomy. An infrared laser system is likely to have fewer detrimental effects on both forms of astronomy, and the mirror system would have its most serious effect on optical astronomy.

Optical Astronomy.– Diffuse reflections from the reference system satellites would cause each to be as bright as the brightest phase of the planet Venus, and produce a diffuse halo of light around it. Because the satellites appear to remain stationary along the celestial Equator, a system of 15 to 60 satellites would meld together to block observation of very faint objects along and near the Equator for telescopes located on Earth between the longitude limits of the satellites (fig. 7). Some major non-U. S. telescopes would be affected as well. Telescopes in orbit, such as the U.S. Space Telescope scheduled to be launched in 1984, will travel in nonequatorial orbits and therefore would not be affected significantly by a reference SPS except to require increased pointing and control complexity on the Space Telescope.

The effect of diffuse reflections from an LEO-based laser SPS could be expected to be much less of a problem for observations of objects near the Equator because the laser portion of the satellite system would be constantly in motion. Thus, no part of the sky would be permanently blocked from view. The relay satellites located in geostationary orbit would subtend a very small angle as seen from the surface of the Earth. Though they would be visible as small points of light, they would be considerably fainter than the geostationary

Figure 7.—The SPS Brightness Profile



Note: This figure shows the predicted brightness of the sky as a result of a 60-satellite SPS system along the meridian at local midnight for Kitt Peak National Observatory at the vernal equinox. The calculation of this profile is based on an assumed 4 percent diffuse albedo

SOURCE: Workshop on SPS Effects on Optical and Radio Astronomy, DOE/Conf 7905143, P. A. Ekstron and G M Stokes (eds.).

satellites of the reference system and would not interfere with optical observations. However, large moving satellites would present optical astronomy with another observational obstacle. Scattered light from them would vary in intensity as the satellite passes near a celestial object of interest, making calibration of the nearby background light very difficult. The laser satellite would interfere with infrared astronomy studies involving wavelengths near the transmission wavelength of the beam. Photometry and spectrometry experiments would be severely compromised during any brief orbital period when the relay satellite passed within a few degrees of an observing telescope.

The mirror system, which would involve a number of large, highly reflective moving mirrors in low Earth orbit, would have very serious effects on optical astronomy. While the precise effect has not been calculated, it would render a large area (a circle of radius 150 km) around the ground stations unacceptable for telescopic viewing. Because of diffuse reflections from the atmospheric dust and aerosols that are up to 3 km above the ground station, the individual mirrors would create moving patches of diffuse light that would completely disrupt the observation of faint objects that lie in the direction of the satellite paths. Thus, astronomers would need to remain outside a 30()-km diameter circle surrounding the site in order to avoid this problem.

Radio Astronomy. – Radio astronomy would suffer two major adverse affects from microwave systems: 1) electromagnetic interference from the main SPS beam, from harmonics, from scattered or reflected SPS signals, and from reradiated energy from rectennas; and 2) additional sources of thermal noise radiation in the sky that have the effect of lowering the signal-to-noise ratio of the radio receivers. Studies by terrestrial radiotelescopes of faint radio objects near the Equator would be impossible. Neither the laser nor the mirror systems would contribute to the first effect; however, they would raise the effective temperature of the sky background. Low-level measurements such as scientists now routinely conduct to measure the amount of background radiation from the primordial explosion of the universe would thus be impossible from terrestrial bases. Thermal microwave radiation from the satellites would exceed present standards for radio interference at nearly all wavelengths.

Space basing of radio telescopes, especially on the far side of the Moon, would eliminate the impact of SPS and other terrestrial sources of electromagnetic interference. However, such proposals, though attractive from the standpoint of potential interference, are unlikely to be attractive to astronomers for many decades because of their high cost and the relative inaccessibility of the equipment.

Optical Aeronomy. –Much of our knowledge of the upper atmosphere is gained by nighttime observations of faint, diffuse light. Some of the observations that are made today must be carried out in the dark of the Moon. The presence of satellites equal in brightness to a quarter Moon would effectively end some studies of the faint airglow and aurora. Other observations would be severely limited in scope.

SPACE PROGRAM

How would development of the SPS affect our civilian space program?*

If pursued, an SPS program would be the largest and most ambitious space program ever undertaken. SPS development could provide: 1) new capabilities for future space ventures; 2) spinoffs for civilian and military use, in space as well as other areas; 3) a political and programmatic focus for the civilian space program; and 4) potential furtherance of U.S. domestic and foreign policy goals.

An SPS program would require the development of a high-capacity space transportation system, the construction of large space structures, and perhaps the deployment of manned space bases. I n addition, an extensive industrial infrastructure would be needed to support these activities. The hardware, knowledge, and facilities generated by such a program would significantly increase our overall space capabilities and lay the groundwork for future industrialization, mining and, perhaps, the colonization of space.

Direct technological spinoffs can be expected in the development of improved large space platforms, energy transmission devices, ground illuminating systems, high-efficiency solar cells, and life-support systems.

Conversely, SPS development will benefit from prior developments in space technology, most notably in space transportation and systems for automated construction of space structures.

An important consideration is the extent to which an SPS program would serve as the focus and driving-force for the space program as a whole. In the 1960's, the U.S. civilian effort was centered on Apollo; in the 1970's on the Space Shuttle. However, in 1978, the Carter administration stated that: "it is neither feasible nor necessary at this time to commit the United States to a high-challenge space engineering initiative comparable to Apollo. " In the absence of a long-term goal such as SPS, some have predicted that future space efforts would lag, or become overwhelmingly military in nature. On the other hand, there is concern that an SPS commitment would draw resources from or otherwise interfere with other space activities, leading to an unbalanced effort. In addition, for SPS as well as other less expensive programs, the annual appropriations procedure for NASA often results in budgetary and programmatic uncertainty; development of SPS would require long-term financial planning and long-term commitment to the project.

In addition to its use as a source of electrical power, the SPS should be judged by whether it is in accord with national interests as reflected in national space policy. The NASA Act of 1958 (as amended), states that space activities should be for peaceful purposes, and can be undertaken in cooperation with other countries, to further the "general welfare and security" of the United States. In 1978 the Carter administration, in its October "Fact Sheet on U.S. Civil Space Policy," reaffirmed these goals while emphasizing the practical and commercial benefits of the civil space program. A civilian-run SPS program open to international participation would further current space policy goals.

Involvement by NASA in SPS operation might require a change of NASA's current charter, which restricts the direct operation of commercial ventures. Currently, DOE has prime responsibility for solar energy research, while NASA is responsible for the U.S. civilian space program. An SPS program would require extensive cooperation between the two agencies; if this caused difficulties, a separate agency or some other organizational alternative might prove preferable.

*For extended discussion see ch. 6