Chapter 2

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As the United States and the world have begun to face the realities of living with a limited supply of oil and gas, and the political uncertainties that accompany impending scarcity, the search for reliable, safe means of using the radiant energy of the Sun has intensified. Solar radiation is already used in many parts of the Nation for direct space heating and for heating water. It can also produce electricity by photovoltaic and thermoelectric conversion. However, nearly all terrestrial solar collectors and converters suffer from the drawbacks of the day-night cycle. On Earth, sunlight is only available during daylight hours, but energy is consumed around the clock. In the absence of inexpensive storage, nighttime and cloud cover limit the potential of terrestrial solar technologies (with the exception of ocean thermal energy conversion) to supply the amounts of energy required for use in homes, businesses, and industries. By placing the solar collectors in space where sunlight is intense and constant, and then "beaming" energy to Earth, the solar power satellite (SPS) seeks to assure a baseload supply of electricity for terrestrial consumers.

Several radically different versions of SPS have been proposed, most of which will be described and analyzed in this report. In the most extensively studied version, a large satellite would be placed in the geosynchronous orbit so that it remains directly above a fixed point on the Earth's Equator. Solar photovoltaic panels aboard the satellite would collect the Sun's radiant energy and convert it to electricity. Devices would then convert the electricity to microwave radiation and transmit it to Earth where it would be collected, reconverted to electricity, and delivered to the electric power grid. An alternative concept envisions using large orbiting reflectors to reflect solar radiation to the ground, creating immense solar farms where sunlight would be available around the clock. Laser beams have also been proposed for the energy transmission medium. These concepts may have significantly different economic prospects, as well as different degrees of technical feasibility. In addition, they would affect the environment and political and financial institutions in different ways.

The first serious discussion of the SPS concept appeared in 1968.[1,2] During the next few years several companies conducted preliminary analyses with some support from the Advanced Programs Office of the National Aeronautics and Space Administration (NASA).[3] In May 1973, the Subcommittee on Space Science and Applications of the House Science and Astronautics Committee held the first congressional hearings on the concept.[4] Following those hearings, NASA began a series of experiments in microwave transmission of power at the Jet Propulsion Laboratory. In 1975, NASA created an SPS study office at the Johnson Space Center that performed several additional systems studies. A number of papers were published,[5] culminating in an extensive report that established most of the basis for the Department of Energy's (DOE) reference system design.[6]

In the beginning it had been assumed that NASA would be the Federal agency with prime responsibility for satellite power stations. However, the Solar Energy Act of 1974 clearly placed the responsibility for all solar energy R&D aimed at terrestrial use under the jurisdic-

[1] P E Glaser, "The Future of Power From the Sun, " Intersociety Energy Conversion Engineering Conference (I ECEC), IEEE publication 68C-21 -Energy, 1968, pp. 98-103,

[2] P E Glaser, "Power From the Sun: Its Future," Science 162, Nov 22, 1968, pp. 857-886,

[3] P E Glaser, O. E. Maynard, J. Mockovciak, and E.L. Ralph, "Feasibility Study of a Satellite Solar Power Station," Arthur D. Little Inc , NASA CR-2357 (contract No. NAS 3-16804), February 1974.

[4] "Power From the Sun via Satellite, " hearings before the Subcommittee on Space Science and Applications and Subcommittee on Energy of the Committee on Science and Astronautics, U S House of Representatives, May 7, 22, 24,1973.

[5] Will Iam J. Richard, "Geosynchronous Satellite Solar Power," ch. 8 of *Solar Energy for Earth: An A /AA Assessment,* H. J. Kill ian, G L Dugger, and J. Grey (eds.), AIAA, Apr. 21, 1975, pp. 59-71. (Also see abridged version in *Astronautics and Aeronautics,* November 1975, pp. 46-52.)

[6] "Initial Technical, Environmental, and Economic Evaluation of Space Solar Power Concepts, " report No. J SC-11568, vols. I and II, NASA, Aug. 31, 1976.

tion of the Energy Research and Development Administration (ERDA). ERDA set up a Task Group on Satellite Power Stations, and in November 1976 recommended two options for conducting a joint ERDA/NASA 3-year SPS concept development and evaluation program, one costing $12 million and one $19 million. ' ERDA elected to pursue a median course, and proposed a 3-year, $15.5 million effort which began in fiscal year 1977, the SPS Concept Development and Evaluation Program.

ERDA's efforts were given impetus by two congressional hearings, one held in January 1976 by the Subcommittee on Aerospace Technology and National Needs of the Senate Aeronautical and Space Sciences Committee[8] and one held in February 1976 by two subcommittees of the House Committee on Science and Technology.[9]

When DOE was created in 1977, it established a special Satellite Power System project office in the Office of Energy Research to complete the Concept Development and Evaluation Program. Its final report was released on December 1, 1980.'0

The SPS research, development, and demonstration bill, ' which was introduced in the House of Representatives on January 30, 1978, reflected a desire by a number of Members of Congress to accelerate the evaluation of SPS and to introduce a more ambitious technology verification effort. It was reported out by the Science and Technology Committee after another round of hearings, '2 and eventually passed by the full House. No Senate bill was introduced. A similar bill,[13] reintroduced in 1979, was passed by the House on November 16, 1979, but again died in the Senate.

The DOE/NASA Concept Development and Evaluation Program[14] was established to identify and evaluate the possible technical, environmental, social, institutional, and economic aspects of the SPS concept. It has generated a broad range of reports that reflect this intent.[5] In order to have a fixed technical basis for the study, DOE and NASA developed two versions of a "reference" satellite power station system, based on extensive studies undertaken by two NASA contractors.[16,17] Although the reference system represented the best choice based on the information available at the time, it was not intended to be the last word in systems definition; the multitude of other options that have been proposed since also need to be evaluated before ultimately settling on a "baseline" system design.

OTA was requested by the House Committee on Science and Technology to pursue an independent study to "assess the potential of the SPS system as an alternative source of energy.'"[8] Hence, this study primarily addresses the benefits and drawbacks of SPS as an energy system. It also identifies the key

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[7]Robert A. Summers (chairman), "Final Report of the ERDA Task Croup on Satellite Power Station," report No. ERDA-76/l 48, November 1976.

[8]"Solar Power for Satellites, " hearings before the Subcommittee on Aerospace Technology and National Needs of the Committee on Aeronautical and Space Sciences, U S. Senate, J an, 19, 21,1976, GPO stock No, 66-608-0, 1976

[9]"Solar Satellite Power System Concepts," hearings before the Subcommittee on Space Science and Applications and the Subcommittee on Energy Research, Development, and Demonstration of the Committee on Science and Technology, U.S. House of Representatives, Feb. 20,1976 (No 67)

[10]"Satellite Power Systems Concept Development and Evaluation Program, "Program Assessment Report Statement of Findings, " DOE/E R-0085, November 1980,

[11]Ronnie Flippo, "Solar Power Satellite Research, Development, and Demonstration Program Act of 1978, " H .R 10601, J an. 30,1978.

[12]"Solar Power Satellite, " hearings before the Subcommittee on Space Science and Applications and the Subcommittee on Advanced Energy Technologies and Energy Conservation Research, Development, and Demonstration of the Committee on Science and Technology, U.S. House of Representatives, Apr 12-14, 1978 (No, 68), GPO stock No. 28-155-0, 1978,

[13]Ronnie Flippo, "Solar Power Satellite Research, Development, and Evaluation Program Act of 1979, " H R. 2335, Feb. 22, 1979

[14]"Satellite Power System Concept Development and Evaluation Program Reference System Report," U S. Department of Energy report No DOE/E R-0023, October 1978.

[15]See the extensive set of references in note 10

[16]C Woodcock, "Solar Power Satellite System Definition Study, " Boeing Aerospace Co., Johnson Space Center (contract No NAS 9-151 96), pt. 1, report No. D1 80-22876, December 1977, pt III, report No D180-24071, March 1978

[17]C Hanley, "Satellite Power System (SPS) Concept Definition, " Rockwell International Corp., Marshall Space Flight Center, (contract No. NAS 8-32475), report No. SD78-AP-0023, April 1978

[18]Letter of request to OTA from the House Committee on Science and Technology, Aug 8,1978

uncertainties of the various SPS concepts and related needs for R&D.

Although SPS would be an energy system it is unique in being a major space system as well. It would therefore require a large new commitment to the development of space technology. Hence, this report also addresses the relationship of an SPS program to other space programs.

OTA has divided the assessment into four major areas: 1) SPS technical alternatives and economics, 2) issues arising in the public debate, 3) institutional and international questions, and 4) the programmatic context, i.e., the place of SPS within our national energy and space programs. A number of working papers were written to provide data for these areas. OTA also convened three workshops to refine and amplify the data presented in several of the working papers: 1) SPS Technical Options and Costs, 2) SPS Public Opinion Issues, and 3) The Energy Context of SPS.

- • *SPS technical options and costs.* The major task of the workshop was to assess the DOE/NASA reference system from a technical perspective and to study alternatives. It discussed the key uncertainties of each major system or subsystem that has been suggested in SPS literature and chose four generic systems for further evaluation in later workshops: 1) the reference system, 2) a solid-state variant of the reference system, 3) a laser system, and 4) a mirror system.
- SPS *public opinion issues.* Participants with experience in analyzing and responding to a variety of public interests and concerns met to identify the major issues that could affect the public perceptions of SPS. The workshop was not an exercise in public participation. Rather, it sought a range of viewpoints from participants who have a sense of the issues, the political players, and public attitudes involved.
- The energy context of SPS. SPS will succeed or fail in competition with other energy supply options and in the context of national and global demand for electricity. This workshop developed criteria for choosing between technologies and compared the major future alternative renewable or inexhaustible sources of baseload electrical power. Participants discussed the many factors that would affect future electricity demand and compared breeder reactors, fusion, terrestrial solar thermal, and solar photovoltaic baseload options. They also discussed the potential role of dispersed photovoltaic systems in meeting part of the Nation's electrical needs.

Because the SPS concept would use a complex future technology about which there are many uncertainties, this assessment is fundamentally different from an assessment of current technology. While it is thought to be technically feasible, many of the details are uncertain; economic projections or possible environmental effects based on them are also uncertain, sometimes by more than an order of magnitude. Hence at this point OTA must be satisfied with identifying the key uncertainties of SPS and, where applicable, suggesting alternate strategies for resolving them. The study also analyzes the major institutional and international issues that accompany decisions about SPS, i.e., how it may affect national security, the international energy market, the utilities industry, and how an SPS project might be financed and managed. Although a definitive treatment of any of these issues must wait for the future, this report attempts to lay the foundation for further consideration of SPS.