Chapter 4

POLICY OPTIONS

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Because the solar power satellite (SPS) is a new energy concept, much of this assessment has led across previously uncharted territory. SPS has potential for supplying a portion of U.S. electrical needs, but current knowledge about SPS, whether technical, environmental, or sociopolitical is still too tentative or uncertain to decide whether SPS would be a wise investment of the Nation's resources. Further research and study, based on the findings of this and other assessments,[1,2] would be needed in order to formulate such a decision properly. The kind and pace of a research program, if one is to be conducted, will be determined by perceptions of when development decisions need to be made.

Decisions about SPS development involve an important tradeoff. In time, more can be learned about the context within which SPS would operate. Furthermore, in view of this study's analysis of future U.S. electricity demand and the availability of alternate energy sources (see ch. 6), domestic need is not likely to be high enough for SPS before 2015-25. Therefore, development and deployment decisions do not have to be made before the 1990's. However, action should be taken in a timely manner. Since the development of a major energy and space system may take more than 20 years, a decision about whether to develop SPS will probably need to be made before the end of the century. The development of SPS may need to be started as early as 1990, if high-growth projections for electricity seem plausible at the time. If an SPS development program is eventually initiated, the Nation must also decide whether it wishes to pursue SPS as a unilateral or as an international venture. The tasks before the United States in this decade are to determine how much and what kinds of information are needed in order to make a sound decision sometime in the next decade. The Nation must also decide when to proceed with a research program and at what pace.

Figure 8 represents a series of possible decision points for SPS. If research on SPS finds no impediments to continued pursuit of SPS, the first in the series of development decisions could occur sometime between 1990 and 2000. By that time, the factors that relate to energy demand and supply and space transportation will be much clearer than they are today. The United States will have had about 10 years of experience with the space shuttle and with initial testing of space platform components. Planning and perhaps testing will have begun for a second-generation space transportation system. The results of the Nation's long-term energy conservation efforts will be felt and assessed, and electricity demand projections for 2000 and afterwards will be better defined than currently possible. Further, a decision about the breeder may have been made and the potential of the fusion, energy storage, and terrestrial solar technologies may be more certain.

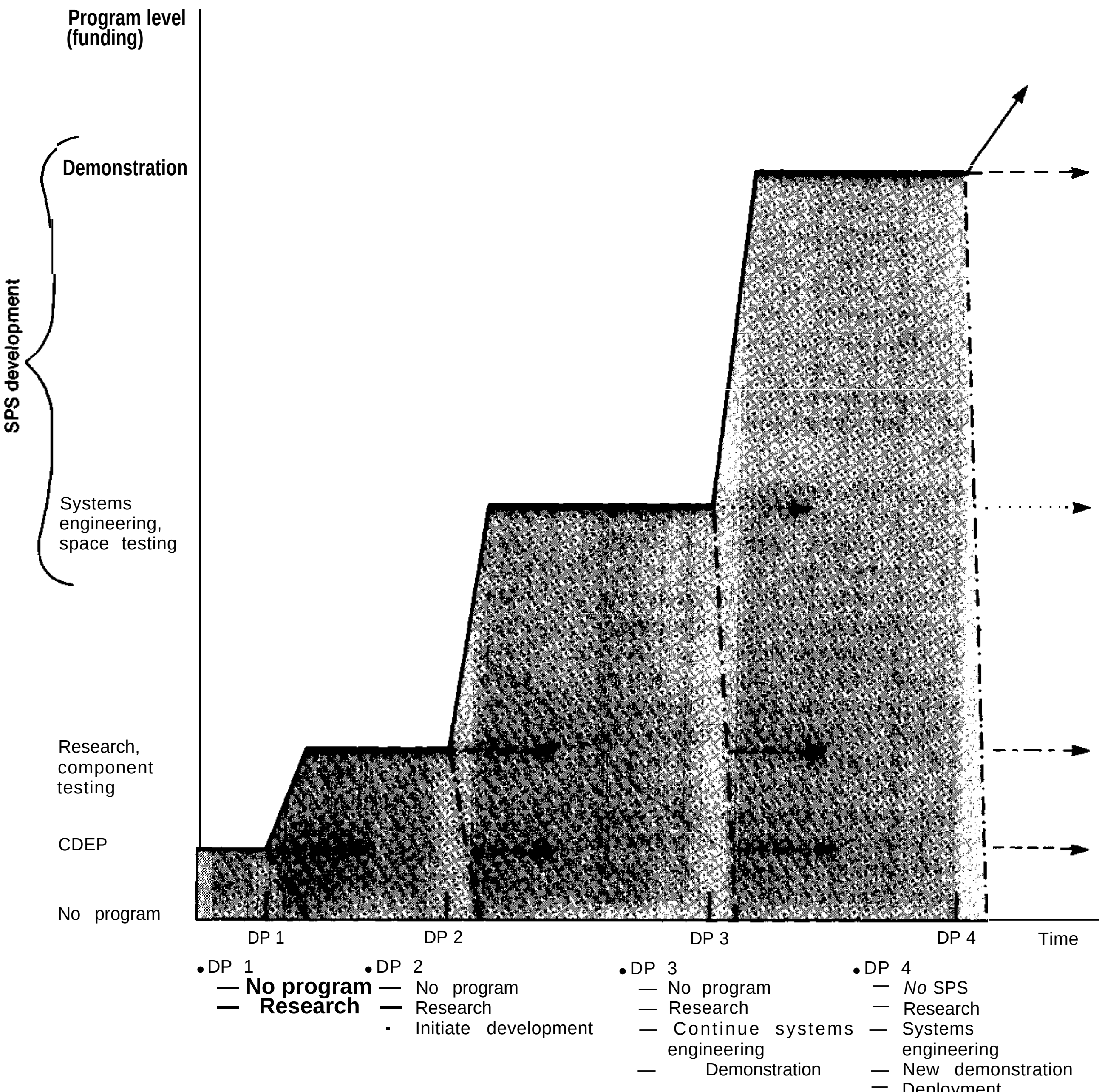
The results of continued tracking of the international, institutional, and public opinion factors relevant to SPS will also contribute to the decision. In particular, the international community's future energy needs and supply potential will be better known, as well as its willingness to cooperate in a multinational development program.

Finally, the results of research related to SPS will be available and can be used to support or reject a decision whether to proceed with SPS development. Some of the needed research is generic in nature, and will be done in other programs whether or not SPS is developed. Among others, these include most of the National Aeronautics and Space Administration's (NASA) activities in space transportation, space structures, photovoltaics, materials and humans in space, as well as the Department of Defense's (DOD) and the Department of Energy's (DOE) laser programs. To some extent

[1] *Program Assessment Report Statement of Findings, SPS* Concept Development and Evaluation Program, DO E/E R-0085, November 1980.

[2] National Research Council Report of the Committee on Satellite Power Systems, June 1981

Figure 8.—SPS Program Phases and Decision Points



SOURCE: Office of Technology Assessment.

they also include work done in the terrestrial photovoltaics (DOE) and microwave bioeffects (the Food and Drug Administration, the Environmental Protection Agency, etc.) programs. However, many needs are directly related to SPS technology and therefore will eventually require a research program specifically funded for SPS.

In order to make an informed decision about the SPS, information about three different types of factors will be needed:

1. **Contextual, independent factors.** These are factors that are independent of SPS but which will markedly affect the need for SPS or the ability to conduct the project:
   - *Future U.S. and global electricity demand.* If demand is relatively low, the need for a new, capital-intensive energy system will be low as well. If future demand is very high, there could be a commensurate need for SPS. Conservation, increased end-use efficiencies, and the expansion of dispersed electrical generation could all affect overall demand for centralized electricity.
   - *Cost, kind, and availability of alternative electricity sources.* If other potential future electric energy sources turn out to be more expensive than a projected SPS, then SPS may be desirable even if electricity demand is relatively low. On the other hand, the development of other technologies might preclude the need for SPS. The status of breeder and fusion technologies, the cost of terrestrial solar and the advisability of expanding the use of coal will all affect the need for SPS.
   - *U.S. and global space capabilities.* A rapidly expanding space program with extensive experience and capabilities would make an SPS program much more feasible than would a low-level program. The experience with the shuttle and other space vehicles will shed light on space transportation capabilities and costs.

Although an SPS research program is not likely to be affected by these factors, they will have a great effect on an SPS development decision. Each of the factors needs to be tracked, studied, and continually reevaluated for its impact on an SPS decision. Projections of these factors 10 to 20 years in the future will have to be made as well, and amended as more information becomes available. Because these factors are of universal interest, such studies need not be funded by a specific SPS program; they will be investigated by other energy and space programs.

Sometime in the next decade, the contextual framework for the future of SPS may be known well enough to make an informed decision about the need for SPS. As time goes on, a narrowing of future projections will occur and knowledge of these factors will be integrated into the overall decision about SPS.

2. *Contextual, semi-independent factors.* These are the factors that arise largely from the public perceptions and international and institutional framework of SPS. Though they are markedly diverse in content, they have the unifying feature that they will each affect an SPS research program only slightly but an SPS development program rather strongly. They will need to be tracked, studied, and evaluated as any SPS research program progresses. They also possess the characteristic that there is no point at which one can say that enough is known about them. Rather, a development decision must take them into account as factors that must be considered in light of what is known about them at the time.
   - *International interest and involvement in SPS.* The worldwide community will be interested in SPS for its potential to provide energy. They will also be concerned about the effects it may have on the use of the geostationary orbit, military and national prestige implications, how it may affect communications, and how it may affect the appearance and use of the night sky. They may also be interested in joining with the United States in multinational development of SPS. Hence, it will also be important to explore possible modes and means of international cooperation.
   - Institutional framework. A main concern of any SPS program would be to continue to study the institutional structures that now exist in the utilities industry, the financial community, and Government, and to identify the major factors that could influence the course of SPS development and affect its feasibility.

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- **Public opinion issues** Public perceptions and public involvement are important components of any publicly funded program. Dissemination of information and sharing of research results would be essential to the SPS program, even in the research phase. It would also be important to continue to solicit responses from segments of the public that would be especially affected, either positively or negatively, by SPS development.

3. Technical factors specific to SPS. Knowledge about these factors can be gathered or generated by deliberate effort. Answers to specific questions in this group will have an immediate effect on SPS development decisions. The kind, quantity, and quality of the information as well as the time at which it can be available are partly dependent on the level of funding. Four general categories of this sort of information are evident:
   - *Environment and human health:*
     - — microwave and laser bioeffects,
     - –high energy particle and ionizing radiation effects on humans in space,
     - — ionospheric effects due to microwave transmission,
     - – land-use impacts,
     - —offshore rectenna environmental effects,
     - – launch vehicle exhaust effects on atmosphere, and
     - —weather modification from mirror systems.
   - *General system studies:*
     - —alternate systems (identify which areas need further research, and possible testing of components),
     - — component and system costs, and
     - —comparison of alternate systems.
   - *Component testing and evacuation:*
     - –Klystrons/magnetrons/solid-state devices,
     - – high-powered, continuous-wave lasers (EDL, solar pumped, FE L),
     - — Slip ring designs,
     - –deployable, large-area, lightweight space structures,
     - — space charge effects, and
     - – photovoltaic design and testing.
   - *Space construction and space transportation:*
     - — evaluate best transportation scheme for demonstration and
     - — evaluate best construction scheme.

information from all three sorts of factors will set the framework and determine the appropriate time for development decisions. It is important to emphasize that a decision not to develop SPS depends on the same information as a decision to proceed with SPS. If further research finds no major technological impediment to proceeding with SPS and the combination of supply alternatives and demand needs indicate that it would be prudent to proceed with the next stage, the program could enter the engineering verification phase where various systems are tested and a demonstration system chosen. This would set the stage for the next decision point.

[f it were possible to make a decision to proceed with the project early in the process (i. e., during the research phase) the various phases could overlap considerably. For instance, the early stages of demonstration could begin before the engineering verification phase is entirely complete. Some economic benefits might accrue from such a procedure. However, because of the very high front-end costs for SPS, any proposal to proceed with development will need to be scrutinized very carefully to be sure it is cost effective. That will necessitate more time and study in the verification stage than might be true for a less costly technology, making it less likely that the various phases will overlap.

SPS research could proceed at different rates and along different lines, depending on the level of funding that is made available. The following presents two different policy options. One is characterized by zero funding for specific SPS research; the other by a sliding scale of funding. They do not exclude one another, i.e., pursuing one option today would not necessarily exclude changing to a different option as time proceeds and information grows. For example, it could be considered prudent to begin with no specific funding for SPS and proceed to allocate a few million dollars per year after a few years. Conversely, a vigorous funding pace may produce results quickly enough so that from the standpoint of those factors that are amenable to research, a development decision could be made before 1990. But because the independent factors are unlikely to be known well enough before 199o, research funding might then be reduced to a lower level to keep the program going pending a decision based on the independent factors.

Option A:
No specific funding for an SPS program.

Although it would be nearly impossible to pursue an SPS program without specifically allocating funding for it, this option would not necessarily mean terminating all interest in SPS. A zero level option could be followed by designating an agency (e.g., NASA or DOE) to track generic research that is applicable to SPS, as well as monitoring and coordinating international interest in SPS. One possibility is to set up a high-level advisory committee to serve this latter function. As in the other option, periodic reevaluation of the potential of SPS would also be needed, in this case to decide whether specific funding should be instituted or the program terminated altogether.

The rationale behind option A is to keep SPS alive as part of our arsenal of possible energy supply options without making a serious commitment at this time. It has the advantages that the risk of premature funding is greatly reduced, as well as the upfront costs. The longer the country can wait before funding a program directed towards SPS research, the more likely it is that other programs will have generated helpful data for SPS.

On the other hand, there is little margin for error in such an approach. If, under option A, inadequate information is generated, the SPS option might be neglected or foreclosed at a time of future decision; or, if the independent factors indicate a strong need for SPS, then an expensive crash program of research to resolve the questions specific to SPS may be necessary. in addition, appropriating no specific funding for SPS carries with it the risk of discouraging future international cooperation, or of allowing other countries to take the lead in SPS development. A final problem with option A is that the agency designated to track SPS may find it very difficult to allocate its financial resources for SPS without some specific allocation in its budget (even though small).

What could be learned from such an option? Other Federal and non-Federal programs are currently exploring issues that are related to SPS development. By tracking this generic research, information of great value to the development decision could be gathered and analyzed.

- Microwave bioeffects.The proliferation of microwave devices at various frequencies makes research into this important area mandatory whether there is an SPS program or not. FDA, EPA, and DOD are studying microwave bioeffects.
- Photovoltaics DOE maintains a strong terrestrial photovoltaics program. Together with private industry and university projects, this program is studying some aspects of photovoltaics that are of great interest to SPS. However, because terrestrial photovoltaic systems have vastly different needs and constraints than space photovoltaic systems, additional research would probably be needed for SPS.
- Space-related activities. NASA, DOD, and the European Space Agency (ESA) are pursuing programs in space transportation, space structures, humans in space, and space photovoltaics by designing and building the shuttle, advanced expendable launch vehicles, space lab, a 25 kW space power supply, etc.
- Laser programs. High-powered, continuous-wave lasers are currently in an early stage of development. Some of the research on high energy pulsed lasers being pursued by the DOD for weapons applications and by DOE for fusion studies will be relevant to the SPS laser concept. Universities and other research labs are studying high-powered, con-

tinuous-wave lasers. This research would be directly applicable to a laser SPS.

- Alternateve energy sources. The results of R&D, prototype construction, and operation of other electricity sources, including solar thermal, breeders, ocean thermal energy conversion, and fusion, will be of great importance in determining future need for SPS.

However, many issues directly pertinent to SPS cannot be answered by generic research programs. For instance, while microwave bioeffects experiments are being performed in generic research programs, the number of studies on low-level, long-term exposure to SPS frequency microwaves is small. To gain information directly relevant to SPS, some specific SPS funding will be needed.

Option B:
Funding of $5 million to $30 million per year.

This option is designed to gather the necessary information before a development decision is needed. It minimizes the risks of not gaining the sufficient and timely information necessary for a rational decision.

This program would, like option A, make as much use as possible of generic research. It would extend the generic research into areas specific to SPS by making small amounts of funding available for expanding generic programs essential to the SPS development decision. It would also initiate research that is not being done in generic programs and explore ways in which to pursue some of this research jointly with other nations. In addition, it would track and study the various semi-independent factors (international, institutional, and public opinion) which would also have a profound effect on SPS decisions. It would actively seek and encourage international cooperation in SPS research.

Table 5 summarizes the most important research and study needs and gives a very rough estimate of what it would cost to do each item. The starred items are ones that could be pursued in the context of a few million dollars of funding per year. The most critical issues relate to the environmental and health area, since they are the most important in determining the feasibility of SPS. However, they could also take the longest to resolve. Some component testing and studies of alternative systems could receive high priority. The amount of funding which would be made available would depend on an evaluation of previous research findings and the state of projected supply and demand for electricity in the 21st century.

It may be prudent to start at a low level of funding and later accelerate research that is specific to SPS as well as make greater funding available for SPS related generic studies. Another possibility is to actively solicit funding for projects of joint international-U. S. interest, perhaps by offering to match foreign funding for research projects undertaken outside the United States, but which are of interest to U.S. planners. An accelerated research program ($30 million per year) could include some component testing in space as well as at the Earth’s surface. It could also include at least one shuttle mission (post 1985) and some space-related experiments on other shuttle flights. It would seek to answer the major environmental and health and safety questions before 1990 and also conduct extensive systems studies. If these concerns are seen to pose no impediments, accelerated funding would provide the quickest way of entering a development phase.

Making funds available for SPS-specific research should ensure that enough information is eventually available in order to make a rational development decision. This approach also has the advantage that it could provide for extensive international cooperation early in the research phase before seeking more extensive financial and managerial cooperation in any subsequent development or construction phase. This would spread the decision to proceed or drop SPS development to other countries as well.

However, a higher level of spending ($30 million or so per year), here and abroad, would make it more likely that an entrenched SPS constituency would form, giving the program momentum and making it harder to stop; more information may not make a program easier to terminate. Under such conditions, our understanding of SPS technology may outstrip our knowledge of future electricity demand. It is also possible that support for a given mode of transmitting power will develop too early and close out SPS options which are uncertain in the near term but which may have more long-run potential.

Table 5.—Summary of Research and Study Needs

Research/study area	Expansion of generic research to SPS-specific needs	Estimated cost	SPS-dedicated projects	Estimated costs
Environmental and human health				
• Microwave bioeffects		$5 million to $10 million	Quantify SPS risks. Epidemiological microwave studies.	$2 million
	• Laboratory studies of long-term exposure to low-level microwaves at 2.45 GHz. Determine possible nonthermal effects, and dose-response relationships, establish extrapolation laws.			
• Ionospheric studies	• Study of ionospheric scaling laws.	—	‘Ionospheric equivalent heating. Upgrade Arecibo facility. Study SPS equivalent heating in upper atmosphere. Test scaling laws and effects on representative telecommunication systems.	$10 million
• Atmospheric studies	• Track and augment observations of the atmospheric effects of launch effluents from the shuttle, other expendable launch vehicles and high altitude rockets.	$2 million	• Experiments to test effects of SPS effluents on magnetosphere and to increase understanding of that region. Quantify and study SPS effects on the hydrogen cycle, and formation of noctilucent clouds.	$1 million
	Refine and test ground cloud models. Study meteorological and air quality impacts.	$0.3 million to $5 million	• Study effect on local climate of SOLARES-type system using an array of ground heaters or a solar pond.	
	Determine the nature and effect of ionospheric depletion, especially in lower ionosphere. Utilize other rocket launches and observe the effects on representative telecommunication systems.	$0.5 million	*Studies of possible weather modification, beam scattering and spreading. Identify transportation scenarios that minimize impacts.	
• Ionizing radiation	• Track and augment existing studies of effects of ionizing radiation on humans. Study shielding methods.	$2 million to $3 million		
• Space	• Track and augment existing programs examining the risks and protection measures for humans in space.	$0.2 million		
• Electromagnetic interference	• Study potential electromagnetic interference and design mitigating techniques. Improve theory of phased array.	$2 million	• Investigate antenna patterns of klystron, magnetron, solid-state devices (see below), their noise levels, and out-of-band harmonics.	$1 million

Table 5.—Summary of Research and Study Needs—Continued

Research/study area	Expansion of generic research to SPS-specific needs	Estimated cost	SPS-dedicated projects	Estimated costs
• Environmental impacts of receiver siting			Offshore receiver studies Land use studies	$0.5 million $2 million
General system studies				
• Laser system			● Develop a "reference" laser system	$0.5 million to $1 million
• Mirror system			*Develop a "reference" mirror system	$0.5 million to $1 million
• Alternative microwave			*Develop alternative microwave systems	
			*Perform a true comparative study between SPS alternatives using common technology and cost basis.	$1 million
Component testing and evaluation				
• Microwave transmission	● Continue solid-state device improvement, study noise, interference problems	$3 million to $6 million	Develop solid-state phased array	$2 million to $10 million
	● Test intermediate power magnetron, high-power klystron	$2 million	Study alternative microwave devices, such as photoklystron	$.3 million to $1 million
• Solar thermal conversion		$1 million		
. Photovoltaics	• Extend research to low mass, thin film cells for space	$2 million	● Adapt optimum photovoltaics for SPS, i.e., low mass, high efficiency, radiation resistant	$2 million
• Lasers	● Improve efficiency of EDL lasers, develop cooling mechanisms for space lasers	$3million to $10 million	● Build solar pumped lasers	$1 million to $3 million
			● Laser optics (feasibility studies)	$0.1 million to $0.3 million
. Mechanical components			● Study means of constructing slip ring and rotating joint	$0.3 million
			*SOLARES mirror materials structures	
• Mirror			Develop prototype mirror design for shuttle launch of a single SOLARES mirror	$0.5 million

'Research priority.

SOURCE: Office of Technology Assessment.