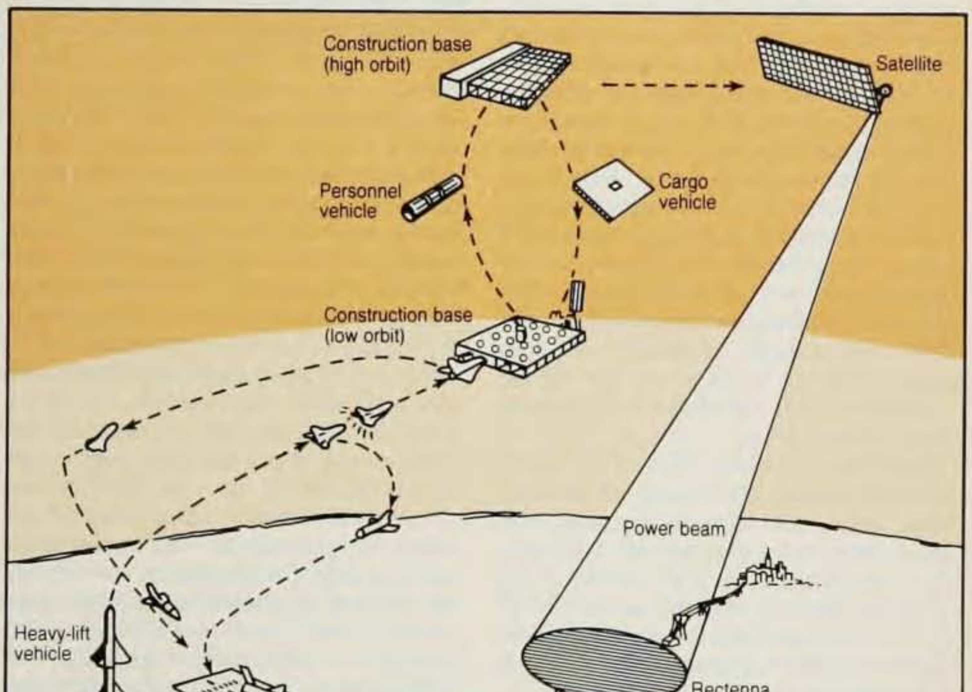
OTA and NAS evaluate solar power satellite problems

What priority will we assign to research of the future, research that explores the potential of future technology? This question arises for the concept of using solar power satellites as a future source of energy, which is just such a technology. Will innovations in photovoltaic cell design make them cost-effective? Will future energy demand cause a 300-GW source of power to be necessary or even attractive? Will research into the effects of microwave and laser radiation on the atmosphere show them to be greater or less than expected? Two studies recently completed, one by the National Academy of Sciences, the other by the Office of Technology Assessment, address these questions. They reach different conclusions, but both identify many technical and environmental problems and key research needs.

The Academy report is the response to a request from NSF and NASA in 1979, to offer an independent opinion about the SPS concept and to evaluate an ongoing NASA/Department of Energy study to identify key scientific and technical concepts, pinpointing omissions. The results of the three-year, $18-million NASA/DOE study of the solar power satellite concept were published in December 1980. The DOE chose to evaluate in detail two versions (one using silicon, the other using gallium-arsenide solar cells) of a NASA/DOE design concept called the microwave "reference system." This choice was made, according to Fred Koomanoff, then director of the Satellite Power System project office, to illuminate technological problems and potential hazards, and provide a framework within which to estimate and evaluate costs. The NASA/DOE reference system was then the only concept about which sufficient data were available to permit rigorous study.

The OTA report resulted from a request in late 1978 by John Wydler (R-N.Y.), then the ranking minority member of the House Committee on Science and Technology, and Olin Teague (D-Tex.), then chairman of the committee and sponsor of a resolution to support the use of space, to evaluate the SPS as an energy system and to make recommendations about future research directions. The OTA approached its task by considering four possible space satellite system designs (including the reference system), identifying technical, environmental, and institutional problems associated with each of them and comparing these four design options to other potential energy sources (fusion, fission, photovolatics, solar thermal).



Solar power satellite system. Each heavy-lift vehicle launched from Earth carries materials and personnel to a low-orbit construction base. Personnel and cargo vehicles provide transportation to a geosynchronous construction base, where construction is completed. The assembled satellite beams radiation to the rectenna, which converts and delivers it to utility grid.

The findings of both the OTA and Academy studies have recently been printed. The Academy study recommends that NASA be given responsibility for monitoring research results that could affect the development of the SPS, but that no funding be provided directly for research specific to the SPS. The OTA concludes that we do not have enough information about the SPS to make a decision about its potential development and that basic research about both technical problems and environmental and health risks needs to be undertaken to provide this information. They considered the monitoring of relevant research as the minimal effort that could be made, and recommended that funds be provided at either a $5–10 million level or a $20–30 million level, for research on both technical and environmental questions, to insure that the SPS option is not foreclosed. Both studies agree that the enormous cost and numerous technical, social and political problems put the question of SPS development several decades in the future.

Technical aspects. The "reference system" employs microwave radiation to supply 300 GW of usable power. It consists of 60 solar power satellites in geosynchronous orbit, each providing 5 GW of usable power, and two construction bases, one in low earth orbit, the other in a geosynchronous orbit. Each satellite, in geosynchronous orbit 35 800 km above the equator, consists

0031-9228 / 81 / 100053-04 / $00.50

of a 55-km^2 flat array of photovoltaic cells that convert solar energy into direct-current electricity. The electricity is conducted to a 1-km diameter microwave transmitting antenna mounted on the array, where 100 000 klystrons convert the current to rf at 2.45 GHz and transmit it to earth. A 102-km^2 antenna on the ground, known as a rectenna, rectifies the radiation back to direct current, which then can either be delivered directly to a dc transmission network in the electrical utility grid or inverted to alternating current.

Both studies evaluated the reference system and identified many major technical problems; of these, the following were considered the most substantive by both—the development of efficient transportation from Earth to geosynchronous orbit, the development of solar cells for space, constructing large structures in space, many problems of scale and determining and minimizing the effects of microwave radiation on the atmosphere and on organisms. The alternative designs considered by the OTA and results of future research could have an impact on the significance of these problems and suggest possible solutions.

Alternative designs. The OTA report also considered three possible alternatives to the reference system design—a solid state variation, a laser transmitting satellite, and the use of large orbiting mirrors. Each alternative offered both technical improvements to aspects of the reference system design and new and unique problems.

▶ One possible variation to the reference system incorporates solid-state devices in a sandwich configuration into the photovoltaic cells of the array, where they convert electricity directly to microwave radiation. Thus the entire array is a transmitting antenna. Research suggests that such devices may have a longer life, be less massive and permit a design with a larger transmitting area and smaller rectennas. The use of solid-state devices instead of klystrons would thus reduce the mass of the satellite and maintenance needs. A smaller rectenna size would allow for construction closer to cities. Thus the cumulative effect would be a lower cost for each satellite and a scale of energy transmission (1000 MW) more compatible with the utility grid. The cost of research and development on these devices is difficult to estimate as the energy efficiencies and design constraints for their use in space are not well known.

▶ Laser transmission from satellites would permit apertures 100 times smaller than microwaves require and would reduce both the size and mass of the antenna and the area of the rectenna. This smaller scale yields greater flexibility to the power demands of the electric utility grid and the possibility of employing design options.

The use of lasers presents problems, the report notes. Because ir radiation is subject to interruption by atmospheric effects, storage capacity is needed. Laser technology for long-range power transmission still needs basic research. Existing high-power, cw lasers, like the electric discharge laser, have very low power conversion efficiencies (less than 25%). Little is known about converting high-energy laser radiation to electric power. The high beam intensity at the rectenna may also provide a safety hazard.

▶ By using large mirrors in low orbit, sunlight could be directed to a ground-based solar conversion system. This simplification would reduce the space segment of the system to planar reflective thin-film mirrors, minimize large-scale operations, be operable in low-earth orbit and be capable of being mass-produced. Because ordinary sunlight is reflected, the potential environmental hazards of laser or microwave transmission are eliminated. The OTA report notes that this concept also has problems. For example, the "baseline" Mark I SOLARES, a design of this type, would require a total mirror area of 46 000 km^2 to provide 810 GW (approximately three times present US electric generation). By using small mirrors, the total mass in space could be reduced to approximately the mass of eight of the 60 reference system satellites. This would necessitate over 900 mirrors in orbit. The increased number of objects in space presents formidable maintenance, construction and material problems. The land area needed for the ground stations is another barrier. The transmittal of sunlight through space may interfere with weather patterns and biological rhythms, and will interfere with astronomical observations.

The impact that research could have on the evaluation of technical constraints on SPS designs was described to us by Peter Glaser, a leading proponent of the SPS (PHYSICS TODAY, February 1977, page 30). Glaser indicated that ongoing developments in photovoltaic cell technology could significantly improve their efficiency, reduce the mass of satellites and thus reduce costs. He also felt that the resolution of international barriers to SPS development could lead to the productive, nonmilitary use of space.

Both reports identified potential environmental hazards and political and social considerations that will influence the potential usefulness, attractiveness or need for development of the SPS.

Environmental concerns. Transmission of microwave radiation will induce ionospheric and tropospheric heating; as both studies indicate, the effect of heating on telecommunications, the upper ionosphere, and the weather is not known. The OTA noted that the effect of long-term exposure to low-level microwave radiation is not known and that lasers and mirrors also cause tropospheric heating. The effluents of rockets used to construct and maintain the space systems are a potential source of pollution and the reference system, for example, requires a projected 20 000 flights for construction. The effect of this much disturbance on the atmosphere is undetermined, according to both reports.

Social and political problems. The scale of the SPS project was discussed in both studies as a possible barrier to political acceptance and support. Because the ability of the SPS to compete with other energy sources ultimately depends on costs, both groups evaluated the cost estimates. The Academy concluded that the costs were prohibitive. The OTA concluded that financing could probably not be undertaken without international cooperation and that utility grid compatibility needs to be considered. The interference of radio communication as an international problem, as well as the need to protect workers in space from radiation exposure, were considered in both reports. The OTA discussed competition with communications satellites for the geosynchronous orbit and the potential for siting problems caused by the large areas of land needed for rectennas and radiation hazards. —JC

Theory reaches heights in Aspen

Next year the Aspen Center for Physics will be twenty years old. A summer haven for theorists, Aspen is fabled for the beauty of its scenery and its relaxed, informal atmosphere. At any one time about 70 theorists are in residence, about half of them participating in workshops or informal working groups. The rest are there to do their own thing and to interact with physicists in other fields. During a week-long visit late in July, I found that much of the lore is true. You can indeed do physics while listening to an orchestra rehearsing at the nearby music tent or while hiking near the Maroon Bells (once you get used to Aspen's 8000-foot altitude).

What's missing is also significant: no office telephones to interrupt your thought, only a couple of scheduled talks a week to attend, no classes, no