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Aeronautics: Frontiers of the imaginable

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Space solar power

Panacea, or pie in the sky?

The concept of beaming electric power from space to Earth, freeing the planet from dependence on fossil fuels, has intrigued scientists for decades. From the beginning, however, such plans have faced a seemingly insurmountable barrier–the high cost of space transportation. But proponents now say recent technological advances are sufficient to justify investing in the next logical step toward this elusive goal–a demonstration.

by Jerry Grey
Editor-at-Large

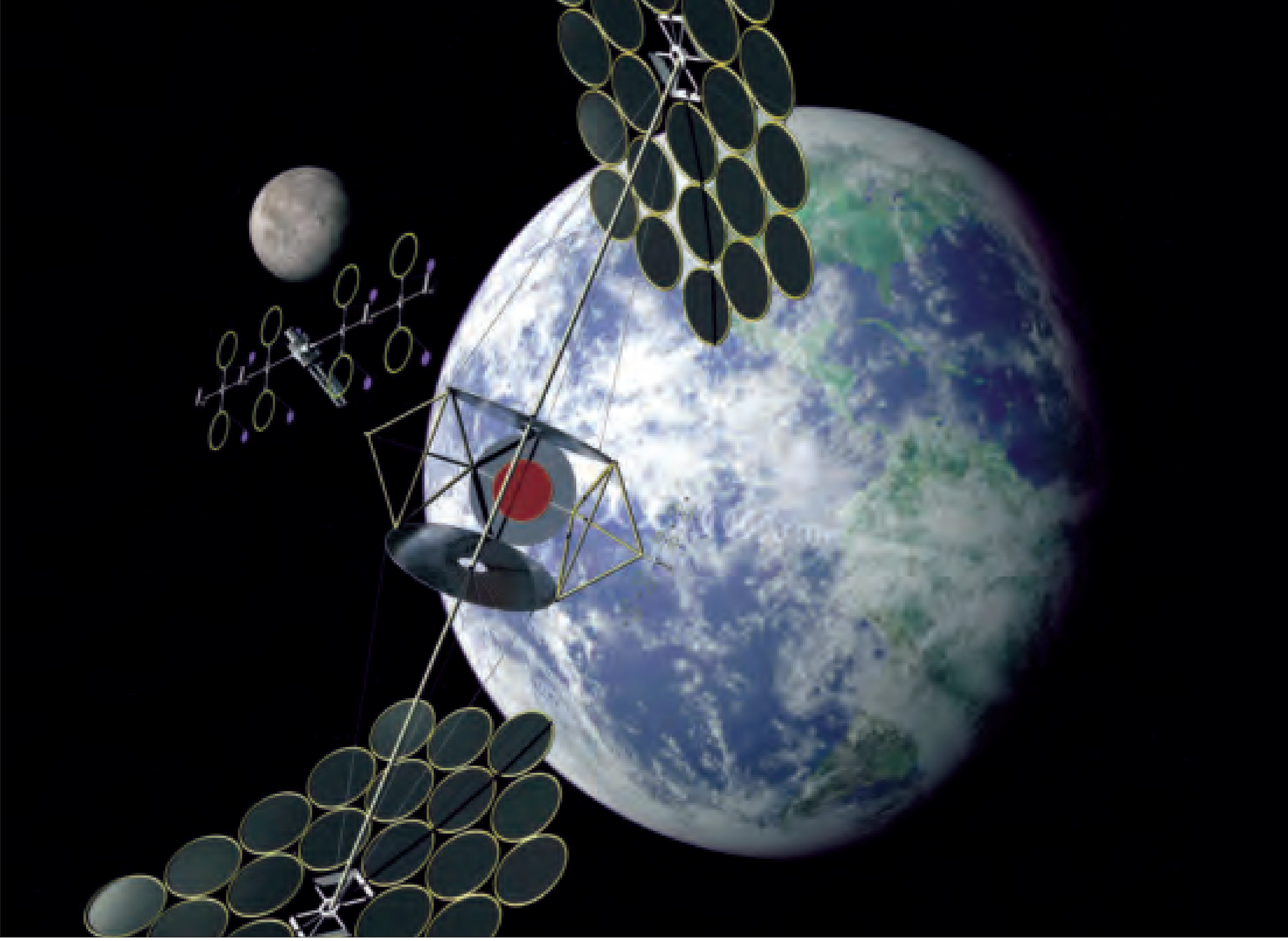
The idea of delivering electricity to Earth from solar collectors in space has been around for over a century. Dozens of studies, analyses, assessments, and proposals for technology development have been generated. But these activities, almost all performed by government agencies or not-for-profit organizations, have not resolved the principal issue: Is the SSPS a good investment?

The key ingredient: Industry interest

Along with the economic barrier imposed by high space transportation cost, the other key factor cited in virtually all the space solar power systems (SSPS) studies and assessments was the need for industry to become actively involved. Government studies and research projects are all well and good, but the driving factor in every successful commercial space effort (and, indeed, in most successful nonmilitary ground-based ones) has been the early and deep involvement of the industrial sector best suited to derive a profit from the endeavor.

A December 1998 NASA workshop on the prospects for future commercialization of space technology, "New Space Industries for the Next Millennium," provided a most interesting revelation. The workshop concluded that by far the largest part of any projected growth in the space industry would not be derived from the current successful commercial enterprises—communications, navigation, and to a lesser degree, remote sensing. Nor would it come from well-recognized potential product development via space processing research and the consequent manufacturing of special products such as crystals and semiconductors. Rather, it would come from wholly new areas of space applications: space tourism and terrestrial energy supply.

Events since the workshop have indicated the potentially explosive growth in



The Integrated Solar Collector, a geostationary-orbit architecture, was examined in NASA's SSPS Concept Development and Evaluation studies of 1998.

space tourism (or whatever euphemisms have been applied to this general area of commerce). But where did this growth originate and find its main support? Not from NASA or other government agencies, but from private-sector investments and corporations. The most promising of these new corporations, The Spacecraft Company, is a joint venture of Scaled Composites, winner of the private-sector X-prize, and Virgin Galactic, a member of U.K. billionaire Richard Branson's Virgin Group, which has already begun to capitalize on the tourism market by accepting several hundred million dollars in deposits from prospective space tourists.

Another promising entrepreneurial company that expects to capitalize on this market (as well as the NASA space transportation needs) is SpaceX, most of whose development and operations funding for its Dragon capsule and Falcon-9 booster comes from the private sector. A third company is Bigelow Aerospace, which has already placed two prototype space stations in orbit with the expectation of deriving profits from the use of their microgravity environment by anyone who can pay for it.

Several other 'newspace' companies have invested substantial private sector funding and effort in developing potential for space tourism and related markets. One legacy space launch company, Boeing, is developing its CT-100 crew capsule as a commercial supplier to the ISS, with plans to promote it for the space tourism market. It is also important to note that the government has assumed its proper regulatory and licensing role in this new industry, as it has done in past new endeavors, by establishing a Commercial Space Transportation Office in the FAA to carry out these essential government functions.

In the case of the SSPS, there *were* a few indications of interest by the electric power industry and the civil engineering profession. The Electric Power Research Institute, the research arm of that industry, had devoted the Spring 2000 issue of its quarterly *EPRI Journal* to the SSPS, and the American Society of Civil Engineers also published a full issue of the *ASCE Journal* on the subject in April 2001.

In 2009 California regulators proposed a plan to approve a 15-year contract for the solar energy firm Solaren to supply space-based solar power to one of the nation's biggest utility companies, Pacific Gas and Electric, by 2016. But that contract was never issued, and no system was ever developed or built.

Another prospective industry venture in the U.K., described in the June issue of the Royal Aeronautical Society's *Aerospace International*, is Orbital Power's visionary project to develop and launch a constellation of 10-tonne satellites, each transmitting 20 MW of microwave power to ground antennas, for a total of up to 5 GW of delivered power during the decade 2030-2040. As yet, however, there is no sign of any actual system elements being designed, developed, or built.

So in the end this minimal recognition of the concept by the industry engendered no real financial or development interest from the industrial energy-supply sector.

Turning point: DOD takes note

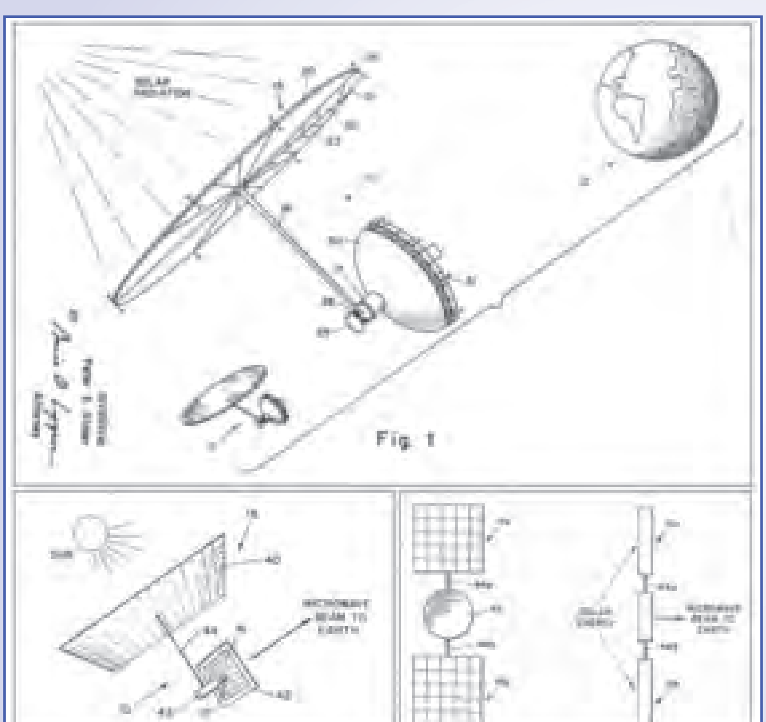
This was the situation when the Defense Dept. got into the act. In October 2007 the National Space Security Office (NSSO) issued a preliminary assessment titled "Space-Based Solar Power as an Opportunity for Strategic Security." Further interest resulted from two events that featured discussions of the then-ongoing NSSO study: an August 2007 roundtable sponsored by Washington, D.C.'s George C. Marshall Institute, and a September 2007 USAF workshop at the Air Force Academy.

This unequivocal interest shown for the first time by the military created a potential turning point for SSPS development. A number of published reports in the trade media, including *Space News* and *Aviation Week*, documented the salient points of the military's interest. A commentary by James Vedda (*Space News*, October 29, 2007) cited

SSPS: A look at its beginnings

In 1890 Nicola Tesla proposed the wireless transmission of electric power, and 10 years later he conducted proof-of-concept experiments. The collection of solar energy in space for transmission to Earth was suggested in 1912 by the grandfather of rocketry, Konstantin Tsiolkowski. The modern version was first published in 1968 by Peter Glaser, vice president of Arthur D. Little, and patented by him in 1973. Glaser's version laid out a specific system design concept that entailed using large orbiting satellites to convert solar energy in space to electricity and beaming the power to Earth for terrestrial use.

Glaser's design concept drew some interest in the ensuing decade, not because of the prevailing hysteria about global warming, but because the price of oil had soared to an unbelievable $12 a barrel. The Dept. of Energy and NASA conducted an extensive study of a so-called 10-GW 'reference design' in 1978-1979. They concluded that although the system was technically feasible, it was nowhere near practical economically. Their conclusion—to shelve the idea for at least a decade to see how the technology and the market would develop—made very good sense at the time.



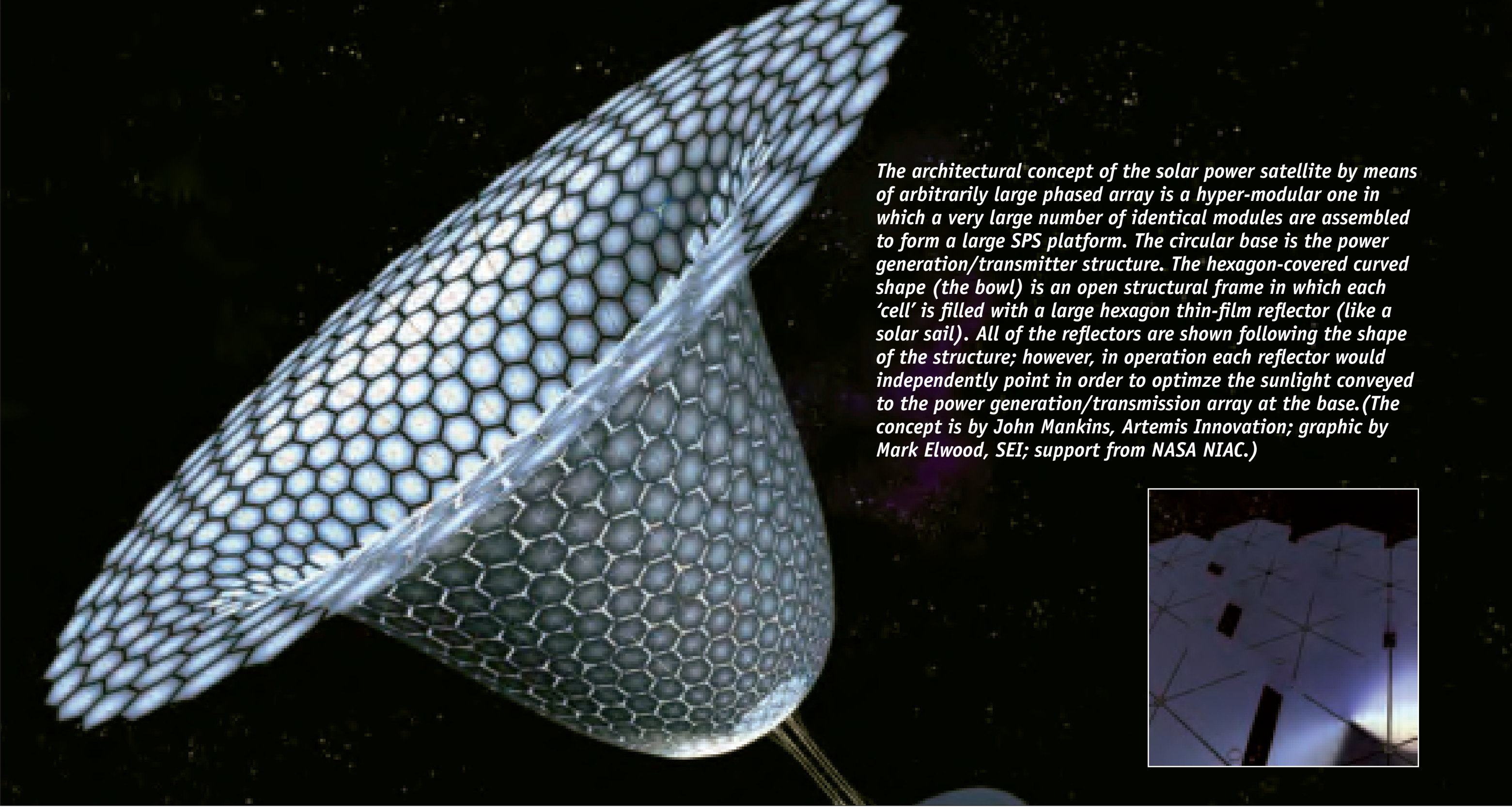
In 1968 Peter Glaser published a modern version of a solar power collector first conceived by Konstantin Tsiolkowski in 1912. It was one of the many SSPS configurations explored in past studies.

Since then, much interest has been expressed in the idea of a space solar power system), also known by other names such as satellite power system, solar power satellite, and space-based solar power.

Despite its infeasible economics—and the high 'giggle factor' associated with the idea of launching dozens of thousand-ton spacecraft to geostationary orbit—the fascinating long-term prospect of delivering the world from dependence on fossil fuels (and their environmental impacts) has stirred up considerable interest. Space-based solar collectors also avoid the factors that limit ground-based solar powerplants—clouds, nighttime, the need for energy storage systems, atmospheric absorption, windstorms, precipitation, lightning, earthquakes, and so on—and therefore can offer baseload service rather than just supplementary power to terrestrial grids.

Early assessments

The congressional Office of Technology Assessment conducted an in-depth evaluation of the DOE/NASA study in the 1980s. Subsequent assessments of the whole SSPS concept were published by the National Academies' National Research Council, the Battelle Memorial Institute, the National Science Foundation, Resources for the Future, and the AIAA. In Congress, three bills were written (and at least three more drafted) proposing various SSPS programs and goals. Controversy raged, not only over the obvious



The architectural concept of the solar power satellite by means of arbitrarily large phased array is a hyper-modular one in which a very large number of identical modules are assembled to form a large SPS platform. The circular base is the power generation/transmitter structure. The hexagon-covered curved shape (the bowl) is an open structural frame in which each 'cell' is filled with a large hexagon thin-film reflector (like a solar sail). All of the reflectors are shown following the shape of the structure; however, in operation each reflector would independently point in order to optimze the sunlight conveyed to the power generation/transmission array at the base.(The concept is by John Mankins, Artemis Innovation; graphic by Mark Elwood, SEI; support from NASA NIAC.)

concerns—orders-of-magnitude increase in space operations and uncertain long-term economics—but also over a host of political, societal, environmental, military, and international regulatory issues. Every assessment and analysis reaffirmed the high cost of space transportation as the principal barrier, even to subscale demonstration projects.

Among those showing broad interest in the concept were the Japanese, who created several technical approaches to various aspects of the system, published technical journals based on annual Japanese SSPS symposia, and designed a comprehensive orbital demonstration project called SPS 2000. This was followed in 2001 by JAXA's 30-year, $2-billion development effort in cooperation with Japanese industry.

There were several ground-based demonstrations of microwave power transmission (the mode espoused by Glaser's patent). The first was a 1-mi. transmission by JPL in 1975; the most recent, by Discovery Channel in 2008, covered 92 mi. A space demonstration proposed in 2009 called for using traveling wave tube amplifiers (donated by the Air Force Research Laboratory and mounted on the Japanese Experiment Module's Exposed Facility on the international space station) to beam ISS solar array power to Earth, but this never took place.

A fresh look

Outside of these peripheral activities, the SSPS idea languished, drawing little attention until 1995, when NASA conducted a 'Fresh Look' study. As the earlier study had recommended, this new effort explored the technological progress made since the 1979 report and the changes in market dynamics.

The Fresh Look study made important strides in recognizing technology advances applicable to SSPS and in developing cost models for evaluating candidate system design concepts and sensitivities. It clearly identified the benefits of using smaller launch packages, multiple modular units, concentrator arrays, and automated assembly. It was also useful in targeting other major cost drivers and implementation difficulties and identified a range of alternative satellite and system concepts for evaluation.

NASA followed up the Fresh Look effort with a series of comprehensive Concept Development and Evaluation studies that documented major advances in technology, market opportunities, and benefits to both civil and military space programs. These studies revised and updated the concepts developed during the Fresh Look and laid out a series of Technology Roadmaps to guide the efforts needed to achieve SSPS cost and operational goals. Work accomplished in 1998 included further definition of the old and new system concepts, of technology advancement planning, and of the economic, market, environmental, regulatory, and political considerations implicit in SSPS development.

Several AIAA assessments in 1999 and 2000 then confirmed the significant technological progress made since the first study: developments in solar photovoltaics; electric power management and distribution; laser power conversion, transmission, and reconversion; lightweight structures (including inflatables, later demonstrated by Bigelow's Genesis modules, now in orbit); structural dynamics of very large spacecraft; robotic assembly; and high-efficiency orbit-transfer propulsion. Such advances had moved these technologies very close to the point where they could soon be incorporated into an operational demonstration SSP system.

One AIAA assessment also identified a number of dual-use options in NASA and military programs—space exploration and geocentric missions—that would both contribute to and benefit from SSPS technology advancements. However, the principal technical barrier remained: achieving sufficiently low-cost, reliable transportation from Earth to low orbit.

Despite these positive indications, in 2001 NASA decided it had more important fish to fry and closed down all research and evaluation of SSPS systems, technology, and economics. There has been, however, one promising recent development: In August 2010 the NASA Innovative Advanced Concepts (NIAC) office awarded a grant to Artemis Innovative Management Solutions for a year-long study of a new SSPS concept. Called SPS-ALPHA, it uses biomimetic technology for a radical new SSPS architecture. Artemis CEO John Mankins presented the idea this year to the March 27-29 NIAC conference. He had led NASA's Fresh Look and Concept Development studies and had generated and led a 2010 Cosmic Study, Solar Energy from Space, *by the International Academy of Astronautics.*

International activities
Several agencies outside the U.S. have conducted extensive studies and symposia on the SSPS, most notably the International Academy of Astronautics, the International Astronautical Federation, ESA, France's CNES and Électricité de France, the French island of Reunion, the Chinese Academy of Space Technology, the Japan-U.S. Science, Technology and Applications Program, UNESCO's World Energy Program, England's University of Oxford, Russia's Maglev institute, the Ukrainian Design Bureau, the Israeli Space Agency, Canada, and the international Sunsat Energy Council.

SSPS as one of the substantial contributions that would make space much more important to mankind than would sending humans to Mars. That opinion was later reaffirmed in a *Space News* commentary by Edward Hujsak on March 26 of this year. And Britain's Royal Aeronautical Society featured "Power from the Sun" in the April 2012 issue of *Aerospace International*.

Although the NSSO report clearly pointed out that the DOD would not be the appropriate agency to fund the development of SSPS, it also stated that the military would be quite interested in serving as an 'anchor customer.' The cost of furnishing electric power to support advance bases in Iraq, Afghanistan, and other far-flung military posts, including the logistics of fuel supply, was then well over $1/kW-hr, vs. the current price of $0.03-$0.05 cited as the competitive barrier for commercial SSPS power.

In the interest of national security, the NSSO report called on the federal government to create a program that would reduce the technical and economic risks of developing a full-scale SSPS, culminating in the funding of a demonstration powerplant in the 5-10-MW range. The key to future growth in both civil and military space activities, said the report, is the development of a space transportation system and the logistic technologies capable of delivering such a unit, either wholly or in parts to be assembled in orbit.

That was precisely what supporters of SSPS had been advocating for years. Modest investments in continued SSPS technology advancement efforts could lead to a space demonstration at reasonable cost in about a decade. Currently available space launch systems would be used pending the evolution of more powerful low-cost launchers.

The extraterrestrial option

Back in 1974, a whole new concept in space development had drawn major public interest: Princeton physics professor Gerard K. O'Neill's proposition that mankind's future would be in space, in the form of enormous orbiting 'space colonies.' As envisioned by O'Neill, these settlements would support thousands of people and could be made self sufficient, drawing their power from the Sun.

During a series of biennial 'Princeton Conferences' cosponsored by AIAA, this grandiose concept was melded with the SSPS, offering life to both programs—a source of jobs and income for the space colonies' populations, and an off-world manufacturing site and workforce for the SSP system. This also would solve the space transportation issue: The materials needed to build and assemble the SSPS hardware would be mined from the Moon and launched to the required geosynchronous Earth orbit locations from the low-gravity, airless lunar surface via solar-powered electric catapults. Additional detailed studies conducted by David Criswell in the 1980s explored the prospects for placing SSPS powerplants on the Moon to deliver power to Earth.

The sizable investment needed to take the next step in SSPS evolution would still be far less than the several trillion dollars now invested annually in the world's terrestrial electric power systems. Indeed, it would be nowhere near a trillion. Yet despite this, and despite the optimistic visions outlined above, today's constrained global economy does not seem to offer any encouragement for investing in that next step: a demonstration, as espoused by the NSSO report and, repeatedly, by SSPS proponents. The NSSO report recommended that, to foster such a demonstration, the U.S. government should:

- Organize effectively to allow for the development of SSPS and conclude analyses to resolve remaining unknowns.
- Retire a major portion of the technical risk for business development.
- Create a facilitating policy, regulatory, and legal environment for the development of SSPS.
- Become an early demonstrator, adopter, and/or customer of SSPS and incentivize its development.

Complying with the first three of these recommendations might have an acceptable budgetary impact and could conceivably be implemented. However, it is likely that in the present budget environment the government would not undertake the more costly 'early demonstrator' role cited in the fourth recommendation.

But unless and until industry commits to that next step—the design, approval, development, construction, launch, testing, and operation of a suitable prototype demonstration in orbit—the half-century-long conundrum will remain: Is the SSPS a potential saviour of our home planet, or just a giant piece of pie in the sky?