SOLAR POWER SATELLITES: THEN AND NOW

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In the early 1970s OPEC (Organization of Petroleum Exporting Countries) caused havoc on petroleum using nations, causing shortages and increasing cost. In the United States, President Nixon commissioned studies as to "Energy Independence." Presidents Ford and Carter created governmental organizations, first ERDA (Energy Research and Development Administration), then enlarged to the DOE (Department of Energy). Research covering new energy sources such as Fusion, expected by the year 2,000, and all forms of Solar, were significantly increased as were studies dealing with conservation. President Carter talked about "The moral equivalent of war." In October, 1977, the following Policy Statement was issued by the DOE and NASA:

POLICY STATEMENT SATELLITE POWER SYSTEM (SPS)

One option by which solar baseload electricity (i.e. essentially continuous 24-hour operation) might be generated is a Satellite Power System (SPS). A satellite station in geostationary orbit, converting solar energy to microwave energy for transmission to earth for ultimate use as a terrestrial energy source was first suggested in 1968 and has been under study by the National Aeronautics and Space Administration (NASA) since 1972. The solar concepts addressed by NASA include photovoltaic and thermal (Brayton cycle or thermionics) types,. No preferred concept has yet been defined. Key issues or concerns include:

A. Environmental, Health and Safety Issues

1. Microwave Power Transmission:
    - International microwave exposure standards
    - Public health risk of radiation exposure;
    - Effects on the biota;
    - Radio frequency interference;
    - Land requirements for receiving antennas and protected areas;
    - Effects on the ionosphere.
2. Rocket Launch and Recovery Operations:
    - Vehicle emission pollutants and their production
    - Chemical, thermal and acoustic — and their effects on public health;
    - Effects on the troposphere and ionosphere.
3. Space Operations:
    - Practicality and cost of maintaining a large productive work force in space;
    - Radiation health hazards to space workers.

B. Economic, International and Institutional Issues:

- Economic competitiveness with respect to expected alternative future energy sources;
- Natural resource requirements, availability and impacts on other national needs;

- Vulnerability and accident potentials:
- Geostationary space availability and ownership;
- Institutional arrangements for the distribution of energy to the user;
- Energy payback period and initial subsidy required.

OBJECTIVE

The objective of the joint SPS concept evaluation program is to develop by the end of 1980 an initial understanding of the economic practicality and the social and environmental acceptability of the SPS concept.

SCOPE OF JOINT PROGRAM

DOE's responsibilities will inclued studies on health, safety, and environmental impacts; international and institutional constraints, effects an socioeconomic and natural resources, and comparative assessments of terrestrial alternatives including fossil, nuclear, fusion and other advanced energy resources.

The systems definition effort will be led by NASA. Its results will be fed back into the ongoing DOE studies to insure the accuracy and consistency of the joint program in determining a preferred system concept. DOE will be the lead agency for the overall management of the concept evaluation program, and any subsequent development program.

Based upon this policy statement, a Concept Development, and Evaluation Program was designed to be similar to goals of venture group in a corporation. Table 1 shows this CDEP/industry analogy.

Table 1

CDEP	INDUSTRY
TECHNICAL POSSIBILITY	MANUFACTURABLE
ECONOMIC VIABILITY	RETURN ON INVESTMENT
ENVIRONMENTAL AND SOCIAL ACCEPTABILITY	MARKETABILITY

The SPS was first examined for fundamental defects (program stoppers) that might have invalidated the concept. Included in this examination were considerations of basic scientific and technical flaws, lack of potential economic viability, unacceptable environmental and social impact, or a poor competitive position relative to other energy options. Table 2 shows the Reference System Characteristics. Each SPS was to produce five gigawatts. It would be 10 x 5 kilometers in size, it would have a satellite mass of possibly 50 million kilograms, located in geostationary orbit; a construction crew of 600 would be required with an estimated construction time of six months.

Table 2. REFERENCE SYSTEM CHARACTERISTICS

System Characteristics

General capability (utility interface)	Number of units: 60
300 GW - total	Design life: 30 years
5 GW - single unit	Deployment rate: 2 units/year

Satellite

Overall dimensions: 10 x 5 x 0.5 km	Satellite Mass: 35-50 x10^6 kg
Structural material: graphite composite	Geostationary orbit: 35,800 km

Energy Conversion System
Photovoltaic solar cells: silicon or galliumaluminum arsenide

Power Transmission and Reception

D. C.-R. F. conversion: klystron
Transmission antenna diameter: 1 km
Frequency: 2.45 GHz
Rectenna dimensions (at 35° latitude)
Active area: 10 x 13 km
Including exclusion area: 12 x 15.8 km

Rectenna construction time:≈ 2 years
Rectenna peak power density: 23 mW/cm ^{2}
Power density at rectenna edge: 1 mw/cm ^{2}
Power density at exclusion edge: 0.1 mW/cm^2
Active, retrodirective array control system with pilot beam reference

Space Transportation System

Earth-to-LEO - Cargo: vertical takeoff, winged two-stage (425 metric ton payload)
Personnel: modified shuttle
LEO-to-GEO Cargo: electric orbital transfer vehicle
Personnel: two-stage liquid oxygen/liquid hydrogen

Space Construction

Construction staging base - LEO: 480 km
Final construction - GEO: 35,800 km
Satellite construction time: six months

Construction crew: 600
System maintenance crew: 240

The study was to take three years at a cost of less than twenty million dollars. Although there were various design configurations, due to the short time and budget, a single design was chosen and was called a "Reference system." At no time was it considered a preferred or optimum system's design. It was chosen so that all the necessary basic research could be conducted to evaluate the concept. The results of the three year effort indicated there were no insurmountable barriers. Research experimentations of non-ionizing radiation using bees and birds show no negative effects and no negative effects were found in the ionosphere,.

At the end of the three year study, world conditions had significantly changed. When President Reagan assumed his office, OPEC had collapsed, inflation was more under control, and many of the fears of energy shortages had significantly diminished. The U. S. National Academy of Sciences' review of the DOE/NASA study recommended that, due to the changing energy needs and the present state of technology, the Solar Power Satellite study should end and the concept should be revisited in 10 years.

During the past 16 years, there have been radical technological changes: photovoltaic conversion efficiencies have grown from 5% to 30% and costs have decreased from $100 per watt to approximately $1.00 per watt. Robotics are common in manufacture and construction and are becoming even more so, and the Shuttle has flown; however, not at the planned one flight per week as first envisioned. But today, research on Single Stage To Orbit vehicles is moving along at a rapid and very promising pace. We are beginning to learn about construction in space. The contributions of the Japanese in using Origami principles; new concepts as to rectennea, the use of robotics, and modular construction have been of significant importance. New materials technology are producing stronger light weight materials.

It has been 16 years since the end of the CDEP, but more importantly, the changed and changing world of then, now, and the future, indicate more strongly than anything else the vital needs for Solar Power Satellites.

In 1970, the world's population was 3.6 billion people. Today, it is more than 5.7 billion, increasing at a rate of approximately a billion people each decade. This growth in population has also seen the tripling, in the same time frame, of urbanization. In 1970, for example, in the developing world, there were approximately 500 million people in urban areas. Today, urban populations in developing regions approach 2 billion. In China alone, in less than 15 years, more than a hundred million people have moved from the rural areas to the urban areas and the demand for energy has increased markedly. Energy demands will not only be for television, refrigerators, and such, but for some of the more truly fundamental urban needs. For example, urban households without safe water in 1970 were 138 million; by 1988 215 million, and growing and growing. During the same time frame, urban households without adequate sanitation grew from 98 million to 340 million. The World Health Organization has stated that 15 million children, 14 years or younger die each year from water-borne diseases. Problems that can be solved with energy to build water and sanitation systems, and to purify the water. This problem has been recognized and the Japanese in 1988 used ground based solar energy and electrolysis on Fukue island and Ohshima for desalinating and converting brakish ground water. This shows what can be done.

We must also remember that 40% of the world population, more then 2 billion people, live in villages not tied to a utility grid. The World Energy Congress has estimated that energy demands will grow from the 1990's 12.2 terawatts to 18.9 terawatts in the year 2020, with almost all the additional demands in the developing countries. Satellites and fibre optics have been the channel to "Open the Window of the World" to all peoples. Radios, televisions, fax machines, personal computers are to be found all over the world. These "windows of the world" have shown people what life can be, and they wish to improve their quality of life. But without energy this will remain just a dream.

Solar power Satellites will not solve all the world's energy problems. It is, however, one vital option, especially linked to ground based Wireless Power Transmission. We must move now to be able to develop advanced energy systems. In the United States, NASA is revisiting the satellite power concept. There is a growing concern by government as to energy needs in the developing world, especially when some consider potential problems in the use of fossil energy.

The knowledge base for microwave power transmission began to be developed one hundred and thirty years ago, in 1865, by Maxwell, when he formulated the equations for electromagnetic induction, followed by Hertz and Marconi in 1877, when they demonstrated wireless focussed transmission of electromagnetic energy and by Clavier in 1927 when he operated a microwave link across the English Channel. And in 1975, when NASA and the Jet Propulsion Laboratory demonstrated overall microwave power transmission efficiency of more than 54% at Goldstone, California.

The knowledge base of wireless power transmission has been fully demonstrated. We now need to create an international consortium to turn this knowledge base into a tangible needed technology for the world. The one key technology required for Solar Power Satellites to become a reality, is the development and implementation of a "Railroad into Space." The cost of lift must be reduced by at least an order of magnitude. The present efforts of NASA and others in the X33 and X34 program, for example, is very promising,. But of most importance, to reiterate, we must find a way to bring government, industry, utilities together so that Energy the Enabler will help improve the quality of life of all people and this must be truly international. **We must learn together and learn from one another.**