SOLAR POWER SATELLITE RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAM ACT OF 1978

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

OF THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

NINETY-FIFTH CONGRESS

SECOND SESSION

ON

S. 2860

A BILL TO PROVIDE FOR A RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAM TO DETERMINE THE FEASIBILITY OF COLLECTING IN SPACE SOLAR ENERGY TO BE TRANSMITTED TO EARTH AND TO GENERATE ELECTRICITY FOR DOMESTIC PURPOSES

H.R. 12505

AN ACT TO PROVIDE FOR A RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAM TO DETERMINE THE FEASIBILITY OF COLLECTING IN SPACE SOLAR ENERGY TO BE TRANSMITTED TO EARTH AND TO GENERATE ELECTRICITY FOR DOMESTIC PURPOSES

AUGUST 14, 1978

Publication No. 95–166

Printed for the use of the
Committee on Energy and Natural Resources

U.S. GOVERNMENT PRINTING OFFICE
35-994 O WASHINGTON : 1978

COMMITTEE ON ENERGY AND NATURAL RESOURCES

HENRY M. JACKSON, Washington, *Chairman*

FRANK CHURCH, Idaho
J. BENNETT JOHNSTON, Louisiana
JAMES ABOUREZK, South Dakota
FLOYD K. HASKELL, Colorado
DALE BUMPERS, Arkansas
WENDELL H. FORD, Kentucky
JOHN A. DURKIN, New Hampshire
HOWARD M. METZENBAUM, Ohio
SPARK M. MATSUNAGA, Hawaii
WENDELL R. ANDERSON, Minnesota
JOHN MELCHER, Montana

CLIFFORD P. HANSEN, Wyoming
MARK O. HATFIELD, Oregon
JAMES A. McCLURE, Idaho
DEWEY F. BARTLETT, Oklahoma
LOWELL P. WEICKER, Jr., Connecticut
PETE V. DOMENICI, New Mexico
PAUL LAXALT, Nevada

GRENVILLE GARSIDE, *Staff Director and Counsel*
DANIEL A. DREYFUS, *Deputy Staff Director for Legislation*
D. MICHAEL HARVEY, *Chief Counsel*
W. O. CRAFT, Jr., *Minority Counsel*

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

FRANK CHURCH, Idaho, *Chairman*

SPARK M. MATSUNAGA, Hawaii, *Vice Chairman*
JAMES ABOUREZK, South Dakota
DALE BUMPERS, Arkansas
WENDELL H. FORD, Kentucky
JOHN A. DURKIN, New Hampshire
WENDELL R. ANDERSON, Minnesota
JOHN MELCHER, Montana

MARK O. HATFIELD, Oregon
PETE V. DOMENICI, New Mexico
JAMES A. McCLURE, Idaho
DEWEY F. BARTLETT, Oklahoma

WILLIS SMITH, *Professional Staff Member*
PETE SMITH, *Professional Staff Member*

CONTENTS

SOLAR POWER SATELLITE RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAM ACT OF 1978

MONDAY, AUGUST 14, 1978

U.S. Senate,
Subcommittee on Energy Research and Development,
of the Committee on Energy and Natural Resources,
Washington, D.C.

The subcommittee met, pursuant to notice, at 10 a.m., in room 3110, Dirksen Office Building, Hon. John Melcher, presiding.

Present: Senators Abourezk, Haskell, and Melcher.

Also present: Pete Smith, professional staff member.

STATEMENT OF HON. JAMES ABOUREZK, A U.S. SENATOR FROM THE STATE OF SOUTH DAKOTA

Senator Abourezk. The hearing will come to order, please. Senator Sparkman, good morning to you. I am opening the hearings on behalf of Senator Melcher, who is scheduled to Chair. I would like to, with the permission of the chairman of the Foreign Relations Committee, read my 5- or 6-minute opening statement.

With respect to the S. 2860, the Solar Power Satellite Research Development and Demonstration Program Act of 1978, I would like to say that I have long been a supporter of solar energy, and have sponsored a great deal of legislation to encourage its use. Nonetheless the harnessing of Sun for the solar power satellite seems to me to be a singularly ill-advised and wasteful approach. Solar-power satellites would be enormously expensive and the money that would be spent on their development would be much more efficiently spent by developing smaller scale, more diversified solar approaches, with total program costs estimated at $1.5 trillion by the turn of the century.

I fear that this bill will only serve to further concentrate economic and consequently political power in the hands of a few corporate giants, while freezing out the innovative smaller business who could, with much less public money, provide this country with a truly solar economy. Moreover, solar-power satellites present enormous environmental hazards in the form of microwave radiation, a subject we are only beginning to understand. There are also very serious military questions which we simply do not have the institutions to deal. Frankly, I feel that this bill will set the stage for a boondoggle of unprecedented proportions. It will be of benefit only to the aerospace industry.

This bill calls for research, development, and demonstration. There is already underway a joint Department of Energy and NASA concept evaluation study to be completed by 1980. This study, which has been allocated $15.6 million will address the economic, environmental, and social possibilities and problems of the solar-power satellite.

To move beyond this study to development and demonstration is to commit us to a massive undertaking before we have even determined that the concept is worth pursuing. Even if Congress did want to develop solar energy in this ill-advised manner, it would make hardly any sense to proceed in this fashion. This kind of wasteful, uninformed Government spending, largely at the behest of industry, is hardly consistent with the mood of the taxpayer, or with the fiscal needs of this country.

Presumably proponents of S. 2860 assume that there is already enough information to move development and demonstration. Studies have been cited showing that the ultimate cost per kilowatt-hour will be no more than those for power generated by nuclear plants. The same studies are based, however, are based on such contradictory and speculative assumptions that we can hardly use them as a basis for a commitment as large as this bill contemplates. To give but one example, the capital cost of the receiving antennas were estimated at 17 percent by project proponent, Peter Glaser, 42 percent by the Johnson Space Center, and 8 percent by the Marshall Space Center. We also do not know about the effects of microwaves, which have been shown to cause central nervous system problems, cataracts, and genetic changes, and possibly may be carcinogenic and involved in sudden infant death. The ongoing Department of Energy-NASA study addresses such cost and environmental problems as these. I see no reason to proceed until we have the answers that study will provide.

Even it it does turn out that there is some potential here, I think there is more to fear if the solar power satellite succeeeds than if it fails.

The promoters of the solar-power satellite formed a group called Sunsat to push the idea. Sunsat's major members are General Electric, MacDonald Douglas, Grumman, Boeing, RCA, Westinghouse, Lockheed, and Martin Marietta, plus various engineering firms and public utilities. If we go ahead and spend hundreds of millions, or even trillions of dollars in this project, we'll be creating a massive energy complex controlled by these industrial giants. One thing this country does not need is the further concentration of our energy resources in the hands of a few large companies. If solar satellites succeed, they will provide one-fifth or more of our total energy needs, and by their nature would be owned and operated by a very small number of companies. Massive government regulation would be necessary to protect the consumer.

Moreover, as the system is being developed, it will freeze out responsible solar development. Proponents argue that this bill only commits $25 million, and that less than $200 million will be spent over the next 5 years.

Boeing, however, is proposing a minimum of $3 billion over the next 5 years, as the amount needed to proceed to development by the turn of the century. Whatever the amount I think we should be guided by the familiar aphorism; that is, Washington projects have only two stages; too early to tell and too late to do anything about it.

The appropriations for this project, as they vow year after year, it will be harder and harder to forsake the previous, accumulated expenditures. Even if we find that the project is no longer as practical as it seems, the cost projections now state the full research and development will cost $40 to $80 billion; with each satellite it would cost $25 million.

These estimates are from the aerospace industry, which is notorious for underestimating costs. Nonetheless, even at these optimistic projections, costs per kilowatt-hour are expected to only compare to nuclear costs. But when cost overruns are included, we may well be struck with an enormous investment in an uneconomical project, a Vietnam of the sky.

At the same time, when future administrations present their solar budget, they no doubt will include amounts for solar power satellite development. Even using the projected costs of industry, we are talking about $2 to $4 billion per year for the next 20 to 25 years for research and development alone, plus an additional $2 trillion or more for enough satellites to supply perhaps 20 or 30 percent of our energy needs. These amounts dwarf what we spend on other forms of solar energy, and, I fear, will continue to do exactly that.

With these billions, we could truly create a solar society. At a cost of $8,000 per household, for one-third of the projected total cost of the solar power satellites, we could equip every home in the country with a comprehensive solar system. Simply by developing small hydroelectric sites at existing dams we could develop the energy potential of five $25 billion solar satellites, and we could do it for a fraction of the cost.

We could provide billions for research on photovoltaic cells—an area which has seen impressive gains in the last few years. We could build thousands of windmills—modern machines producing many kilowatts each at competitive rates today, with the promise of even lower costs in the future.

The point is that for the most part solar energy can be used now. All that is needed is the incentive to use it. Where research and development is needed, money could be provided for a variety of approaches, so that if one direction fails, another can be tried without causing a disaster for the country.

The future solar society could, according the Council on Environmental Quality, rely on the Sun for 25 percent of its energy by 2000 and 50 percent by 2020, but only if we make a commitment now. The future solar society could be one in which the provision of energy was decentralized and based on innovative, competitive entrepreneurship. If we pursue the solar power satellite path, however, the future solar society would depend on massive industries and a single technology. If something were to happen to that industry or technology, we would face the same kind of energy crisis we face today with our reliance on fossil fuels—uncontrollable inflation, international political problems, et cetera. To give one example, the solar satellite would be very vulnerable to attack. Would we defend this precious and vital resource, which would be providing 20 percent or more of our energy? Would the satellite be perceived as a weapon, since it easily could be used for military purposes? If so, how would that affect our military posture? Would we be required by international politics to abandon the satellites, or share their control with a potential enemy worried about their military uses?

For years, we have been seeking a technological fix to our energy problems—a massive and miraculous solution requiring no real sacrifice. Unfortunately, massive technological fixes are usually fixes in the street sense—expensive addictions that prevent us from seeing the real solutions to our problems. The solar power satellite would be just such a fix, and I strongly urge that this bill be defeated.

Now, Mr. Chairman, I will defer the rest of my statement so that we might hear from you this morning, and we would be pleased to hear your testimony now.

[The texts of S. 2860 and H. R. 12505 follow:]

95TH CONGRESS
2D SESSION

S. 2860

IN THE SENATE OF THE UNITED STATES

APRIL 7 (legislative day, FEBRUARY 6), 1978

Mr. MELCHER introduced the following bill; which was read twice and referred to the Committee on Energy and Natural Resources

A BILL

To provide for a research, development, and demonstration program to determine the feasibility of collecting in space solar energy to be transmitted to Earth and to generate electricity for domestic purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Solar Power Satellite Research, Development, and Demonstration Program Act of 1978".

FINDINGS AND POLICY

SEC. 2. (a) The Congress finds that—

(1) the United States is faced with an unparalleled increase in the consumption as well as the cost of energy;

(2) the current imbalance between domestic supply and domestic demand for fuels and energy is likely to persist;

(3) dependence on nonrenewable energy resources cannot continue indefinitely at the current rates of consumption;

(4) it is in the interest of the United States to expedite the long-term development of renewable and nonpolluting energy resources such as the Sun;

(5) to date, this Nation's effort in research, development, and demonstration activities relating to the utilization of solar energy has focused on ground-based equipment;

(6) many studies indicate that a satellite-based energy system would be a vastly superior method of utilizing solar energy, but such a system has not been adequately investigated;

(7) the average citizen is being adversely affected, both economically and ecologically, by the depletion of fossil fuels;

(8) with the increasing dependence of the United States on foreign energy supplies, a solar power satellite system would enable the United States to rely to a lesser extent on foreign countries to satisfy our essential energy needs, and would help eliminate a balance-of-

payments deficit and the threat that such a deficit imposes;

(9) the construction of a solar power satellite system would provide economic stimulation in the form of jobs throughout all the States of this Nation; and

(10) the technology and the trained technical community to support a solar power satellite research, development, and demonstration program are available, and the Space Shuttle and other relevant technology already under development provide a substantial impetus to accomplish such a program.

(b) The Congress declares that it is the policy of the United States—

(1) to pursue a vigorous research and development program on solar power satellites as a major source of energy to satisfy our national energy needs, and

(2) to provide for the development and demonstration of practicable means to employ solar power satellites.

ESTABLISHMENT OF PROGRAM

SEC. 3. (a) There is established a Solar Power Satellite Research, Development, and Demonstration Program (hereinafter referred to as the "Program") to carry out the policy expressed in section 2 (b).

(b) There is established within the Department of Energy an office to manage the Program.

(c) Funding requests for the Program shall be specifically identified.

INITIAL RESEARCH AND DEVELOPMENT

SEC. 4. (a) The Secretary of Energy (hereinafter referred to as the "Secretary") and the Administrator of the National Aeronautics and Space Administration (hereinafter referred to as the "Administrator") shall initiate the Program by carrying out research and development for the purpose of resolving the major technical problems regarding the viability of the solar power satellite concept.

(b) In connection with or as part of such research and development, the Secretary and the Administrator shall—

(1) carry out systems definition studies, space-related technology, health, safety, and environmental studies, socioeconomic studies, and a comparative evaluation of the solar power satellite concept and the terrestrial alternatives to such concept to provide a basis for research, development, and demonstration planning and phasing; and

(2) perform or cause to be performed comparative technology assessments of a solar power satellite concept and terrestrial alternatives to such concept, including—

(A) photovoltaic concepts,

(B) solar thermal (Closed Brayton Cycle, thermionic conversion, cascaded system) concepts, and

(C) nuclear (Closed Brayton Cycle and thermionic conversion) concepts.

CONDUCT OF THE PROGRAM

SEC. 5. To implement and carry out the Program—

(1) the Secretary shall—

(A) contract with the Administrator to conduct and coordinate all space-related research, development, and demonstration projects and activities which are necessary or appropriate under the Program.

(B) coordinate with appropriate power distribution agencies in evaluating the ground portion of the Program, and provide a report on the Program's potential impact on the power network, and

(C) take such other actions as may be necessary or appropriate for the effective conduct and administration of the Program; and

(2) the Administrator shall—

(A) carry out the space-related research, development, and demonstration projects and activities provided for in the contract or contracts entered into pursuant to paragraph (1) (A),

(B) utilize to the maximum extent possible the existing technology, facilities, and expertise of the National Aeronautics and Space Administration, and

(C) coordinate with the Secretary and the power distribution agencies the application of space and energy technology developed under the Program.

COMPREHENSIVE PLANNING AND PROGRAMING

SEC. 6. The Secretary, after consultation with the Administrator, shall transmit to the Congress on or before September 30, 1978, a comprehensive plan for the Program and for continuing research on a solar power satellite, which plan shall be designed (consistently with the provisions and requirements of this Act)—

(1) to provide for the conduct of definitive studies and ground-based research leading to a solar power satellite total system definition and the placing of a demonstration satellite unit or units into orbit to determine the economic viability of collecting and transmitting solar energy for commercial purposes; and

(2) to identify (A) the basic elements of the Program, (B) the Program schedule, (C) a series of decision points within the Program at each of which the Program may be evaluated to determine its feasibility,

and (D) the funding required to carry out each major element of the Program in each fiscal year of the Program.

APPROPRIATIONS

SEC. 7. There is authorized to be appropriated, to carry out this Act, the sum of $25,000,000 for the fiscal year ending September 30, 1979, and such sums as may hereafter be authorized by law for subsequent fiscal years.

95TH CONGRESS
2D SESSION

H. R. 12505

IN THE SENATE OF THE UNITED STATES

JUNE 23 (legislative day, MAY 17), 1978

Read twice and referred to the Committee on Energy and Natural Resources

AN ACT

To provide for a research, development, and demonstration program to determine the feasibility of collecting in space solar energy to be transmitted to Earth and to generate electricity for domestic purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Solar Power Satellite Research, Development, and Demonstration Program Act of 1978".

FINDINGS AND POLICY

SEC. 2. (a) The Congress finds that—

(1) the United States is faced with an unparalleled increase in the consumption as well as the cost of energy;

(2) the current imbalance between domestic supply and domestic demand for fuels and energy is likely to persist;

(3) dependence on nonrenewable energy resources cannot continue indefinitely at the current rates of consumption;

(4) it is in the interest of the United States to expedite the long-term development of renewable and nonpolluting energy resources such as the Sun;

(5) to date, this Nation's effort in research, development, and demonstration activities relating to the utilization of solar energy has focused on ground-based equipment;

(6) many studies indicate that a satellite-based energy system would be a vastly superior method of utilizing solar energy, but such a system has not been adequately investigated;

(7) the average citizen is being adversely affected, both economically and ecologically, by the depletion of fossil fuels;

(8) with the increasing dependence of the United States on foreign energy supplies, a solar power satellite system would enable the United States to rely to a lesser extent on foreign countries to satisfy our essential energy needs, and would help eliminate a balance-of-

35-994 O - 79 - 2

payments deficit and the threat that such a deficit imposes;

(9) the construction of a solar power satellite system would provide economic stimulation in the form of jobs throughout all the States of this Nation; and

(10) the technology and the trained technical community to support a solar power satellite research, development, and demonstration program are available, and the Space Shuttle and other relevant technology already under development provide a substantial impetus to accomplish such a program.

(b) The Congress declares that it is the policy of the United States—

(1) to pursue a vigorous research and development program on solar power satellites as a major source of energy to satisfy our national energy needs, and

(2) to provide for the development and demonstration of practicable means to employ solar power satellites.

ESTABLISHMENT OF PROGRAM

SEC. 3. (a) There is established a Solar Power Satellite Research, Development, and Demonstration Program (hereinafter referred to as the "Program") to carry out the policy expressed in section 2 (b).

(b) There is established within the Department of Energy an office to manage the Program.

(c) Funding requests for the Program shall be specifically identified.

INITIAL RESEARCH AND DEVELOPMENT

SEC. 4. (a) The Secretary of Energy (hereinafter referred to as the "Secretary") and the Administrator of the National Aeronautics and Space Administration (hereinafter referred to as the "Administrator") shall initiate the Program by carrying out research and development for the purpose of resolving the major technical problems regarding the viability of the solar power satellite concept.

(b) In connection with or as part of such research and development, the Secretary and the Administrator shall—

(1) carry out systems definition studies, space-related technology, health, safety, and environmental studies, socioeconomic studies, and a comparative evaluation of the solar power satellite concept and the terrestrial alternatives to such concept to provide a basis for research, development, and demonstration planning and phasing; and

(2) perform or cause to be performed comparative technology assessments of a solar power satellite concept and terrestrial alternatives to such concept, including, but not limited to—

(A) photovoltaic concepts, and

(B) solar thermal (Closed Brayton Cycle, thermionic conversion, cascaded system) concepts.

CONDUCT OF THE PROGRAM

SEC. 5. To implement and carry out the Program—

(1) the Secretary shall—

(A) contract with the Administrator to conduct and coordinate all space-related research, development, and demonstration projects and activities which are necessary or appropriate under the Program.

(B) coordinate with appropriate power distribution agencies in evaluating the ground portion of the Program, and provide a report on the Program's potential impact on the power network, and

(C) take such other actions as may be necessary or appropriate for the effective conduct and administration of the Program; and

(2) the Administrator shall—

(A) carry out the space-related research, development, and demonstration projects and activities provided for in the contract or contracts entered into pursuant to paragraph (1) (A).

(B) utilize to the maximum extent possible the existing technology, facilities, and expertise of the National Aeronautics and Space Administration,

(C) utilize to the maximum extent possible the technology and resources of the universities and private sector, and

(D) coordinate with the Secretary and the power distribution agencies the application of space and energy technology developed under the Program.

COMPREHENSIVE PLANNING AND PROGRAMING

SEC. 6. The Secretary, after consultation with the Administrator, shall transmit to the Congress on or before January 3, 1979, a comprehensive plan for the Program and for continuing research on a solar power satellite, which plan shall be designed (consistently with the provisions and requirements of this Act)—

(1) to provide for the conduct of definitive studies and ground-based research leading to a solar power satellite total system definition and the placing of a demonstration satellite unit or units into orbit to determine the economic viability of collecting and transmitting solar energy for commercial purposes; and

(2) to identify (A) the basic elements of the Program, (B) the Program schedule, (C) a series of decision points within the Program to evaluate the major

technological achievements and uncertainties and justify further program commitments (including the decision point for commitment to construction of a demonstration satellite), and (D) the funding required to carry out each major element of the Program.

APPROPRIATIONS

SEC. 7. (a) There is authorized to be appropriated, to carry out this Act, the sum of $25,000,000 for the fiscal year ending September 30, 1979, and such sums as may hereafter be authorized by law for subsequent fiscal years.

(b) Notwithstanding any other provision of this Act, no authorization to make payment or to enter into contracts under this Act shall be effective except to such extent or in such amounts as are provided in advance in appropriation Acts.

Passed the House of Representatives June 22, 1978.

Attest: EDMUND L. HENSHAW, JR.,

Clerk.

STATEMENT OF HON. JOHN SPARKMAN, A U.S. SENATOR FROM THE STATE OF ALABAMA

Senator SPARKMAN. Thank you, very much. I am supposed to be at another committee meeting with Secretary Vance at the Foreign Relations Committee, but I have a very brief statement that I should be glad to make at this time.

I'm pleased today to testify in behalf of S. 2860, the Solar Power Satellite Research Development, and Demonstration Program Act of 1978, before my colleagues on the Subcommittee on Energy and Research Development.

We have a well recognized responsibility in our country to investigate alternative sources of energy for the future. I believe that the collection of solar energy in space provides us with the promising goal of harnessing an energy source which is clean, renewable, and cost efficient. We must investigate fully such a promising source of energy.

Since 1976, preliminary study has been conducted by the Department of Energy and the National Aeronautics and Space Administration, to investigate the concept of solar powered satellite systems. S. 2860 is the next logical step toward reaching our goals. This legislation authorizes the Department of Energy and NASA to spend $25 million to conduct jointly research for the purpose of resolving technical problems to prove the viability of this energy system.

The Secretary of Energy, with NASA's assistance, would submit the comprehensive program to weigh the economic feasibility as well as the environmental safety of the solar-powered satellite concept. They would set a series of decision points at which time, the advisability of continuing the program could be evaluated, and the Congress would have an opportunity to review this finding before deciding to continue funding, in each fiscal year.

As you know, we imported $45 billion worth of foreign oil last year. We simply must begin to move away from such foreign energy dependence. The Sun is a promising solution to our energy problems, and S. 2860 is a promising means toward that beginning.

I just think that it is too good a source, too much of a plentiful source of energy for us to investigate the various possibilities for using that energy. That is all I have to say.

Senator MELCHER [presiding]. Thank you very much, Mr. Chairman. Your remarks are very brief, and to the point. I very much appreciate them. And we know of your long service here, and your efforts to set the Senate as well as the whole body here in Washington in a mood to get on with an energy program that is not only practical now but is practical in the decades to come. Thank you very much.

Senator SPARKMAN. Let me say, I should like to stay and hear my colleague testify, but supposedly they are waiting for me to get to the Foreign Relations Committee. I apologize to her for not being able to stay.

Senator MELCHER. Senator Allen, the committee would be delighted to hear from you and to have you here.

STATEMENT OF HON. MARYON ALLEN, A U.S. SENATOR FROM THE STATE OF ALABAMA

Senator ALLEN. I am delighted to be here, Mr. Chairman.

Senator MELCHER. Please proceed.

Senator ALLEN. I join with some of my colleagues in cosponsoring the legislation for possible answers to our country's long-range energy problems. The Solar Power Satellite Research, Development, and Demonstration Program Act of 1978 is just such a measure. Recognized by the House of Representatives, this bill makes a national commitment to the scientific and technical concept that many of us have been seeking for a very long time, a way to tap the inexhaustible energy of the Sun for earthbound energy needs. Yet, Mr. Chairman, while the commitment is made, our country is not locked into a multimillion dollar development program until and unless the Congress, the industrial and scientific communities, and the public are convinced of the results of the research that further investigation would prove beneficial.

The decision points feature of S. 2860. is a valuable and unique demonstration of our awareness of the public's finite monetary resources. In short, in order to go ahead the Government, industry, and the scientific community will have to prove to all that a go-ahead will pay off, and will be cost effective.

Passage of S. 2860 puts all on notice that it is time to upgrade our consideration of solar-power satellites in a thorough going, scientific investigation. It is necessary that we start now with the legislation to think about the future energy security of our country and the future energy needs of our grandchildren and their children.

S. 2860 will make that commitment. Since I realize that there are many others to testify, I have made my statement very short. Mr. Chairman, I would like to introduce my colleague from Alabama, Congressman Ronnie Flippo.

Senator MELCHER. Thank you very much, Senator, we appreciate your being here this morning.

Congressman Flippo.

STATEMENT OF HON. RONNIE G. FLIPPO, A U.S. REPRESENTATIVE FROM THE STATE OF ALABAMA

Mr. FLIPPO. Thank you, Mr. Chairman. Mr. Chairman, I want to thank you for providing me with this opportunity to testify before this distinguished subcommittee. I have a great deal of respect and admiration for the leadership that you and other members of the subcommittee have demonstrated over the past few years, in helping our Nation cope with the energy problem. Thus, I am pleased with the interest that you have shown in the solar power satellite concept, and I congratulate you on holding these hearings on this important piece of legislation.

Mr. Chairman, the SPS concept has been under consideration for a number of years. It has been the subject of detailed analysis by industry, by academic institutions, and Federal agencies. The House Committee on Science and Technology has demonstrated continued interest in this concept for a number of years. The House Subcommittees on Space, Science Applications and Energy, have held hearings on this subject at least four times on separate occasions in May 1973, September 1974, February 1976, and again this year.

These hearings and related research have documented the viability and the potential of the SPS program. Despite all of the evidence in support of this program, it has been treated in the past with benign neglect by responsible agencies. They say that the SPS program is needed and that it shows great promise, but they request little or no funding for it, which in turn stifles its development.

At the present time the Department of Energy and NASA are conducting a joint, 3-year SPS study. Their overall objective is to develop an understanding of the technical requirements, the economic practicability, and the social and environmental acceptability of the SPS concept. They hope their findings will be sufficient to reach a preliminary program continuation decision in 1979, and a final decision in 1980 to either continue the program or phase it out.

The DOE–NASA program is a good start. However, the program only entails an expenditure of $15.6 million over the 3-year period. These funds will provide for paper studies only which will focus on systems definition, environmental issues, and economic considerations. These are issues that have been under study for the past few years.

Testimony presented during hearings in the House have confirmed that the technical, environmental, economic, and other related issues cannot be resolved without an adequate technology verification program. Studies to date have not identified any barriers with respect to technical feasibility. Although solar powered satellites represent a large engineering endeavor, I've been assured by a number of respected scientists and engineers that there are no scientific breakthrough required to fully develop a solar power satellite.

Senate bill 2860 will complement and strengthen the current DOE–NASA program. This bill would provide for a research, development, and demonstration program to determine the feasibility of collecting in space solar energy to be transmitted to Earth, and used to provide electricity for domestic purposes.

Senate bill 2860 will complement the existing program by providing for the necessary technological verification program. It would strengthen the existing program by bridging the gap between paper studies and hardware verification.

Sometime in 1980, DOE and NASA will be making a decision to continue or stop the SPS program. Congress in turn will have to confirm or reverse this decision. This responsibility suggests that Congress would be prudent to begin now to thoroughly examine the technical, economic, and the environmental issues and to generate the experimental data necessary to make a sound go- or no-go decision on the SPS program.

The Solar Power Satellite Research, Development, and Demonstration Program Act is designed to provide the information necessary to fully evaluate the SPS concept. The bill would firmly establish an SPS program within DOE to identify the basic elements of the SPS program, a program schedule, decision points, and funding requirements for each program element.

The program structure of this bill, and the information that it would provide is necessary if we are to make a rational and informed decision about the viability and the practicability of the SPS concept.

This Nation must embark on a national energy strategy which will result in the development of a nondepletable source of energy. It is beyond question that our Nation and the world must develop sources of energy other than depletable fossil fuels. We must explore alternatives beyond the short-term measures of energy conservation. We should seek an energy alternative which will provide long-range solutions to the energy supply problem. The characteristics of long-run alternatives would include domestic availability, abundance, environmental acceptability, and a competitive price.

For these answers to our energy questions, we should look to the source of our energy in our universe; we must look to the Sun. We have tapped that energy resource which is stored in the fossil fuels. We know there's abundant energy in the universe that streams past our planet from that giant, existing fusion reactor, the Sun.

Solar power satellites offer us a means to capture energy from this vast resource. Solar power satellite would be bathed in sunlight 99 percent of the time, receiving 4 to 11 times the solar energy available in areas of the surface of the Earth. These powerplants in space would collect the Sun's energy while they orbit the Earth, beam the energy back to the ground, and provide baseload electrical power from ground receivers.

The SPS concept holds great promise as a viable, longrun energy source. Yet when placed in the context of other longrun, nondepletable, baseload energy options, solar power energy research is being shortchanged. Fusion research receives congressional support on more than $400 million per year. Nuclear fission receives more than $1 billion per year, while solar power satellites receive less than $5 million per year. We need to pursue all the energy options, and each option should be given a balanced examination commensurate with its potential.

In the final analysis, it is clear that an increase of $25 million for solar power satellite in fiscal year 1979 is a prudent, first step toward developing a more balanced emphasis on solar-powered satellites, as a nondepletable, energy alternative. SPS offers the potential to help meet the vast energy needs of the United States and the world. This Nation must take the necessary steps to determine the environmental soundness and the economic feasibility of the SPS concept, if we are to fully utilize the great energy resources of the Sun.

Mr. Chairman, I'm sure the committee, is fully aware of what the Senate bill 2860 does. I would like to direct a few remarks to what the bill does not do, and want to clearly state that the bill does not commit this Nation or the Congress to commercial-sized satellites.

In the course of the House hearings a number of criticisms were leveled against the bill. For the most part the objections to the bill were valid and legitimate, representing some of the same questions in my mind when I first explored this concept. These objections and criticisms were very much in the mind when the list of witnesses was developed for the House hearings on the SPS legislation.

In view of the testimony presented in these hearings, the content of House report 95–1120, and the considerable publicity provided by the bill, I believe the objections have been laid to rest. In case they have not, I would like to review for this committee the major criticisms of the SPS concept.

The criticism of the SPS bill on the basis of cost have been most perplexing. To say that the SPS program will cost trillions of dollars is unfounded, unfair, misleading, and downright ludicrous. To say that the legislation under consideration here today will authorize a multibillion dollar space program is untrue and irresponsible.

Senate bill 2860 does not provide for, or authorize, a multibillion dollar space program. The bill does not commit this Nation or the Congress to commercial-size satellites. Senate bill 2860 does authorize $25 million to initiate a technology verification program to move beyond paper studies. These funds will enable DOE to determine whether or not the concept is economically and fiscally sound.

Senate bill 2860 directs DOE in consultation with NASA to develop a comprehensive plan for the SPS program to determine whether or not this country can apply the knowledge and hardware we have developed and paid for through the space program to solve the Nation's energy problems.

This plan will identify the basic elements of the SPS program, a program schedule, and a series of decision points within the program to evaluate its progress and efficacy. At each decision point Congress will have the opportunity to evaluate the program and determine if further funding is justified.

The program is well organized and designed to develop the information necessary to allow Congress to make an intelligent and informed decision about the feasibility of the SPS concept. At each decision point the Congress will have the opportunity to continue or stop the program on the basis of fact not conjecture.

The $25 million provided for in this bill appears to me to represent a prudent investment in the future of our country. There are no known technical barriers to the design, development, and operation of the costs for future terrestrial power generating methods. Risk analysis solar-power satellite. Economic studies show that projected capital generating costs of the SPS are within the competitive range of the provides economic justification for proceeding now with the program provided for in S. 2860.

The Boeing Co. has developed cost estimates of a complete SPS program under a contract awarded by NASA. The Boeing estimate of $84 billion includes not only research, development, and demonstration costs, but also includes the cost of placing the first full size—10,000 megawatt—operational satellite in orbit.

This estimate covers the cost of constructing or developing all the elements necessary for the construction of the solar power satellites at the rate of one per year including heavy lift launch vehicles, an orbital construction base, solar cell production facilities, ground stations, et cetera. It should also be noted that the SPS is generally viewed as an incrementally funded program taking approximately 15 years to fully implement.

Initially the Space Shuttle would serve as the developmental vehicle. Commitment to the development of a heavy lift launch vehicle need not take place until about 8 years before SPS placement takes place. Development of the heavy lift vehicle is not necessary for the technical verification phase.

For some, the $80 billion price tag attached to the SPS program appears exorbitant and sufficient reason to stop the program now in its infancy. Those who follow this line of reasoning are surely unfamiliar with the capital needs of the enregy industry and the projected costs of any of the proposed long-run energy alternatives. The United States will be required to invest large amounts of capital over the next two decades to meet the demand for energy. Virtually every estimate of the capital investment needs of the energy industries is measured in multibillion dollar figures. Consider, for example, the cost of fully exploiting the nuclear option. The estimated costs of new enrichment facilities, uranium mines, nuclear waste storage, breeder technology and facilities, and nuclear plant decommissioning are astronomical. The cost of exploiting our reserves of coal is also unsettling.

On the contrary, Mr. Chairman, the members of the House Subcommittee on Energy and Space programs made every possible effort to identify and assess the environmental issues. Distinguished scientists from academic institutions and private research laboratories and Federal agencies were invited to participate on hearings on this bill held this year.

These learned scientists clearly identified all the environmental issues associated with the SPS concept for the members of the subcommittee, provided information on the status of ongoing research efforts to analyze and solve these environmental questions, and outlined research programs, that would seek to resolve these environmental issues by a combination of analysis, systems studies, and experiments on Earth and in space.

For those who want to know more about the committee approach, I would recommend a careful reading of the committee report on H.R. 12505. In addition to thoroughly reviewing the environmental issues, the report contains an innovative and, I believe, unique approach to addressing the environmental concerns. The report recommends the establishment within the overall SPS program, a mechanism that will allow for independent review and consultation on the environmental, biological, and ecological issues. This independent review mechanism would isolate the environmental judgments from the program management and from the program proponents. In short, we recognize the environmental issues and are willing to work to address these issues in an objective and open manner.

Based on current available data, adverse environmental effects are not anticipated because of the relatively low level of transmitted microwave energy being considered. The SPS can be designed to operate effectively and efficiently within the existing microwave exposure standards in this country and elsewhere. However, all possible effects of microwave transmission must be reevaluated in the context of the SPS design to resolve outstanding environmental questions.

Additional research is necessary. This is the purpose of the SPS legislation. If effects are discovered the SPS system design can probably be modified to alleviate the effects. If the appropriate design changes cannot be made, then we will have to pursue other energy alternatives.

The environmental research initiative provided for in Senate bill 2860, will supplement and complement existing research efforts to assess the biological effects of nonionizing electromagnetic radiation. At the present time the Federal Government is spending approximately $9.3 million on this form of research. These funds are distributed among nine departments or agencies with three agencies—HUD, DOD, and EPA—accounting for 94.3 percent of the research funds.

The research and development of the SPS will require an increase in the efforts to resolve the questions surrounding microwave radiation. More than likely the SPS research program will double the expenditures on microwave radiation research next year. The SPS legislation may be the driving force in solving the mysteries of microwave radiation.

Mr. Chairman, critics also contend that the exhaust from numerous launches of a heavy lift, freight vehicle will pollute the upper atmosphere. Exhaust products on the launch vehicle for commercial satellites are anticipated to be water vapor created by burning hydrogen and oxygen. Again, we need additional experimental data. A technical verification program would provide the necessary data to fully resolve the concerns of our critics.

Testimony presented during the House hearings by Dr. Gordon, the dean of natural sciences at Rice University confirmed that experiments conducted to date have not indicated that microwave transmissions would disrupt communications systems. I believe DOE has conducted further tests that tend to confirm the findings of Dr. Gordon. Further testing is necessary.

Mr. Chairman, it's been said that this Nation would be better off too if we rely on small applications of solar power to satisfy our demand for energy in the future. Consumer level energy systems such as solar cells on rooftops or windmills in backyards can help some individuals; but in our high powered, highly interdependent society, we need a permanent and complete solution that will turn the engines of society. We need an energy source that will place a cap on energy costs. The solar power satellite offers that.

Mr. Chairman, I believe, and the House obviously believes that the time has come for Congress and this Nation to move forward with development of a long-run solution to the energy problem. We think that the SPS concept is a good concept, and that Congress should move toward a go or no go decision point that we can have an energy system that will place a cap on energy costs and that will do something about the rising utility bills.

Thank you, Mr. Chairman.

Senator MELCHER. Thank you, Congressman Flippo. Were there many amendments to the bill as it passed the House?

Mr. FLIPPO. Mr. Chairman, the Obey amendments were fairly technical in nature. One of the amendments changed the date for the DOE–NASA report to the Congress from January to the next January. The original bill had a September reporting date. But for the most part they were only technical amendments.

Senator MELCHER. Is there an amendment to section 6(2) (c) regarding a decision point on the commitment to a demonstration satellite?

Mr. FLIPPO. Mr. Chairman, I don't believe there were any changes. I believe your staff has a copy of the amendments. The only decision point—we asked DOE–NASA to report back to the Congress in September 1978. The bill was introduced in January. We needed to change that date and we moved that date forward to January 1979, so that DOE and NASA would have adequate opportunity to research it, and to present how they intend to get us to a go or no go decision point.

Senator MELCHER. The House intended that there would be a review by Congress prior to any actual development, or demonstration of the satellite.

Mr. FLIPPO. That is exactly right, it was the intent that there be many decision points at which Congress could say we should go forward or not go forward, based upon objective information and facts.

Senator MELCHER. This authorizes $25 million for the next fiscal year. Is there any background in the House's discussion on how much would go to NASA and how much to the Department of Energy?

Mr. FLIPPO. There were no identifications of allocations.

Senator MELCHER. Did the House contemplate that the authorization was for the Department of Energy, but that the Department of Energy would in effect funnel it into NASA, as was needed?

Mr. FLIPPO. That was the anticipation. I believe, and DOE–NASA officials can comment on this. It was expected that DOE would deal with the environmental issues and NASA would deal with some of the other technological verification programs. That they would work together, they would have a joint role in preparing the program plan.

Senator MELCHER. Thank you.

Senator Haskell.

STATEMENT OF HON. FLOYD K. HASKELL, A U.S. SENATOR FROM THE STATE OF COLORADO

Senator HASKELL. Thank you, Mr. Chairman, I have a statement that I would like to have put in the record, if I may.

Senator MELCHER. Without objection it will be made part of the record at this point.

[The prepared statement of Senator Haskell follows:]

STATEMENT OF HON. FLOYD K. HASKELL, A U.S. SENATOR FROM THE STATE OF COLORADO

I am very pleased that the subcommitee has taken this opportunity to hold hearings on S. 2860, "The Solar Power Satellite Research, Development and Demonstration Act." I have been a strong supporter of Solar Energy, and am very proud that the Solar Energy Research Institute is located in my state. I firmly believe that solar energy can and should play a major role in our energy future. It may be that solar power satellites will be part of that future, but, I am convinced, before we proceed to commit ourselves to the development and demonstration of this approach, we need to answer some very crucial questions about the economics, ecological effects, and military problems of solar power satellites. A study is already underway at the the Department of Energy and NASA to provide us with answers to these questions. Until that study is completed in early 1980, I believe that enactment of a bill including development and demonstration would be premature.

One of the greatest advantages of solar power is that it provides employment to a wide variety of occupations through businesses of all sizes throughout the country. There are a great number of different solar approaches, and if one fails, another can take its place. This pattern of competitive and varied business activity has always been the basis for our country's most innovative and creative enterprise. I fear, however, that the construction of solar power satellites would have the opposite effects, for the satellites, by their nature, would be built and controlled by industrial giants using high technology, capital intensive approaches. Massive government regulation would be needed to assure that the potential for monopolistic practices inherent in using energy from the satellites did not take unfair advantage of the consumer.

I also fear that the cost of constructing the satellites would seriously deplete both government and private capital resources available for solar technology on the ground. Future administrations would probably include the research and development costs of the project in their solar budgets. Since industry estimates done by the Jet Propulsion Laboratory indicate that annual appropriations for research and development for the satellites will be $2–4 billion per year, there may be even less enthusiasm than there is now for making a full commitment to all the other promising solar technologies already available or currently being developed. Since each satellite is estimated to cost $25 billion and proponents hope for eventual deployment of 40 to 80 units, the total cost of developing the satellite is an estimated $1 to 2 trillion dollars. Using figures developed by the Office of Technology Assessment for the cost of fitting solar systems on residential homes, we could supply every house in the country with a 65 percent solar system for roughly one-third of the cost (OTA, Application of Solar Technology to Today's Energy Needs). Similarly, the Corps of Engineers has estimated that simply by installing generators at existing small dams around the country, we would supply the energy equivalent over five solar satellites.

There are but two examples of available solar technologies that only require government and private commitment to provide substantial amounts of energy. Other technologies, such as photovoltaics, are already proven but require further development to become economical. When such promising avenues are open, it seems to me that we should pursue solar power satellites only if we are very certain of their practicality and desirability.

Solar power satellites also raise serious ecological and military questions. Microwaves have been implicated in genetic and central nervous system changes and in cataracts, and may cause cancer and sudden infant death. Microwaves can also seriously disrupt communications.

The Soviet Union already has the ability to sabotage satellites, and surely these satellites, which I have been told could be as large as Manhattan, would be vulnerable to blackmail of this sort. We would either have to arrange for the defense of the satellites, or risk considerable loss of electrical energy during a potential military conflict. This, of course, would substantially add to the cost of the project.

Finally, at projected costs, the satellites would provide power at competitive rates, but cost projections for such projects have been notoriously subject to overruns. We could, therefore, end up making substantial investments in an uneconomical system, but we would not know just how uneconomical it was until we had already committed too much to simply scrap the idea.

Given the seriousness of these questions, it seems to me that we should be very certain that we want solar satellites as a major component of our energy future. The potential here for making an enormously costly and dangerous error is simply too large not to wait until a thorough proof of concept study is completed.

SOLAR SATELLITE QUESTIONS

How vulnerable to attack would a solar satellite be? How would they be defended? Are the costs of defense included in the $25 billion per satellite figure?

Currently there is approximately $16 million being spent over a three year period ending in 1980 to specifically determine the feasibility of solar satellites. What are the paramenters of this study? Has this program worked out the bugs and indicated the feasibility of the project?

How much do we know about the effects of beaming massive quantities of microwaves from space back to earth? Shouldn't we know exactly what these effects are before throwing millions and possibly billions of dollars down a black hole?

Senator HASKELL. Congressman Flippo, we certainly appreciate very much your coming here. I have only one question. It is my understanding that both DOE and NASA are already making a feasibility study to answer some of the questions that you've raised. If that is the case, what does this bill do that the feasibility study wouldn't do.

Mr. FLIPPO. Senator, that is a very good question. The main thing that it would do, it would move us into a technology verification phase. The status of DOE-NASA activities were confined primarily to paper studies to the introduction of this bill.

I understand that since the introduction of the bill, NASA and DOE moved forward, in first of all establishing in DOE a department whose function it would be to direct the activities of the solar-power satellite. I think they have moved forward in the technology verification of communications interaction, and perhaps there would be some in other areas.

But this would certainly put Congress—would express the intent of Congress—that we intend to look at all energy alternatives commensurate with their potential, to get the answers if they are show stoppers associated with solar-power satellites, such as some of the environmental areas. And we must have answers to those, and we cannot base a program based on paper studies or surveys in current literature, alone.

We must prove the foundation or the assumptions on which these paper studies have been based, and that is what this bill intends to do. To do the types of technology verification that are necessary to substantiate what we think is true in the paper studies. Essentially what the bill does is get us in the position of making a decision as to whether or not we should commit this Nation to a national program.

It is not the intent of the legislation to commit this country to a commercial size program, but to secure the information so that Congress can decide whether or not we can go forward with a solar satellite program.

Senator HASKELL. Thank you, Congressman, very much indeed. I guess what I should really do is when the Department comes up, is quiz them pretty carefully on where they are, and what they intend to do. Thank you, sir, very much.

Mr. FLIPPO. Thank you, Senator.

Senator MELCHER. Congressman, I have a short statement, and I would like you to listen to it to see whether we are thinking on the same track. The concern of Congress must be to examine all options to assure the availability of future energy supplies, and that is the thrust of the approach we've taken.

Our Nation has already developed several base technologies which will enable us to explore this energy resource. The technology for putting solar power satellites into space was paid for through the development of our space program. What we now must determine are the economic and environmental effects of developing the solar power satellite system. We need to know if the theory is feasible, sound, and safe,

Our bill would initiate research for the purpose of resolving technical problems; to prove the viability of the solar power satellite system. Whether it will be advisable or cost effective to continue this program would be made in a series of decision points. The movement to reach

each new stage would be evaluated at the completion of each prior stage.

This bill does not contemplate early results, but we do have the desire to find out if this vast source of energy is at all feasible. I see this as a potential, baseload energy source over the very long run, perhaps not in my lifetime, but a possibility in the lifetime of our children and grandchildren.

What we could pass to our future is a source of clean, baseload energy at stable costs, long after our current major fossil fuels are either gone or are used to sustain our petrochemical industry.

I want to bring to the committee's attention the SPS factsheet which the staff is making available to you which I received on my bill from Consumer Action Now. It reflects a great number of misunderstandings. I will submit it for the record at this point.

[The factsheet follows:]

Solar Power Satellites

Present Status

The Department of Energy and the National Aeronautics and Space Administration are conducting a joint three-year Solar Power Satellite study. Their overall objective is to develop an understanding of the technical requirements, economic practicability, and social and environmental acceptability of the solar power satellite concept. This understanding is to be sufficient to enable a preliminary program continuation decision to be made in calendar year 1979 and a final decision to be made in 1980 to either continue with the program or phase it out.

The Problem

The DOE/NASA program is a good start. However, it allows for only $15.6 million over a three-year period. These funds are being used solely for paper studies while precluding any ground or space testing. To examine the questions of envronmental acceptability of the microwave beam, as well as the economics of a solar power satellite system, a hardware verification phase is needed.

Proposed Solution

Passage of S. 2860 which would provide for a research, development and demonstration program to determine the feasibility of collecting in space solar energy to be transmitted to earth and used to generate electricity for domestic purposes.

Rationale

S. 2860 would initiate a verification phase for solar power satellites. It would accelerate the movement from merely paper studies toward hardware verification. The foundation for a "go-no go" decision for study continuation in 1980 could be better made on the basis of firmer data made available through examination of the technical, economic and environmental issues. Much of this data could be gathered from hardware component testing done on the ground. This is specifically where the $25 million requested in S. 2860 would be applied in F.Y. 1979. At a future date, to be determined by these preceding results, a next logical step would be space component testing using the space shuttle. If these results prove fruitful, the project would culminate in a pilot plant demonstration in earth orbit. S. 2860 also establishes a solar power satellite project office at DOE to identify the basic elements of the solar power satellite program, a program schedule, decision points, and funding requirements for each program element.

When placed in the context of other post-1995 non-depletable, baseload energy options, solar power satellite studies are being short-changed. Fusion research receives more than $400 million per year; nuclear fission receives more than a billion dollars per year; while solar power satellites receive less than $5 million per year. Each energy option should be given balanced examination commensurate with its potential. Hence, an increase of $25 million for solar power satellites in F.Y. 1979 is in line with the emphasis placed on the other non-depletable energy alternatives.

Additionally, the House passed the solar satellite bill, H.R. 12505, on June 22 by a vote of 267 to 96.

35-994 O - 79 - 3

Senator MELCHER. The companion bill which you introduced, Congressman Flippo, was introduced here in the Senate on April 7. There are no changes from the way the bill stood at that time in the House. I am advised that almost a decade ago, a farsighted Dr. Peter Glaser suggested a large scale conversion of solar energy using a satellite solar power station directed in geosynchronous orbit.

Dr. Glaser saw the great potential of this power source and understood the need this Nation would soon have, the need we are now facing to find new sources of energy. I am especially pleased that Dr. Glaser is here with us today to show with the subcommittee his latest thoughts on solar-power satellites. It's a fascinating concept, large antennaes covering several square miles would be assembled in space, and directed toward the Sun, so that they would continuously absorb the Sun's energy.

This energy is converted to microwaves, which penetrate our atmosphere under even the worst weather conditions, by receiving these microwaves with large land based antennaes and converting them to electricity. The solar-power satellite provides a continuous source of electrical power from the Sun.

Other energy sources have inherent disadvantages; nuclear plants produce nuclear wastes, mining and burning coal has its environmental drawbacks, natural gas when transported as LNG is sometimes extremely dangerous to handle. One of our goals in developing new energy sources must be to minimize these problems. Initial studies by Dr. Glaser and others in the industry indicate solar power satellites are technically feasible.

Objections to the concept are not usually based on technical feasibility but on economic and environmental concerns. DOE and NASA and several industries have been studying these problems. S. 2860 would provide the funding and the program authority to determine the advantages and disadvantages of solar-power satellites so that the concept can be given priority relative to other energy sources.

I state and I draw your attention to it, Congressman Flippo, to give the proper priority concerning this program relative to other energy sources is a big job before us, deciding how much we can afford to do on various research and development programs. We have some very short-term programs underway which should give us considerable energy sources, including conservation, which is just saving on energy.

Conservation is something that we have still not begun to take hold of in this country. We are involved with solar, in terms of heating and cooling rooms and buildings, and are very close, I believe, to a level of development and production, commercially, that will give us a great deal of aid in the energy problem. We are quite close to some coal development that is better from an environmental standpoint, which is our principal hangup as I see it right now, with using an increased amount of coal for energy.

We also have, perhaps a little farther off, a method of converting coal into gas, or using wood chips as a part of our energy resources. I would think that perhaps gasahol has a place in the next few years in our energy uses, and perhaps mid-range is MHD, for converting coal into electricity without environmental hazards.

We also have to look at the longer range and I would put solar satellites in the longer range category. Congressman Flippo I notice you said something about 15 years. I tend to look at it as perhaps being farther off than that. Perhaps you can elaborate on the time span.

Mr. FLIPPO. Mr. Chairman, I think that we have to consider that when President John Kennedy said we would put a man on the Moon, I'm sure he didn't know exactly how we would put a man on the Moon, but once he defined objective then the brilliant minds that existed in this country came together to work on the program and accomplished that ambitious objective.

Another example, I suppose, is the Polaris submarine. The submarine was completed far ahead of schedule once the objective was clearly defined. I think that once we get the answers to the environmental questions and the economic questions that are associated with the solar power satellite, and the Congress and the people are able to arrive at some consensus as to the feasibility of what we want to accomplish, I believe the great resources of this country and the world can be brought to bear on it.

An estimated time for completing the SPS program is very hard to pin down, but based on our past experiences with programs of this magnitude I believe that we could accomplish our objective swiftly.

Senator MELCHER. Thank you very much, Congressman Flippo. You have introduced a bill in the House on January 30 of this year, and steered it through the hearing process and onto the floor for a vote on June 22. The vote was 267 to 96, and I think you've done a rather outstanding job in steering the bill quickly through the House.

Mr. FLIPPO. Thank you, Mr. Chairman, I deeply appreciate your kind remarks, and I appreciate the hearing you have given the bill. Thank you very much.

Senator MELCHER. Thank you very much. Now, the bill in the House has really had overwhelming support, but that is not to say that it was unopposed. Congressman Ottinger lead the opposition, and I specifically invited him to come here today to state his position, the position of the opponents in the House, but for a late plane arrival, Mr. Ottinger would be with us this morning, right at this point.

Our next witness is the Department of Energy, Dr. John M. Deutch, Director, Office of Energy Research. Dr. Deutch, welcome back to the committee. The last time I think we talked to you we were trying to figure out how to get rid of the nuclear waste question.

STATEMENT OF DR. JOHN M. DEUTCH, DIRECTOR, OFFICE OF ENERGY RESEARCH, DEPARTMENT OF ENERGY; ACCOMPANIED BY DR. JAMES J. KRAMER AND DR. FRED KOOMANOFF

Dr. DEUTCH. That's correct, Mr. Chairman.

Senator MELCHER. I think we're still grappling with it. We appreciate your testimony on this bill this morning.

Dr. DEUTCH. Mr. Chairman, with your permission I would like to submit my prepared testimony for the record, and just comment in a very few minutes on the highlights of that testimony.

Senator MELCHER. That would be very agreeable with us.

Dr. DEUTCH. I am accompanied this morning by Dr. Kramer from NASA on my right, sir, and Dr. Fred Koomanoff, who is the director of the satellite power systems project office which has recently been established in the Office of Energy Research in the Department of Energy.

The testimony that I am presenting today encompasses the point of the Department and the administration on this proposed bill, and is identical to the testimony presented by Under Secretary of Energy, Dale Meyers, in front of the House several months ago.

What I would like to do is describe to you what the present administration program is for the satellite power system, and how we are organized to pursue this new technological concept. Finally, I would like to summarize our views on the legislation pending before you.

At the present time, we are entering the second year of a 3-year program to evaluate the satellite power system. That program runs to a total of $15.6 million with expenditures in fiscal year 1978 of $4.5 million, in fiscal year 1979 of $4.6 million and in fiscal 1980 of $3.4 million. In fiscal year 1976 the Department of Energy was designated as the lead agency for this systems concept evaluation.

We have established in my office a project office for the space power satellite. Dr. Koomanoff, who is here with me, is the very able director of that office. Our view in the Department is that the space power satellite represents a considerable set of technical hurdles which must be overcome before it becomes a remotely practicable system.

It is evidently a vastly expensive enterprise to undertake. I believe our SPS concept development and evaluation program plan is available to the committee, if not, we should ask that a copy of our existing program plans be inserted in the record.

Senator MELCHER. I don't know if we want it in the record, but we will surely keep it on file.

Dr. DEUTCH. At the present time I believe that the solar power satellite is at the stage of development which we call concept evaluation. There are a variety of major considerations that must be studied before we proceed to technical development.

The fact that the program, in our view, is in the category of concept evaluation as opposed to technical development, explains its placement in my office. I would like to touch on three of the areas that we believe are most important to evaluate before proceeding with this concept through technical development.

First is the environmental effects of large-scale space power satellites. You have already heard, Mr. Chairman, of the possible interference of microwaves on communications, and the possible health and safety effects of the long-term exposure of microwaves on the surface of the Earth.

We also believe that there are considerable institutional considerations that must be examined before we proceed to beam down from synchronous, or near synchronous orbit, energy to be used by a specific region or part of the Nation.

Finally, there is a series of comparative studies that must be undertaken about the contribution that a space power satellite system could make to our energy future, relative to other alternatives. The Department is presently pursuing that.

Accordingly, our present posture is that the space power satellite is a concept that is to be evaluated, but which we are not yet prepared to proceed to systems development. Since the ultimate sponsor of this space power satellite system would be the Department of Energy, with its charter to work toward assuring cheap and useful energy for the country in future years, we are the program managers and we provide funding to NASA for systems evaluation.

In our view, the proper position for the space power satellite program is in concept evaluation. We do not favor at the present time technical development of the program; we think that is premature. Accordingly, the administration does not favor S. 2860 primarily because it calls for systems development and for the provisions for the space launches and demonstration.

In summary, the Department is serious in an attempt to evaluate this system from an environmental point of view and a cost point of view and an effectiveness point of view. We think it is a concept requiring evaluation and we are not prepared to proceed toward technical development at this time.

Thank you very much, Mr. Chairman, I will do the best I can to answer any questions that you may have for me at this time.

[The prepared statement of Dr. Deutch follows:]

STATEMENT OF DR. JOHN M. DEUTCH, DIRECTOR, OFFICE OF ENERGY RESEARCH, DEPARTMENT OF ENERGY

Dear Chairman and Members of the Subcommittee, I appreciate the opportunity to testify before your subcommittee on our solar power satellite program and to discuss Senate Bill S-2860, "The Solar Power Satellite Research. Development and Demonstration Program Act of 1978."

In February 1978, the Department of Energy and the National Aeronautics Space Administration published a "Satellite Power System Concept, Development and Evaluation Program Plan." This program plan delineates a 3-year research and assessment program to evaluate the technical feasibility, economic viability, environmental and social acceptability of an SPS concept.

The program plan, jointly prepared by DOE and NASA with a planned expenditure of $15.6 million is designed to obtain the initial information which will enable us to make recommendations on developing this energy option in the future.

SPS ORGANIZATION

In March 1978, an SPS Project Office was established under my supervision in the Office of Energy Research with a full-time Director. We have an excellent organization with which to conduct the assessments and related research. The Systems Definition activities are under the direction of NASA's Office of Aeronautics and Space Technology, Energy Division, with assistance from the Marshall Space Flight Center and the Johnson Space Center in determining technically attractive SPS concepts and defining a baseline or reference system concept. The Environmental Assessment area is being managed by the Assistant Secretary for Environment of DOE, assisted by Argonne National Labs, the Environmental Protection Agency (EPA), the Institute of Telecommunications Sciences (ITS) of the Department of Commerce as well as other DOE laboratories including Lawrence Berkeley Laboratory, Los Alamos Scientific Laboratory, and Pacific Northwest Laboratory. Major universities and contractors are also assisting in this area. The Societal Assessment area is under the Director of the SPS Project Office, which considers the international, institutional, resources, and public acceptance aspects of the SPS concept. Assisting in this area are Planning Research Corporation, other private firms and the university community. Comparative Assessment activity, by which we intend to compare the SPS concept to other alternative energy sources such as nuclear, fossil and terrestrial solar, is under the direction of the Office of Energy Research and is being assisted by ANL. I am pleased to report that, approximately 10 months into our 3-year assessment effort, we feel that we have and are making excellent progress in assessing this concept.

PROGRAM STATUS

By October we expect to meet the milestones delineated in our program plan of having a preliminary environmental assessment based upon a reference system definition concept developed by NASA, and to have proposed a program for ground-based exploratory research which may be required in the post-1980 time period. NASA's systems definition activities have to date produced a reference SPS system concept with which we can compare other technology alternatives. This reference system becomes more important as our cost and environmental analyses continue. The basic advances in technology such as improved systems for converting sunlight to electricity, solid state systems for generating and transmitting radio frequency (RF) energy as well as the possibility of new energy exchangers and laser transmission systems are additional technology options that must be seriously considered prior to any commitment to hardware development or demonstration. Both NASA and DOE consider it premature to start hardware development based upon the reference concept.

In the field of environmental assessment, a major study of the impact of microwave radiation on the health and safety of the public and workers is now well underway within the Environmental Protection Agency. Preliminary results of these assessments will be forthcoming in FY 1979. In a similar fashion, the radio frequency interference potential of microwaves on communications and navigation systems as well as computers are being studied in detail by the Institute for Telecommunication Science. We are concurrently studying means by which these problems can be eliminated or mitigated. This, however, takes time and must be carefully considered prior to making any hardware decisions.

An example of the kind of potential interference problem I am discussing is the interference caused by high powered airways surveillance radars and military radars on television reception in adjacent areas. The contribution of the SPS to the emerging problem of global electromagnetic smog must be assessed.

Based upon our present knowledge and understanding of the SPS systems concept, we feel that it is premature to proceed with any orbital demonstration or SPS hardware systems development. We, therefore, recommend against the Senate Bill #2860 being considered by your subcommittee.

I will be glad to answer questions at this time.

Senator MELCHER. First of all, Dr. Deutch, how much money would you be spending in fiscal 1979 on the program that you have started?

Dr. DEUTCH. In fiscal 1979, I believe the request in front of Congress is for $4.6 million, sir; $3.3 million of those dollars would be spent by the Department of Energy, and $1.3 would be spent by NASA on systems definition.

Senator MELCHER. And only on systems definition?

Dr. DEUTCH. Correct, sir. Mr. Chairman, I might add that at the present time, while we have a reference system from which we do our environmental evaluations of the solar power satellite, we do not yet have a precise definition of a system in an engineering sense.

Senator MELCHER. You have already gone through NASA's systems definition activities?

Dr. DEUTCH. We are collaborating with NASA, and NASA is actually undertaking a systems definition with an expenditure of $1.3 million in fiscal 1979.

Mr. Chairman, it might be useful to add that in fiscal 1980 our plan calls for expenditures of $3.4 million, and it is my judgment that that sum should be somewhat increased in order to hasten the evaluation of some of the environmental and institutional considerations that are of concern.

So I believe that our fiscal 1980 budget will, if I have anything to do with it, come in at slightly a higher amount than was programed for fiscal 1980. But I anticipate, of course, the reaction of the President's budget office.

Senator MELCHER. Yes, that was set a year from this October.

Dr. DEUTCH. Yes.

Senator MELCHER. Please explain the technical development in a little more detail to me regarding this program.

Dr. DEUTCH. Let me try and do it in my own words. If my colleagues would like to add, please permit them to do so. When one has decided that there is a systems concept that deserves development, it becomes necessary to develop all the different subsystems and components which are required for the overall system; for instance, such things as the collectors, the antennae on the ground and the transmitting antennae to beam the microwave power down. A whole series of requirements concerning components of the system would have to be developed and tested.

Of course in addition to that there would have to be the work done on the entire space transportation system, in parallel to assure that one could bring the SPS up into space——

Senator HASKELL. Excuse me, Mr. Chairman. Are you now describing what the bill would provide in the development of the actual satellite, or are you describing something that will have to go on after your evaluation is made?

Dr. DEUTCH. Senator Haskell, I apologize, I believe the bill only calls for planning of those activities. I was trying to respond to the chairman's question, which I thought had to do with technical development as opposed to concept evaluation.

The bill only calls for, I believe, the planning objective.

Senator HASKELL. Thank you.

Senator MELCHER. Now, one of the first answers you have to have, and indeed it is practical to have this answer first before we spend too much money, is the environmental assessment. As I understand the major concern is the impact of microwave radiation on the health and safety of people. An assessment by the Environmental Protection Agency is already underway.

I'm a bit mystified here. Congressman Flippo said that the microwave activity would be within acceptable ranges of what we are experiencing now. Is that just wishful thinking on his part?

Dr. DEUTCH. I believe that there are many who believe that the operating characteristics of a possible space-powered satellite would fall under environmentally permissible or health-permissible standards. I believe it is fair to say, and I can be corrected on this if I'm wrong, that the EPA has not yet issued definitive microwave exposure standards, and that the process of developing such standards, particularly when one has a potential of the kind of magnitude that we're talking about with the space-powered satellite, is a very, very complex matter, especially for the long-term, long-dose exposure of the public.

Now, we would not be doing our job at the Department of Energy if, when we evaluated energy technology, we didn't look at the environmental consequences. We have to worry about the effects on a hierarchy of life forums including fruit flies, bees, bats, and other experimental organisms to get information on the health effects for exposure to low-level, long-term, microwave radiation.

We feel that for this type of environmental evaluation we may require additional funding for our fiscal 1980 program.

Senator MELCHER. If EPA comes up with a definitive range that that is safe, I suppose that based on that, we have to now determine, in terms of microwave exposure for all the various species and all levels of life. What the potential microwave radiation would be from the—from such a system.

Dr. DEUTCH. Yes, sir, that certainly is a first step.

Senator MELCHER. How is that accomplished? Are paper studies sufficient, or will technical work need to be done in laboratories?

Dr. DEUTCH. Sir, we certainly don't work just on paper. I should like to emphasize that our program does contain, and will contain increasingly in the future, laboratory tests and direct experimental work. You cannot do these things entirely on paper. When I say concept evaluation, I don't mean only paper studies, and I do not mean absence of experimental work. Technical development, on the other hand, is the development of an orderly program with schedules and milestones to develop the subsystems and components required to actually put system into operation.

Senator MELCHER. Under existing law, we don't have any of these checkpoints that we've been discussing here this morning. Since there is such great apprehension, do you see the need to assure the public that indeed there are checkpoints, and if there are going to be such checkpoints, I suppose we could do it either through the Congress acting, or the Chief Executive issuing an Executive order.

It seems, one way or the other, that the public has some apprehension about the overall effects of the space satellite, so what would be your recommendation of assuring them of those check points?

Dr. DEUTCH. Mr. Chairman, we have, as I mentioned earlier, produced a 3-year concept, development, and evaluation program, and we should be updating that annually, so that at each stage of the game we will have a document that would reflect the program under which we are operating, and those points in the future where we anticipate getting results bearing on such questions as the effects of microwave exposure.

So the answer to your question, I believe, is that the place where we intend to communicate those milestones will be provided in the plan that accompanies this program in our Department.

Senator MELCHER. Which would be in June 1980.

Dr. DEUTCH. The last one was published in February 1978, and I would anticipate that we would want to issue another one in approximately February 1979, which would be reflective of the action in the fiscal 1980 budget.

Senator MELCHER. I want to ask you directly, if you ought to have a checkpoint? There are only two possibilities that I see; a definitive checkpoint, meaning a decision made either by the Executive or by Congress, which would be reassuring to the public that there is such a thing in place.

I could see only an Executive order so outlining, or an act of Congress, yet you have said you don't want a bill. Are you thinking of an Executive order, or do you think neither one is necessary?

Dr. DEUTCH. I'm not sure that I quite understand the difference in your mind, sir, between a bill and a checkpoint. I believe that we have to proceed through this course of concept evaluation until we are much firmer about the kind of system we have in mind, its relative cost effectiveness and its possible environmental consequences.

Senator MELCHER. Well, perhaps then by your reports, you are giving Congress a chance to say yes or no each time.

Dr. DEUTCH. That is correct, Mr. Chairman.

Senator MELCHER. And in each budget—I see, that is not a formal checkpoint, as I think the supporters of the bill have envisioned, but it is indeed a checkpoint. Senator Haskell.

Senator HASKELL. Dr. Deutch, so that I get this clear in my mind, I think I understand what you mean by conceptual evaluation. If you put this in other spheres, it would be a bench scale versus the pilot plant scale, I assume, is generally what you are talking about. You are talking about laboratory work. Can you tell me what the bill does that you feel you are not yet ready to get into?

Dr. DEUTCH. Let me try and answer that, Senator. The bill, I think, has three features in it which we feel are premature. First, the sum of money is greater than we think is called for at the present time. Second, the bill calls for some Earth-based hardware development which would bear on the components for the technology development which we believe is not required at the present time.

Senator HASKELL. Which you consider premature.

Dr. DEUTCH. Premature, that is correct. And finally the bill mandates planning activities which would be premature. So it's a combination of the sum of money involved in fiscal 1979, and the implications that we are in a position to proceed expeditiously with technical development, that we do not favor.

Senator HASKELL. The bill, in other words, would require the development of hardware, or at least not just the development of the hardware, but you're not ready to get to that point until you've taken these other steps, am I correct?

Mr. DEUTCH. That is our view, sir.

Senator HASKELL. It is my general school of thought that you ought to try everything, but obviously you shouldn't be premature, and there are a few things to be evaluated. Microwave has been one. It is my understanding that if the system went forward, fully forward, and it would be something like 40 to 80 units, by that I mean satellite units, with their concommitant Earth controls that would be developed.

And, of course, the total cost that I have is between $1 and $2 trillion. That is going full blown. Assuming that occurred, what proportion of the Nation's electricity might be satisfied by that program?

Dr. DEUTCH. Just one moment, let me do a brief calculation.

Senator HASKELL. All right.

Dr. DEUTCH. Let me see if I can give you some measure.

Senator HASKELL. Just a ballpark.

Dr. DEUTCH. Yes, I believe we are talking 60 satellites at roughly 5 gigawatts electric each which would be a total of 300 gigawatts of electricity. Now, to put that in perspective, we anticipate, with all the uncertainty that I know you are familiar with, having approximately 300 gigawatts of nuclear power installed by the year 2000.

So the numbers that you quoted would suggest that the amount of solar based electricity, 300 gigawatts would be equal to in the year 2030 what the nuclear power generation in the country is planned to be, or anticipated to be by the year 2000.

Senator HASKELL. And retranslate it into what the proportion of electricity is calculated to be generated by nuclear power. If you have that figure then we could arrive at the proportion that is meant to be generated by this particular device.

Dr. DEUTCH. Let me take a wild guess.

Senator HASKELL. Will you?

Dr. DEUTCH. I'll give a wild guess, and I would say that that 300 gigawatt number for nuclear power in the year 2000 is one-third of the electrical generation capacity.

Senator HASKELL. Then assuming your ballpark figure is accurate, and it's got to be ballpark, obviously, we do know that satellites are subject to extinction by hostile hands, we do know that satellites can be—I don't know how you shoot them down, but we do know that they can be eliminated. So I presume that if we have 60 satellites, and one-third of our national electricity was dependent on those satellites, I suppose one of your problems, your conceptual problems, is how do you defend those satellites.

Dr. DEUTCH. Senator, it's a problem common to all the space assets in the United States. We do have to worry about vulnerability.

Senator HASKELL. So that is something you would want to think out very carefully before you went into the next step of planning for development of hardware.

Dr. DEUTCH. We are paying some attention to this question.

Senator HASKELL. Now there's another aspect of this thing that bothers me somewhat. The proponents of the bill are asking for $25 million, and unfortunately, admittedly under the Federal scheme of things, that's not a tremendous amount of money.

But I wonder if this doesn't get us further down the road to a commitment. I think I interpret you as saying, you can correct me if I'm wrong, that the bill gets you further down the road toward commitment to this system than you feel is prudent at the present time.

Would that be an accurate reflection of your review?

Dr. DEUTCH. That is exactly correct.

Senator HASKELL. And another thing, I assume that you have to take into consideration, the Office of Technology Assessment. For example, it is estimated, and these figures, I think, should be supplied for the record from the original source, that for one-third of the ultimate estimated cost of the SPS program, we could supply every house in the Nation with a solar system. We have to take the ultimate cost of going this way versus the ultimate cost of going on an individual basis, which would have obvious advantages and the proponents of the bill would say obvious disadvantages, but we have to take that into consideration that we only have so much money to put into the solar effort.

And we have to take into account those relative costs of doing it in different ways. Am I correct in that?

Dr. Deutch. Absolutely, Senator.

Senator Haskell. I assume it is one of the things you would be considering in your conceptual evaluation.

Dr. Deutch. That is absolutely correct, Senator.

Senator Haskell. Well, I must say that I share your viewpoint. We don't want to get committed or semicommitted to something of this magnitude before we think it out very carefully. I guess that is not a question, I guess that is a conclusion.

Dr. Deutch. Senator, I think that we are recognize that we are embarked on a serious system development program for solar power satellites. The expenditure will rapidly rise from $25 million per year to $1 billion or so, just to do the systems development.

So you are quite right, and I think the administration does not yet see itself embarking on such a technology development program.

Senator Haskell. Now the figures that are available to me, and I don't know how accurate they are, is that one satellite might cost $25 billion. Whether that's a ballpark figure, I don't know if anybody is around who can say that's either right or wrong as a ballpark figure.

Dr. Deutch. I was going to ask my friend, Mr. Boileau, if that was accurate or not. I would guess the first satellite might cost that much.

Senator Haskell. When you finish your conceptual evaluation which you are embarked on which includes laboratory work, will the department then be in a position to present both to the Congress and to the American people an analysis of this program, and a recommendation?

Dr. Deutch. We certainly hope so. That is the purpose of the concept evaluation program that is underway. First, we would have to conclude that the environmental effects do not preclude proceeding, and then we would have to determine that the technology itself has a cost benefit relative to other inexhaustible energy programs which we are undertaking.

Senator Haskell. And you would have to, it seems to me, address yourselves at least to the defense capabilities.

Dr. Deutch. The satellite vulnerability question would be something that would be certainly widely discussed.

Senator Haskell. Thank you, Dr. Deutch, I have no further questions, Mr. Chairman.

Senator Melcher. Dr. Deutch, you are contemplating in fiscal year 1979 that expenditure of about $4.6 million.

Dr. Deutch. Correct, sir.

Senator Melcher. If that were the case, what would you suspect would be needed in fiscal year 1980?

Mr. Deutch. Mr. Chairman, the present 3-year program calls for $3.4 million. As I indicated to you, sir, it is my judgment, and I believe the judgment of our Department, that that would be too low an expenditure to continue a timely evaluation of the environmental and institutional aspects of this technology.

Accordingly, it is my suggestion that the SPS budget for fiscal 1980 be somewhat higher than the $3.4 million now planned. I prefer not to give you a specific number because clearly it is a number that has no merit other than as my own budget.

However, it will be substantially less than the $25 million requested in the bill pending before you for fiscal 1979.

Senator MELCHER. Well, we ponder when we get answers like that, since we seem to live on the same Earth, in the same country, in the same government. But I do understand the restraints that are placed on agencies before the budget is approved. And it doesn't give us much to go on at this particular time.

Senator HASKELL. Mr. Chairman, if I could interrupt, let me ask this question. Would it be fair to ask to submit your idea, Dr. Deutch, of what you would need, in whatever year that was. Now, I don't want to get you in hot water with the whole administration, but I must say I share the chairman's view.

Dr. DEUTCH. Mr. Chairman, I'm always ready to take risks. I'm looking for about $8 million in fiscal year 1980.

Senator HASKELL. Thank you.

Dr. DEUTCH. That may not happen, so don't come back to me on it.

Senator MELCHER. Well, we have had a habit of authorizing round figures that are never appropriated, and we seem to be overcoming that because we are witnessing pretty close adherence in the Senate, last year and this year, to an appropriation process.

We have to balance it out with the House, but at least as far as the Senate is concerned, the appropriation process for energy is not too far off of what is authorized, and I think that is much wiser myself.

I don't think there is anything very sacred about the $25 million figure in the bill at all, and I personally did not expect that the Department, even if the bill were enacted, would be an authorization or an appropriation any more than around $15 million. And of course I find out in checking it that is about what you intend to spend for next year.

I do have a question that is a little bit technical. In the SPS concept, development and evaluation program plan, dated this year on page 26, under microwave power transmission, there's a third item, that is microwave beam interaction and ionosphere and magnetosphere of chemical ion emissions.

How do you do anything about that? Unless you are going to put something up there in space, how can you evaluate anything of that nature without actually doing it?

Dr. KOOMANOFF. First we can go from the ground up, rather than from the space down. For example, we just ran an experiment using a receiving antennae and a transmitter that we have down in Puerto Rico, the large radio astronomy dish. What we did was use a high-frequency narrow beam radio transmitter to shoot up into the ionosphere, approximately 110 kilometers up.

We simulated the power at the center of the SPS beam to see if we would get what the ionospheric physicists predicted, namely, thermal runaway. At these altitudes, the ambient temperature is about 230 degrees.

We expected, based on the physical model, to go up to over 2,000 degrees. We found out that this did not occur in this first experiment, and that it only ran up to 300 or 400 degrees. These results are encouraging, but we're going to be carrying on more experiments. This is an example of the field experimentation now underway as part of the DOE–NASA SPS assessment effort.

Senator MELCHER. I understand that, and it fits into what were earlier question marks in my mind concerning whether this was just paper, or goes beyond that. The experiments that you are describing are rather notable experiments and of great substance that would continue during the next 2 years. Have you contemplated those costs?

Dr. DEUTCH. Yes, Mr. Chairman.

Senator MELCHER. In your figures?

Dr. DEUTCH. Yes, sir.

Senator MELCHER. Now, Dr. Kramer, does NASA expect funding for SPS directly in the future?

Dr. KRAMER. Directly without passing through DOE?

Senator MELCHER. Yes, without passing through DOE.

Dr. KRAMER. We don't have any expectation of that in the near term at all.

Senator MELCHER. Do you think it's better to work with the same system?

Dr. KRAMER. Yes, sir.

Senator MELCHER. What is NASA's view of the development of a heavy lift vehicle? Is one needed?

Dr. KRAMER. Well, Mr. Chairman, if we were to be in a position where we were expecting a very substantial fraction of the U.S. energy, electrical energy to be derived from SPS-type systems, then the sheer economics would indicate that it would be much better to develop a heavy lift vehicle for transporting subsystems and the parts into orbit. Rather than using the existing shuttle capability.

Senator MELCHER. When will you decide that that is needed?

Dr. KRAMER. I think we are some years away from a decision like that now.

Senator MELCHER. It is much too early to make a decision of what is going to be needed. Can you carry on enough experimentation to arrive at an answer with the one that is relative, to assure feasibility or nonfeasibility before we go into this?

Dr. KRAMER. Yes, it's part of our advance space technology program to do studies on various forms of vehicles which would follow up a Shuttle sometime in the future. Perhaps around the year 2000, perhaps in the early 1990's. We examine configurations, we do a certain amount of very advanced technology work, to make such configurations feasible, in the time they would be required.

We don't look at them totally in support of the SPS system at all, but for a variety of potential uses of very large space vehicles. And that kind of work goes on at a fairly low level, pretty much independent of this SPS issue. What we are discussing today.

Senator MELCHER. It is ongoing work in any event.

Dr. KRAMER. Correct.

Senator MELCHER. If I understood Congressman Flippo correctly, I think he said the vehicle would use hydrogen or oxygen as a fuel. Is that correct?

Dr. KRAMER. Well, hydrogen and oxygen is the most energetic era of chemical propellants, aside from the possible use of chlorine, which has a very special hazard associated with it. And it's never been used for space boosters.

Hydrogen-oxygen is the technology on which the Saturn vehicle operated very successfully for the Apollo program. It would take something awfully good to depart from hydrogen-oxygen as a propellant combination.

Senator MELCHER. Perhaps you are not prepared to answer this. Well, you ought to be able to answer. You didn't view the Saturn as causing any problem.

Dr. KRAMER. No; the only—with the use rate of Saturn there is no problem with offsetting the balance, the atmosphere. If we were to have a very heavy schedule of launches, and we were to introduce very sizable amounts of water vapor into parts of the atmosphere which normally—where there normally are none, then you might consider that we have a problem.

Senator MELCHER. I see; and that is part of your ongoing work, too.

Dr. KRAMAR. Yes, we looked at that, too.

Senator MELCHER. Is there any reluctance, either at NASA or the Department of Energy, to pursue the straightforward course in seeking this basic document? In other words, we are told by the opponents of the bill that this is all a pipe dream anyway, and I guess I don't want you to answer, Dr. Kramer, because they would say it is almost a perpetual bailout of NASA.

So I guess I will direct my question just to Dr. Deutch, speaking for the Department of Energy. I assume that since you are engaged in it, you feel that it is essential that we pursue a course in determining if this is feasible, and practical, and cost effective, and safe.

Dr. DEUTCH. That is correct, Mr. Chairman; that's the way the Department feels; that's the way I feel personally. Let me say that I have not seen an absolutely, unassailable analysis which said that the solar power satellite is of necessity cost ineffective, or of necessity environmentally hazardous, or of necessity unsafe.

And until we are able to provide an analysis on one or the other side of these issues, we should continue these evaluation programs.

Senator MELCHER. You think you would probably have some sort of an answer, by June 1980?

Dr. DEUTCH. Mr. Chairman, I don't believe that. That is an impression I would like to repair.

We will be updating our concept evaluation plan in a 3-year cycle. Any answers we develop will depend on our environmental study, our communication interference study, the communication mitigation studies, other atmospheric evaluations, and the cost sampling analysis.

So we are not at the present moment prepared to testify to you regarding the time certain by which we think the process of evaluation will be completed. I regret that is the case, but this is a very complex and large technology.

Senator MELCHER. I understand.

Senator HASKELL. Mr. Chairman, I assume, Dr. Deutch, that you hope that if all goes well you will have an answer by that time, and your goal, I assume, is to make some kind of an assessment.

Dr. DEUTCH. Senator, of course our goal is to make some kind of assessment. We have to be candid about expressing the certainties that we will make.

Senator HASKELL. Sure.

Senator MELCHER. The diagram here on page 3 lists June 1980 for a final program recommendation, so that is really the goal, is it not?

Dr. DEUTCH. I'm not sure what expectation has been left in your mind as a result of that document, Mr. Chairman, but we do expect by June 1980 we will be able to define for you how we intend to proceed.

Senator MELCHER. By that I'm going to interpret this circle here of final program recommendations to mean the recommendations of the status after 3 years.

Dr. DEUTCH. That is exactly right.

Senator MELCHER. Which may or may not be final at all in terms of giving us definitive answers.

Dr. DEUTCH. That is exactly right, Senator.

Senator MELCHER. Thank you very much.

Senator HASKELL. May I just add one more question, Mr. Chairman?

Senator MELCHER. Yes.

Senator HASKELL. For my own curiosity, how do you go about testing the problem of the microwave and environmental effects? What do you do?

Dr. DEUTCH. The environmental effects?

Senator HASKELL. Yes.

Dr. DEUTCH. We have a two-thrust program. Dr. Koomanoff may wish to elaborate on this. One of them is to examine the influence of microwaves on organisms, cells, bees, bats, and ultimately primates. That's one thrust of the program.

It's a lengthy process; it has to be done right; it has to be done carefully. It's a lengthy process because one has to follow several generations of these species until one is in a position to extrapolate properly to humans.

Second, we have a program which is aimed at ecological effects. In that program we try to develop model ecological systems and expose them to microwave radiation to see what it does to the chemistry of a soil, the balances of the plants, and so on.

Senator HASKELL. Thank you, sir, and thank you, Mr. Chairman.

Senator MELCHER. Dr. Deutch, Senator Durkin would like to send some questions to you and ask you to report specific answers to those questions. Is that agreeable?

Dr. DEUTCH. Absolutely, Mr. Chairman. I would be delighted to.

Senator MELCHER. Thank you all very much. Next we will hear from Mr. Garry DeLoss, a Washington representative of the Environment Policy Center. Mr. DeLoss, we are pleased to have you here and to have your testimony, and I wonder if you would accommodate us by summarizing it.

STATEMENT OF GARRY DeLOSS, WASHINGTON REPRESENTATIVE, ENVIRONMENTAL POLICY CENTER, WASHINGTON, D.C.

Mr. DELOSS. Thank you, Mr. Chairman, I will try to race through this, kind of bounce around as fast as I can. To begin with, the Environmental Policy Center opposes this bill to finance research and development of the solar power satellite. But we support greater Federal spending on development of land based and decentralized solar energy systems.

One of our major concerns is that money diverted into the solar power satellite program is money that then cannot be used to develop land based solar energy systems. And this bill actually, even though it only begins at the $25 million authorization, envisions at least $270 million over the next 5 years going into this development program.

Last week I participated in a review of the solar energy budget at the Department of Energy, a 2-day program that was hosted by the Department, and I think that it was the consensus of the various panels who reviewed that budget that we need to increase dramatically the spending for the land based solar energy program.

I did not detect any sign of enthusiasm for a solar power satellite program among any of the participants in that review process. I, in my testimony, have tried to break down the discussion into three sections; technical feasibility, economic feasibility, and political feasibility. Now, in the area of technical feasibility, I really don't want to contest technical feasibility today. I would like to just reference a couple of the matters of scale that are involved here because they are a little mind boggling.

Development of the SPS, as I'm sure you've heard, is going to require the development of a totally new subsystem such as a heavy lift launch vehicle, and these HLLV's as they are known, would be launched at the rate of one to five launches a day. To put up a single SPS might require 50 to 500 of these launches.

Now, if dozens of SPS's are built, as is the plan, these launches would continue for decades. Indeed, the eventual replacement of the wornout SPS's, and they have a 30-year predicted life span, seems to me to require such launches into the indefinite future. We're talking about something that is thousands of times the scale of the Apollo program.

After the raw materials, manufacturing equipment, and the workers are transported to orbit, they have to manufacture the solar powered satellites in an extremely efficient manner. According to a report by the Jet Propulsion Laboratory, "man must develop the capability to be as productive in space as on an automated automobile assembly line, in terms of kilograms of finished products per man-hour worked, in order for the SPS costs to be competitive."

Now, I think that the technical feasibility at this stage of the game, the claims are very optimistic, but as I said, I don't want to contest those claims today because I think it's more interesting to concede technical feasibility for the sake of argument and then to go on and look at the claims that have been made about the economics of these systems, and then go on beyond that to look at some of the political barriers to the development of the SPS.

Now, there are a number of studies floating around that purport to show that solar power satellites would be cost effective 25 and 50 years from now in competition with Earth based energy sources, including Earth based solar energy sources.

I think that all of these studies, at least all of those that I have come across, and I've looked at several of them, are seriously flawed, and I will go through some of what I detect as flaws in those studies very briefly. To begin with, these studies are supposedly objective, but I think that they are inherently colored by a conflict of interest.

They all seem to be done by corporations, or NASA space flight centers, or consulting firms, or academicians who have a very obvious vested interest in encouraging a massive Government commitment to the SPS.

Now, this leads to cost estimates that are mere self-fulfilling prophesies, or what one critic, Dr. John Cummings of the Electric Power Research Institute calls "legislating all the answers." And Richard Caputo, who directed a 2-year Jet Propulsion Laboratory study of the SPS, I think it's really a study of the SPS studies, recognized the same pattern of behavior and characterizes the cost estimates he examined as based on "assumptions of success" rather than a real data base.

The SPS proponents appear to begin by calculating the cost goal which the total SPS system must meet to compete with other energy sources and then allocate that cost goal among the various subsystems of the SPS. Hence they tend to reach similar conclusions about the total cost of the SPS based on widely varying estimates about the cost of the subsystems.

And I notice that Senator Abourezk in his statement pointed out this extreme variation among the estimates about the respective costs of the various subsystems. And I think there is a clear reason why that happens. It's the way they devise their cost estimates, starting from a predetermined goal and working backward.

Another major criticism of these so-called cost effectiveness studies, several criticisms, can be grouped under what I have described as diseconomies of scale. There's been a failure to acknowledge the disadvantages inherent to a technology that is so large in scale, and so expensive to develop to a state of commercial readiness, that projected electricity costs do not fall to acceptable lows unless hundreds of billions of dollars are invested in the construction of dozens of the satellites.

What we really have are diseconomies of scale masquerading as economies of scale. Now, one of these diseconomies that has been commented on is that solar power satellite, which is going to supply the power equivalent of four or five large nuclear-powered generating plants, is going to require some kind of a backup power system here on Earth.

There's been mention of this problem, but there's been very little work done on it that I can detect. And according to Dr. Cummings, a utility receiving electricity from an SPS would require a reserve standby capacity equal to or greater than the SPS power of 5 gigawatts. Even the pooling of reserve power from several utilities may be inadequate. The largest power pool in the company is 50 gigawatts.

That's the largest one. The other ones are much smaller and the loss of 1 gigawatt, in that power pool, much less 5 gigawatts, "would cause havoc," according to Dr. Cummings. Paradoxically, the cost of backup power for the SPS could be reduced by lowering the size of the SPS, but the cost of an SPS goes up as the size is reduced.

This causes Dr. Cummings to view the process very skeptically, in his words it "is a long, long, long, a very long way off."

Now, another diseconomy of scale is this large commitment of about $60 million of Government funds that is suggested for the development of the SPS to a commercial scale so that the question of economic feasibility can be answered definitively.

Now, this investment first is much, much greater than the proposed development cost of competing energy sources. For example, the cost of developing photovoltaic cells for land-based uses to a 10-megawatt scale commercial powerplant by 1985 will be from $0.2 to $0.4 billion. In other words, the SPS would require 150 to 300 times as much money just to test its economic feasibility.

Now, we have a very great concern about this kind of diversion of funds into developing a single technology because obviously this is the kind of large scale that ultimately can be financed only by preempting funds that could have been used to develop other energy technologies. So we're very concerned that money not be diverted into the SPS program and away from what we consider superior solar energy technologies.

There are some other diseconomies of scale involved here that I will mention very briefly. I notice in one of these studies that the rate of construction of these satellites is critical in the cost calculations. So what that means is that the construction costs would go up drastically on a per unit basis if the rate of construction didn't follow the construction plan.

We've already seen how in the years 1974 through 1976, the electricity demand in this country stagnated and electric powerplant construction, therefore stagnated. It seems to me that we can envision future experiences like that and I don't think that we want to commit ourselves to the construction of a multihundred billion dollar solar power satellite program if we know or knew that any interruption in the rate of construction is going to raise the cost drastically.

Another big problem that is related is that when electric power demand, or the rate of growth of demand, changes, the utilities end up with excess capacity. Now, that is really idle investment and somebody has to pay for it, either the ratepayer or the utility company shareholders have to bear this burden.

It seems to me that even a group of utilities jointly buying an SPS would still risk a mismatch between consumer demand and the delivery of power from the SPS which would be ordered years in advance of the critical need. And finally, a diseconomy of scale which I would like to touch on is that probably the Government is the only entity in this country that could afford the investment that it takes to build a system of solar power satellites, and to absorb the risk that is entailed in that investment.

And so what we're really talking about is something like a TVA in the sky, and I think that's why the investor-owned utilities have been somewhat skeptical of this concept.

Now, I would like to hit what I think is the other great flaw of these cost studies.

That is that they don't consider the lowest cost alternative to the SPS. Typically, what they've done is they've avoided entirely considering an alternative investment scenario that would take the $60 billion of Federal research and development funds that are proposed, or the hundreds of billions of dollars that are proposed for the satellite construction itself, and put the same money into a program of improving energy efficiency in this society.

And we've seen here in a series of hearings before congressional committees, including this committee, over the past few years, since the oil embargo, many experts have come in and described the fantastic energy conservation potential in this country if we did devise that kind of investment program.

These investments are just as important as investments in conventional energy production. They effectively produce energy by saving energy because that Btu of energy that is saved now becomes available to do productive work. And so the energy inefficiency that we have in our own society, in our energy use, means that we have what amounts to a reserve of "conservation energy" that is waiting to be produced. And we should be directing more investment into the "production" of that energy.

A recent report to the Joint Economic Committee suggests that cost effective investments could reduce our energy use by 40 percent, so in effect we should be "mining" and "drilling" this reserve of conservation energy through investments that improve the efficiency of our homes, office buildings, factories, and transportation systems, just as diligently as we seek new discoveries of oil and gas, or new technological marvels such as the SPS.

One expert on energy conservation in just existing buildings testified 2 years ago that "cost effective conservation techniques which are commonly available today" could cut energy use in buildings "equal to the yearly input of about 600, 1,000-megawatt generating plants. In other words, if one 1,000 megawatt plant came out every 2 weeks, starting today, it would take until the year 2000 for the capacity of these new plants to equal the savings which could be achieved in existing buildings using readily available, economically viable conservation techniques."

And I believe that witness was Carl Stein, who was with an architectural firm in New York City.

In short, the cheapest powerplant is the one that is never built, but these studies are not really considering that option. And the other way they distort their cost comparison is that when they compare the solar powered satellite with land based, solar energy alternatives, they set up a strawman, because they compare it with the highest cost, land based solar energy system, and that is the centralized electric generating plant, using solar energy.

This creates a distortion in favor of the SPS by raising the cost of the land-based solar energy alternative. Even the most objective of the SPS studies, a report by JPL, compared the SPS with what the report's director has described as "the worst solar terrestrial options" centralized solar energy powerplants at sites remote from their markets. The JPL study also distorted its results by omitting from its calculation the $60 billion of Government investment needed to develop the SPS to a commercial scale.

And in spite of this rigging of the rules of the game, the JPL study concluded that the SPS would cost more than a land-based, centralized, solar energy powerplant, using a solar thermal process, and fossil fuel backup systems, and about the same as a centralized, photovoltaic, solar energy system with a fossil fuel backup system

Yet, if the SPS costs were compared with decentralized solar energy systems, using photovoltaic cells, the SPS would look even worse. Decentralized solar energy systems would be lower in cost than the centralized solar energy system used in the JPL study because transmission costs can be eliminated land acquisition costs can be reduced by using airspaces over roof tops, and parking lots, and waste heat can be put to work near the generating site.

Now, objections by SPS proponents that electricity storage costs are an insurmountable barrier to lowering the cost of land-based solar energy, whether centralized or decentralized, have to be taken with a grain of salt. For the people who suggest that major reductions in the cost of electricity storage are not likely are the same people who are extremely optimistic that costs for the various subsystems of the SPS will fall drastically.

Moreover, the present low level of Government spending on research and development of electricity storage may increase soon. A review of the Department of Energy Solar budget that I mentioned produced recommendations last week that the R. & D. budgets for electricity storage systems, for use with decentralized solar energy systems, be increased greatly in fiscal year 1980 and succeeding years. Practically nothing has been done in this area today. Most of the electricity storage R. & D. that has been done by DOE as is related to working with conventional central electric powerplants.

Now, I would like to finish by looking at some political feasibility questions here. Previously I think a new technology or a new energy source really only had to pass two basic tests.

One, whether it was technically feasible, and two, if it's technically feasible, would it also be economically feasible on a commercial scale. But in recent years, we've seen that as our society becomes more crowded and as competing uses of finite resources sharpen, there's more and more a factor of what I call public acceptance or political feasibility, and any big new commitment of resources in this society to any major new technology or energy source, is going to have to pass this test of public acceptance or public feasibility.

I think even the proponents of the SPS acknowledge this, and they've already begun their public relations campaign to soothe concerns about the possibilities of microwave effects on health, microwave interference with radio frequencies, destruction of the upper atmosphere by launch vehicle exhausts and microwave beams and other impacts.

The critics of the bill being considered here today are told that the money in this bill is needed to develop technology to test these possible environmental impacts. The fact is that this $270 million program is not needed to verify two of the biggest barriers to the political feasibility of the SPS.

First, the public enthusiasm for solar energy is based on an interest in decentralized or dispersed solar energy systems, not highly centralized systems such as the SPS, which must be owned by giant utility companies or the Federal Government. Solar energy enthusiasts are looking forward to development of solar energy systems scaled for use by individiuals, neighborhoods, and communities. The majority of the thousands of public witnesses who appeared at DOE's series of 11 public hearings on Federal solar energy policy this summer expressed a preference for development of decentralized solar energy systems, and many of those specifically objected to the SPS concept.

Also delegates representing 50 States and the District of Columbia at the National Solar Congress here in Washington on August 4 through 6, expressed similar views in the policy program which they ratified. Thus public support for Government promotion on solar energy is, in part, a vote for increased consumer control of the supply of energy and should not be construed by members of this committee to include support for the SPS.

Indeed, I expect that resistance to the SPS will grow as consumers become aware that the large-scale commitment required to make the SPS work would effectively foreclose consumer and public utility commission influence over electricity rates and construction decisions.

I don't think that consumers who are already revolting against utility rate policies and are already clamoring at the doors of the State public utility commissions are likely to take kindly to the SPS proposal when it finally penetrates down to that level.

Another political barrier to the SPS that can be discerned without waiting for the technology development proposed in this bill is the problem of siting the new launch facilities, and dozens of receiving antennae required for the SPS. The new launch facility would preempt a large area due to the need to launch and land several very noisy, heavy lift launch vehicles per day over a period of many years, perhaps into the indefinite future.

An HLLV being launched would be much louder than the less powerful Saturn rocket, and by land they would be much louder than the SST. And we all know how many objections the SST's landings raised. One report has suggested that the sonic overpressures produced by space freighter reentry indicate that the final 200 kilometers of the path should be over open ocean. That was from an article written by an executive at Boeing.

Now, this means that the HLLV launchsite must be in a coastal zone; presumably, where the climate is warm year around. Areas that meet these requirements just happen to be attractive for meeting other uses, both onshore and offshore. And population density in such areas is already high and getting higher.

I find it difficult to believe that even Cape Canaveral could be used as the HLLV launchsite. And if you don't use Cape Canaveral, I don't know where you would go with it. Orlando, Fla., and the Disneyworld amusement park are just a few miles from Cape Canaveral, and nearby population is growing rapidly.

Siting of the receiving antennas also appears to confront a very high political barrier. The siting of new electric powerplants, whether nuclear or fossil fuel plants, has been a controversial issue for years. Proposed Federal legislation to accelerate siting decisions is not progressing rapidly. Even if it is passed, siting controversies can only grow due to the shrinking number of potential powerplant sites, and the competing uses of those sites.

Also, the siting of high-voltage powerlines is emerging as a major new area of political controversy. Some very politically conservative rural residents of upstate New York and northern Minnesota have resorted to unfamiliar acts of civil disobedience to resist the siting of these unwanted powerlines.

I'm sure that many people here recall seeing films of these demonstrations on the network news, and one of my colleagues is helping to form a national coalition of groups which are resisting these powerline siting decisions.

Another example of siting problems is the legislation enacted by several States to prohibit the siting of nuclear waste disposal projects within their borders.

Also, the Navy has failed repeatedly to sell the public on proposed sites for Project Sanguine, which entails burying a grid of highly charged electric cables for low frequency communication with submerged submarines. And with regard to Project Sanguine I would like to add a little aside here.

When I was speaking to a few Members of the House of Representatives when this bill was progressing through the House, I happened to contact the office of Congressman Obey from northern Wisconsin and I learned that the Congressman got elected to Congress by running against a 30-year incumbent who supported the siting of Project Sanguine in his district.

And Congressman Obey opposed this siting and that's the issue that won the election for him. So I just wondered if we're going to have 100 more of these sites in this country, how many Congressmen and Senators would want to advocate the siting of maybe three or four of those antennas in his or her own district.

The SPS proponents are aware of the same problem. A NASA study could find only 69 potential landsites. I'm sure that's a very optimistic number. And some people have suggested that ocean sites could be used, although I am not aware of any calculations on the cost of such structures. As I understand it, that would require the building of a big, artificial reef covering an area of several square miles.

And I think it would probably be very expensive. Moreover, offshore sites do not avoid the problem of conflicting uses. Perhaps Boeing or the Arthur D. Little Co. should study the current controversy over a proposal to site nuclear powerplants off the coast of New Jersey. As I said, these coastal zones, both offshore and onshore, are very busy areas, and I don't think siting problems are going to be easily solved in those areas, either onshore or offshore.

Inded, it is likely to get worse. If the U.S. standard for microwave exposure is tightened to the East European standard, the area preempted by receiving antennas would triple from 300 square kilometers to 900 square kilometers. And I think your siting problems will more than triple.

I would like to close on a slightly more positive note, by identifying a few areas where I agree with the proponents of this legislation.

First, I agree that there should be a transition to the use of solar energy in place of the environmentally disruptive and nonrenewable fossile fuels and uranium. Second, I agreed that the Government should commit billions of dollars to developing solar energy technologies to a commercial stage, including a bigger effort to lower the cost of photovoltaic cells.

Finally, I agree that the Government should fund studies of the health effects of microwave radiation. However, in spite of these areas of agreement, I don't believe that further Government funding of research on the SPS concept can be justified.

If the current Government study of the SPS is adjusted to make its cost comparisons more realistic, and to adequately account for political barriers to the SPS, I am confident that it will recommend no further work on the SPS.

Thank you.

[The prepared statement of Mr. DeLoss follows:]

ENVIRONMENTAL POLICY CENTER
317 Pennsylvania Ave., S.E., Washington, D.C. 20003
(202) 547-6500

Statement of Garry DeLoss

before the

Subcommittee on Research and Development

of the

Senate Committee on Energy and Natural Resources

August 14, 1978

Mr. Chairperson:

Thank you for the opportunity to comment on the "Solar Power Satellite Research, Development and Demonstration Program Act of 1978."

As you know, the solar power satellite (SPS) concept has been promoted for several years by some of the witnesses present today. Previously they have persuaded the Congress to fund a three year, $15.6 million study of the SPS concept by the Department of Energy (DOE) and the National Aeronautics and Space Administration (NASA). Although that study is only half completed, the SPS proponents are now asking for an escalation of the federal commitment to "technical verification" work that they predict will cost $270 million over the next five years, beginning with the $25 million in this bill.

The Environmental Policy Center opposes the SPS concept and this bill's commitment of funds to SPS technology development because we believe that (1) even if the SPS could be shown to be technically feasible, it will never be economically and politically feasible, and, (2) the money which this bill would allocate to SPS technology development instead should be allocated to land-based, decentralized solar energy technologies.

FEASIBILITY QUESTIONS

In appraising the prospects for any new energy source, the first question is whether it is technically feasibile, or whether proponents of the proposed technology have failed to discern some insurmountable technical barrier. Even if technical feasibility can be demonstrated, a new energy source must pass a second test, economic feasibility. That is, it must supply energy to consumers at a price which is similar to or lower than the price of alternative sources of energy. In the past, positive answers to the questions of technical and economic feasibility might have been sufficient to assure the development of a new energy source. But today our society is more crowded, competition for the use of finite resources such as minerals, air, water, and land has increased, and the social and environmental impacts of a new technology are major factors in determining whether it will be developed on a large scale. Hence, in a democratic society, a proposed energy producing technology such as the SPS must be acceptable to the public, or politically feasible, as well as technically and economically feasible.

TECHNICAL FEASIBILITY

The SPS concept envisions perhaps 100 or more giant satellites, each with 50 square miles of surface area covered by photovoltaic cells, stationed 22,000 miles from earth in a "geosynchronous" orbit that makes them appear to be stationary over a given spot on the earth's surface. The photovoltaic cells would collect solar energy 24 hours a day and convert it to electrical energy. The electrical energy would then be converted to a beam of microwave energy aimed at a receiving antenna several square miles in area on the earth's surface, where the microwave energy would be converted back to electrical energy and transmitted over high voltage power lines to the population centers where it is used.

For economic reasons, it is impractical to prefabricate an SPS on earth and then launch it into orbit. Instead, densely packed raw materials must be launched into orbit and the SPS constructed in orbit by hundreds of workers. Because existing launch vehicles such as the Saturn rocket and the Space Shuttle are not big enough to propel the raw materials for an SPS into orbit economically, a new "heavy-lift launch vehicle" (HLLV) must be developed. According to SPS proponents, the HLLV would be a single stage, completely reusable vehicle capable of carrying into orbit several times the payload of the Space Shuttle. It would be three to five times more powerful than the Saturn rocket and therefore require construction of a new launching site. Construction of a single SPS would require 50 to 500 flights of the HLLV at the rate of one to five launches per day. If the dozens of SPS's needed to achieve claimed economies of scale are to be built, the launches would continue at this rate for decades. Indeed, eventual replacement of worn out SPS's (a 30 year life is predicted) would require such launches into the indefinite future. The HLLV would transport people, manufacturing equipment, and raw materials into low earth orbit, where highly automated factories operated by a few hundred workers would convert raw materials such as sheet metal rolls into an SPS. According to a report by the Jet Propulsion Laboratory (JPL), "Man must develop the capability to be as productive in space as on an automated automobile assembly line in terms of kg of finished products per man-hour worked in order for the SPS costs to be competitive". After an SPS is constructed in low earth orbit, the SPS and maintenance personnel must be transported to geosynchronous orbit with chemical or ion propulsion systems.

SPS proponents are quick to claim that no scientific breakthroughs are required to accomplish the technical wonders described above. Indeed, given unlimited mineral resources, money, and public acceptance, the proposed construction of dozens of solar power satellites might be technically feasible. But the fact is that no energy technology will be given such unlimited commitment of resources merely because it is technically feasible. The SPS must be economically and politically feasibile, as well as technically feasibile, or it will never be built.

ECONOMIC FEASIBILITY

Several studies have purported to calculate the cost of producing dozens of solar power satellites over a period of many years beginning near the end of this century and then compare that cost with projected costs for other possible sources of electricity. All of these studies of the economic feasibility of the SPS are flawed in major respects.

Suspect Objectivity of Studies of SPS Costs

First, the supposedly objective cost estimates for the SPS are being made by corporations, NASA space flight centers, consulting firms, and academicians who have a vested interest in encouraging a massive government commitment to the SPS. This leads to cost estimates that are mere self-fulfilling prophecies, or what one critic, Dr. John Cummings of the Electric Power Research Institute (EPRI), calls "legislating all the answers."[1] Richard Caputo, who directed a two-year Jet Propulsion Laboratory (JPL) study of the SPS, recognized the same pattern of behavior and characterizes the cost estimates he examined as based on "assumptions of success" rather than a real data base.[2] The SPS proponents appear to begin by calculating the cost goal which the total SPS system must meet to compete with other energy sources and then allocate that cost goal among the various subsystems of the SPS. Hence, they tend to reach similar conclusions about the total cost of the SPS based on widely varying estimates about the costs of the subsystems.

One example of the wishful economic thinking of SPS proponents is that they assume that any advances made in the technology of photovoltaic cells for land-based conversion of solar energy to electricity will be transferable to photovoltaic cells used in the SPS. The fact is that the cells used in the SPS must be thinner and lighter weight than cells used on earth, due to the need to hold down the cost of launching billions of the cells into orbit. Also, the cells for the SPS must be resistant to damage by micrometeorites, charged particles, and ultraviolet rays. Efficiency and cost reduction improvements in cells developed for land-based uses, therefore, will not necessarily be transferable to the specialized cells needed for the SPS.

Diseconomies of Scale

A second flaw in the studies of the economic feasibility of the SPS is the failure to acknowledge the disadvantages inherent to a technology that is so large in scale and expensive to develop to a state of commercial readiness that projected electricity costs do not fall to acceptable levels unless hundreds of billions of dollars are invested in the construction of dozens of the satellites. What we have here are several diseconomies of scale masquerading as economies of scale.

One diseconomy of scale is that the SPS will require enormous back-up power to fill the gap in the event that the power supply from one of the satellites is interrupted without notice. According to EPRI's Dr. John Cummings, a utility receiving electricity from an SPS would require a reserve of standby power capacity equal to or greater than the SPS power of five gigawatts (GW). Even the pooling of reserve power among several utilities may be inadequate. The largest power pool in the country today is 50 GW and the loss of one GW in that powerpool, much less five GW, "would cause havoc."[3] Paradoxically, the cost of backup power for the SPS could be reduced by lowering the size of each SPS, but the cost of an SPS goes up as its size is reduced. This problem and others have led Cummings to view the prospects for the SPS very skeptically. In his words, it "is a long, long, long---a very long---way off."[4]

A second diseconomy of scale is the large minimum commitment of 60 billion dollars of government funds required to develop the SPS to a commercial scale so that the question of economic feasibility can be answered definitively.[5] This proposed taxpayer investment in the development of a new energy technology is much greater than the investment required to develop competing energy technologies to a commercial scale. The cost of developing photovoltaic cells for land-based uses to a 10 MW scale commercial demonstration powerplant by 1985, for example, will be from 0.2 to 0.4 billion dollars.[6] In other words, the SPS would require from 150 to 300 times more RD & D dollars just to test its economic feasibility. Even the breeder reactor's proposed development cost of about ten billion dollars is dwarfed by the SPS proposal.

The diseconomy of scale inherent to such a large development cost is that it can be financed only by preempting funds that could have been used to develop other energy technologies. In effect, the extremely large development cost requires a commitment in favor of the SPS technology versus competing energy technologies even before the economic feasibility of the SPS is demonstrated. The economic risk of committing funds to SPS development is intensified by delaying the development of alternatives which would have to fill the gap if the SPS proved to be uneconomic.

A third diseconomy of scale of the SPS is that projected costs depend on maintaining a specified rate of construction of new satellites. In other words, if future electricity demand growth leveled off unexpectedly for a few years, as it did from 1974 to 1976, and consequently the rate of SPS construction was slowed, costs per unit would rise sharply.

A related diseconomy of scale of large powerplants such as the SPS is that it is difficult to match the addition of new powerplant capacity to growth in consumer demand. Unexpected variations in demand growth, such as those of recent years, lead to excess capacity, or idle investment. Either ratepayers or utility company shareholders must bear the burden of supporting the excess capacity. If a utility company already finds it difficult to match new powerplant construction with demand growth in today's circumstances, the problem can only be intensified by investing in the construction of an SPS, which would equal the power generating capacity of several nuclear powerplants. Even a group of utility companies jointly buying an SPS would still risk a mismatch in timing between consumer demand and delivery of power from the SPS, which would be ordered years in advance of predicted need.

A fifth diseconomy of scale of the SPS is that due to the high cost and high risk of relying on the SPS, the federal government is likely to be the only entity with the resources and hence ability to absorb risk needed to finance the SPS. Utility companies would be relegated to the role of distributors of SPS power rather than producers. Perhaps the prospect of government ownership of the SPS explains the healthy skepticism toward the SPS displayed by the Electric Power Research Institute, which is funded by investor-owned utilities.

A sixth diseconomy of scale of a large, centralized power supply system such as the SPS is its vulnerability to intentional disruption. A hostile government with access to modern technology could destroy a system of SPS's in orbit, certainly with missile warheads and perhaps with earth-based weapons such as laser beams. Saboteurs could attack the receiving antennae, which would have almost indefensible perimeters of many miles, or the high voltage transmission lines. Widely dispersed, small scale power systems are more easily defended and easier to repair when damaged.

Omission of Lowest Cost Alternatives

The most obvious flaw in the existing studies is their failure to adequately consider the lowest cost alternatives to the SPS, which are, first, efficiency improvements that will reduce our need for new energy supplies, including new electric generating capacity, and second, land-based, decentralized solar energy technologies.

Energy Conservation Alternative

Typically, the studies of SPS economics deal with the role of improvements in our efficiency of energy use by discussing low growth and high growth energy demand projections. The problem is that even their low growth demand projections are too high because they don't reflect the realistic possibility that we will use energy much more efficiently two or three decades from now, especially if resources are committed to energy conservation on the scale proposed for SPS development. No report on SPS economics that the Environmental Policy Center has reviewed includes speculations on how much energy could be saved if the hundreds of billions of dollars proposed for SPS development and deployment were instead spent on improving our energy efficiency. Yet energy that is saved by an efficiency improvement is just as important to society as a unit of energy that is produced from a new energy source. The opportunity for energy conservation investments that effectively "produce" energy is great because we have developed very inefficient ways of using energy. That inefficiency means that we have within our borders a tremendous "reserve" of "conservation energy" waiting to be "produced" through investments in energy conservation. A recent report to the Joint Economic Committee suggests that cost-effective investments could reduce our energy use by 40 percent. We should be "mining" and "drilling" this reserve of conservation energy through investments that improve the efficiency of our homes, office buildings, factories, and transportation systems, just as diligently as we seek new discoveries of oil and gas, or new technological marvels such as the SPS.

One expert on energy conservation improvements in existing buildings testified before this committee two years ago that "cost-effective conservation techniques which are commonly available today" could cut energy use in buildings "equal to the yearly output of about six hundred 1000 megawatt generating plants. In other words, if one 1000 megawatt plant came on line every two weeks starting today, it would take until the year 2000 for the capacity of these new plants to equal the savings which can be achieved in existing buildings using readily available, economically viable conservation techniques."[7]

In short, the cheapest powerplant is the one that is never built. Alternative investments in efficiency improvements would permit existing powerplants to serve more electricity users. By failing to consider such an alternative investment scenario, the SPS cost estimates have purposefully avoided the lowest cost competitor to the SPS. SPS proponents know that even if, for the sake of argument, the very optimistic cost projections for the SPS are accepted without waiting for years of "technology verification," alternative investments in energy conservation still can be shown to effectively produce energy at a lower cost. No new research and development, or "technology verification," is needed to verify the economic feasibility of energy conservation investments and their enormous potential as a source of new energy. The economics of energy conservation are not speculative; they are will understood.

Decentralized Solar Energy Systems Alternative

Another omission from cost comparisons with the SPS has been land-based, decentralized solar energy systems. The SPS proponents prefer to set up the straw man of a centralized solar energy powerplant alternative and then knock it down by claiming high costs for electricity storage, land acquisition, and transmission lines up to 2,000 miles long from solar powerplants concentrated in the Southwestern states. Even the most objective of the SPS studies, the report by JPL, compared the SPS with what the report's director has described as the "worst solar terrestial options", centralized solar energy powerplants at sites remote from their markets. The JPL study also distorted its results by omitting from its calculations of SPS costs the 60 billion dollars of government investment needed to develop the SPS to a commercial scale. In spite of this rigging of the rules of the game, the JPL study concluded that the SPS would cost more than a land-based, centralized solar energy powerplant using a solar thermal process and fossil fuel backup system and about the same as a centralized photovoltaic solar energy system with a fossil fuel backup system.[9]

If the SPS costs were compared with decentralized solar electric systems using photovoltaic cells, the SPS would look even worse. Decentralized solar energy systems would be lower cost than the centralized solar energy systems used in the JPL study because transmission costs can be eliminated, land acquisition costs can be reduced by using air spaces over rooftops and parking lots, and waste heat can be put to work near the generating site.

Objections by SPS proponents that electricity storage costs are an insurmountable barrier to lowering the cost of land-based solar energy, whether centralized or decentralized systems, have to be taken with a grain of salt. The people who suggest that major reductions in the cost of electricity storage are not likely are the same people who are extremely optimistic that costs for various subsystems of the SPS will fall drastically. Moreover, the presently low level of government spending on research and development of electricity storage may be increased soon. I participated in a two day review of the DOE solar energy budget last week, and one of the recommendations of the budget reviewers was that the R & D budget for electricity storage systems for use with decentralized solar energy systems be increased greatly in fiscal year 1980 and succeeding years.

POLITICAL FEASIBILITY

One diseconomy of scale of the SPS that even its proponents acknowledge is that it requires such a large commitment of resources and entails so many environmental and social impacts that public acceptance, or political feasibility, will be a critical factor in determining whether the SPS is built. They have already begun their public relations campaign to sooth concerns about the possibilities of microwave effects on health, microwave interference with radio frequencies, disruption of the upper atmosphere by launch vehicle exhausts and microwave beams, and other impacts. Indeed, critics of the bill being considered here today are told that the money in this bill is needed to develop technology to test possible environmental impacts.

Public Preference for Decentralized Solar Energy Systems

The Environmental Policy Center believes that a 270 million dollar, five-year technology development program is not needed to verify two of the biggest barriers to the political feasibility of the SPS. First, the public won't buy it. Public enthusiasm for solar energy is based on an interest in decentralized, or dispersed, solar energy systems, not highly centralized systems such as the SPS, which must be owned by giant utility companies or the federal government. Solar energy enthusiasts are looking forward to development of solar energy systems scaled for use by individuals, neighborhoods, and communities. The majority of the thousands of public witnesses who appeared at DOE's series of 11 public hearings on federal solar energy policy this summer expressed a preference for development of decentralized solar energy systems and many of them specifically objected to the SPS concept. Delegates representing 50 states and the District of Columbia at the National Solar Congress here in Washington on August 4 to 6 expressed similar views in the policy program which they ratified. Thus public support for government promotion of solar energy is, in part, a vote for increased consumer control of the supply of energy and should not be construed by members of this

35-994 O - 79 - 5

committee to include support for the SPS. Indeed, resistance to the SPS will grow as consumers become aware that the large scale commitment required to make the SPS work would effectively foreclose consumer and public utility commission influence over electricity rates and construction decisions.

Siting Problems

Another political barrier to the SPS that can be discerned without waiting for the technology development proposed in this bill is the problem of siting the new launch facilities and dozens of receiving antennae required for the SPS. The new launch facility would preempt a large area due to the need to launch and land several very noisy HLLV's per day over a period of many years, perhaps into the indefinite future. An HLLV being launched would be much louder than the less powerful Saturn rocket and an HLLV landing would be much louder than the SST. One report has suggested that the "sonic overpressures produced by space-freighter re-entry indicate that the final 200 km of the path should be over open ocean."[10] Now, this means that the HLLV launch site must be in the coastal zone, presumably where the climate is warm year round. Areas that meet these requirements are attractive for many other uses, both onshore and offshore, and population density in such areas is high and getting higher. I find it difficult to believe that even Cape Canaveral could be used as the HLLV launch site. Orlando, Florida and the Disneyworld amusement park are just a few miles away and the nearby population is growing rapidly.

Siting of the receiving antennae also appears to confront a very high political barrier. The siting of new electric powerplants, whether nuclear or fossil fuel plants, has been a controversial issue for years. Proposed federal legislation to accelerate siting decisions is not progressing rapidly. Even if it is passed, siting controversies can only grow due to the shrinking number of potential powerplant sites and the competing uses of those sites. Siting of high voltage powerlines is emerging as a major new area of political controversy. Politically conservative rural residents of upstate New York and northern Minnesota have resorted to unfamiliar acts of civil disobedience to resist the siting of unwanted powerlines. One of my colleagues is helping form a national coalition of groups which want broader citizen representation in power line siting decisions.

Another example of siting problems is the legislation enacted by several states to prohibit the siting of nuclear waste disposal projects within their borders. Also, the Navy has failed repeatedly to sell the public on proposed sites for Project Sanguine, which entails burying a grid of highly charged electric cables for low frequency communication with submerged submarines.

SPS proponents are aware of the siting problem. A NASA study could find only 69 potential land sites and some people have suggested that ocean sites could be used, although I am not aware of any calculations of the cost of such structures. Moreover, offshore sites do not avoid the problem of conflicting uses. Perhaps Boeing or the Arthur D. Little company should study the current controversy over a proposal to site nuclear powerplants off the coast of New Jersey. Offshore siting is not the solution. Probably, there is no solution to the siting problem. Indeed, it is likely to get worse. If the U.S. standard for microwave exposure is tightened to the East European standard, the area preempted by receiving antennae will triple from 300 km^2 to 900 km^2.[11]

I would like to close on a more positive note by identifying some areas where I agree with the proponents of this legislation. First, I agree that there should be a transition to the use of solar energy in place of the environmentally disruptive and nonrenewable fossil fuels and uranium. Second, I agree that the government should commit billions of dollars to developing solar energy technologies to a commercial stage, including a bigger effort to lower the cost of photovoltaic cells. Finally, I agree that the government should fund studies of the health effects of microwave radiation. However, in spite of these areas of agreement, I don't believe that further government funding of research on the SPS concept can be justified. If the already funded government study of the SPS is adjusted to make its cost comparisons more realistic and to adequately account for political barriers to the SPS, I am confident that it will recommend no further work in the SPS.

Thank you.

- - - - -

FOOTNOTES

1. Telephone conversation, July 28, 1978
2. Telephone conversation, August 11, 1978
3. Telephone conversation, July 28, 1978
4. David Johnston, "Solar Space Power," Sundancer magazine, July, 1978, p.32.
5. An Initial Comparative Assessment of Orbital and Terrestial Central Power Systems (Final Report), Prepared by the Jet Propulsion Laboratory for the NASA Office of Energy Programs, March, 1977, p. 4-35 (Hereinafter cited as JPL Study).
6. JPL Study, p. 6-6.
7. Statement of Carl Stein, in Hearings on the Energy Conservation Act of 1976, before the Senate Committee on Interior and Insular Affairs, April 26, 1976, pp. 109-10.
8. Telephone conversation, August 11, 1978.
9. JPL Study, pp. 1-1 to 1-6.
10. Gordon R. Woodcock, "Solar Satellites Space Key to Our Power Future," Astronautics & Aeronautics, July/August, 1977, p.30.
11. JPL Study, pp. 6-18 to 6-19.

Senator MELCHER. Garry, this $270 million, now whose figure is that?

Mr. DELOSS. It comes from a table in a report accompanying the House bill, and I'm not sure where they got it. I'm sure there were plenty of people willing to offer prosepective authorization schedules for the next 5 fiscal years, but it's in that report.

Senator MELCHER. How many years is that?

Mr. DELOSS. It goes through the next 5 fiscal years.

Senator MELCHER. They are projecting $270 million for 5 years?

Mr. DELOSS. Right.

Senator MELCHER. Well, of course, that's way ahead of me, and ahead of this committee. I don't think we would be prepared to earmark that much funding for this project at this time. It has been stressed by Congressman Flippo and others that there are checkpoints in the proposed bill. Do you think these checkpoints are necessary?

Mr. DELOSS. Well, the checkpoints are only important if you believe that we've already started down the road, along those checkpoints. Now, I think that the existing study which is approximately one-half completed, will possibly, if it is altered a little bit in some of the ways I've suggested, come up with a negative answer. And the first checkpoint is the end of that study. That's the checkpoint I'm interested in.

I think that when we get to the end of that study, we should have an answer that says that this is not a good idea to continue to try to put money into the SPS development.

Senator MELCHER. Did you envision a checkpoint being an administrative checkpoint?

Mr. DELOSS. The checkpoint would be that if the study comes to a negative conclusion, it would be very difficult for the advocates of the SPS to come before the Congress, and get authorizations to fund research and development work in the SPS.

Senator MELCHER. What if it's a positive finding?

Mr. DELOSS. Well, then we'll still fight it, and I think for the reasons I've enumerated, for the reasons that I've enumerated here in my testimony today, and some more, that the chances for success of the SPS is very slight.

Personally, I suspect that if there's any additional funding for the SPS, that it might go on for a few years and then die out, and perhaps somewhere in the offices of NASA they are expecting that too. But they're hoping that if the economy rebounds, and the public feels like it's got a little more money to spend, they might be able to revive the manned flight to Mars again.

Senator MELCHER. You were comfortable, though, with an administration checkpoint?

Mr. DELOSS. Well, I think that's the next obvious checkpoint. I'm not comfortable with anything that is proposed in the bill being considered here today. Except that they do talk about funding additional studies of the health effects of the microwave radiation. But that doesn't justify for me the rest of the $270 million program.

I think we could talk about separate legislation to deal with that.

Senator MELCHER. My question is whether or not you want a legislative checkpoint.

Mr. DELOSS. Well, this bill envisions annual authorizations, so I suppose you could say there are annual checkpoints in the bill already.

Senator MELCHER. Were you aware there was $4.6 million in the proposal by the Department of Energy prior to the introduction of this bill on January 3?

Mr. DELOSS. Oh, yes, we complained then that the money being spent to study the SPS concept is approximately double the money that was being spent in grants to small inventors and entrepreneurs in the area of what is termed appropriate technology goals.

And I think that that is a misplaced sense of priorities, and the fact that we're spending $5 or $6 million this year on studying the SPS and only spending about $3 million in grants to these very innovative people is a mistake.

Senator MELCHER. That is a nice, round comparison. I don't know what you're going to do about getting more money into appropriate technology, that is more successful than what we had, but I would certainly welcome your active and visible support.

Mr. DELOSS. I'll do that.

Senator MELCHER. We just had a little scuffle with that a couple of days ago, you remember, on the money for appropriate technology in weatherization. And I did not see you people beating the drums for it, were you?

Mr. DELOSS. At that time I was preoccupied with another problem.

Senator MELCHER. Probably with this.

Mr. DELOSS. I share your enthusiasm for appropriate technology, I assure you.

Senator MELCHER. I think you are right. Until we know something about this, the Government is the only one that can assume the risk to make these experiments to find out where there are harmful effects from the points we were discussing with Dr. Deutch earlier, concerning the microwave potential hazards.

Mr. DELOSS. I think that's a very important area to public support of SPS, and we can see that things like Paul Brodeur's book, "The Zapping of America," which is a very popular book, they are informing the public much more about the possible hazards from microwave radiation. And I'm sure we'll find a lot of public support for legislation aimed very narrowly at studying that problem, as opposed to this legislation.

Senator MELCHER. We have adopted an amendment which I offered in this committee to the fiscal year 1979 DOE authorization act that would prohibit the siting of a nuclear waste disposal in States where there was no nuclear energy unless the Governor approved it. I believe that is probably constitutional, and I hope it stays in the bill. It is an example of how a State such as mine, Montana, with quite a bit of coal and no real interest in nuclear energy, protects itself from what may or may not be. I consider it a hazard, and I guess probably others would disagree with me, but one of the hazards that I seem to consider exists. We also have some problem getting coal-fired generating plants built now. As you know, coal is our big resource in Montana.

If we are going to have a development of that coal for the purposes of generating electricity right now or in the next few years anyway, that's going to be the steam generating facility. Isn't the Environmental Policy Center also opposing that?

Mr. DELOSS. I couldn't tell you for sure because we have 10 lobbyists there, and I don't work in the coal mining area but we are very active on issues involving coal mining, and we were very active on the passage of the legislation regarding strip mining, which I'm sure you are aware.

Senator MELCHER. Yes; I know the passage of the strip mining act set the stage for possible development of western coal.

Mr. DELOSS. But we do support the use of coal as a transitional fuel. Until we develop a society based more on solar energy technologies.

Senator MELCHER. Well, I only mentioned it because here we are resisting nuclear because of the waste disposal problems, and many people are opposing coal strip three and four because of the air quality deterioration.

We are not really getting into the field of more development of power generating capacity, very quickly that is. I cannot disagree with you on your assessments of, or conclusion that we need more money in solar here on Earth, in more conventional methods.

The point concerning this bill is its passage or nonpassage, and this committee's oversight responsibility of the Department of Energy. Regarding this field of SPS, we need to have some answers, do we not? We cannot just simply say scuttle it, without having the answers. Or is there a quantitative point on that?

Mr. DELOSS. What I tried to suggest in my statement, is that there are some answers that we can get that will probably be crucial answers in terms of deciding whether to go or not go forward with the SPS that don't require the so-called technology verifications that would be funded in this bill.

For example, if they haven't yet attempted a cost comparison between the SPS and an alternative investment program in energy conservation, we don't need to do technical R. & D. to answer that question. We could accept the cost estimates that are already proposed for the SPS, just for the sake of argument. We could still beat the SPS by looking at the potential for investment in energy conservation.

Those investments do not require research and development to verify their economics. Those investments are very well understood already.

Senator MELCHER. Well, I think we're getting semantic on what is research and development, and what is feasibility, and what is not. But you wouldn't object to what Dr. Deutch described, and Dr. Koomanoff described on their experimentation, which is pretty hefty experimentation, to determine whether or not there is danger from microwaves.

Mr. DELOSS. We don't object to the existing study, in fact, as I said, I think if the study is changed somewhat, and we've already met with Dr. Koomanoff and some of his colleagues to discuss this, that the results of this study would probably be negative.

Senator MELCHER. You do want to find out though, do you not?

Mr. DELOSS. We want to find out to the extent of the existing study, and I'm sure, and I'm fairly optimistic that the answer at that point would be negative.

Senator MELCHER. For instance, you pose the question: Who wants antenna sites in their own State? That doesn't mean much unless you say there is a danger from the antenna sites. Isn't that correct?

Mr. DELOSS. Well, there's at least a perceived danger, and that could be as important as a real danger. We're talking about a public that is not confident in the calculated degree of risk for nuclear powerplants, that the Government and the nuclear power industry claim. We're talking about a public that is not confident that nuclear waste proposal sites can really be contained. You're talking about a public that is sensitized by things like the chemical waste disposal problem that is popping up literally in people's backyards in Niagara, N.Y.

It's very hard to convince the public to accept a technology that has a potential for danger, at least, and there are much less dangerous alternatives that are available. But they can perceive those alternatives, they know they exist.

Senator MELCHER. First of all I assume that you approve of what Dr. Deutch and Dr. Koomanoff are dong now, and what they propose to do next year, for about $8 million. Part of that answer, or a major question to begin with, is the danger of microwaves involved here. You would want us to get those answers, would you not?

Mr. DELOSS. I'm all in favor of completing the ongoing study, that is correct.

Senator MELCHER. What if we don't have any answers by then, would you want us to quit?

Mr. DELOSS. Well, I think as I said, if you look realistically at the alternatives for the SPS, and if you go back, and alter some of the cost studies that have been done today, to take into account the alternative of energy conservation investments and decentralized solar energy systems instead of centralized solar energy systems, I think we can get our negative answers very soon. I don't expect a positive answer, I don't think it's possible.

Senator MELCHER. I assume that you agree, up to a point, you want the answers on whether it is feasible, cost effective. That's the first thing you talk about, and which you are pretty sure is negative. The second point is, regardless if it is cost effective, whether there are dangers from microwaves.

Mr. DELOSS. I would like to see the existing study completed with some alterations, and that is all I could support. I can't support this bill.

Senator MELCHER. I do not think the bill does much more than the Department and NASA are doing, except to give it a little more definition within the Department of Energy, and although the amount of $25 million is obviously more than we contemplate on spending per year, as you well know, authorization figures are adjusted whenever we think there is a need.

Probably, a greater benefit to the bill could be measured only in whether there is the congressional check point. The Environmental Policy Center has sponsored, since I've been here, several congressionally mandated check points.

I tend to think that they are right and don't want to overburden the Congress and make unnecessary check points, but I think that on a technology of this type, a congressional check point is absolutely necessary for me to feel comfortable with it.

Perhaps when we get through we will find the Environmental Policy Center even advocating that. Thank you very much.

Mr. DELOSS. Thank you, Senator.

Senator MELCHER. Mr. Boileau, president of Boeing Aerospace Co. Mr. Hedrick from Grumman and Mr. Nansen, please proceed.

STATEMENT OF OLIVER C. BOILEAU, PRESIDENT, BOEING AEROSPACE CO., SEATTLE, WASH., ACCOMPANIED BY IRA GRANT HEDRICK, SENIOR VICE PRESIDENT, GRUMMAN AEROSPACE CORP., BETHPAGE, N.Y.; AND RALPH NANSEN, BOEING SPACE-BASED SOLAR POWER SYSTEMS MANAGER

Mr. BOILEAU. My name is Oliver C. Boileau, and I am president of the Boeing Aerospace Co. I would like to thank you for this opportunity to speak in support of Senate bill 2860, the Solar Power Satellite Research, Development, Demonstration Act of 1978. With me is Ralph Nansen, Boeing's space-based solar power systems manager.

In addition to my statement I have a supplement, which I wish to place in the record.

Senator MELCHER. It will be made a part of the record. Is this the supplement here?

Mr. BOILEAU. Yes, sir.

Senator MELCHER. It will be made a part of the record immediately following your statement.

Mr. BOILEAU. I have a lot to say in a relatively brief time. I will describe what we've done and where we are in the development of the solar power satellite concept. I will attempt to show you why we need this legislation, and I will outline for your consideration a technical verification plan designed to meet the legislation's mandates.

Simply put, we envision the creation of a series of huge satellites which would intercept the Sun's rays in deep space, transforming them into electricity which would be beamed to Earth in the form of microwaves. Large ground antennas would reconvert this beam, in essence radio waves, to electricity which would be fed to homes and factories through utility power grids.

Simply put, yes. But not simple to accomplish. These satellites may measure in size anywhere from 8 square miles to even an astounding 34, depending on the desired power output. They would be constructed in space by orbiting crews numbering in the hundreds. A new transportation system eventually would be needed, and here on Earth, a new industry would be created.

Quite a mouthful. Sort of like trying to swallow an elephant. But engineers at Boeing, and elsewhere, think it can be done. The elephant will have to be chopped into little bites, and a lot of it will be tough to chew. But it's possible. Costly, but possible.

Why would anyone want to do it? Let's examine the need. I will not dwell upon the fact that we are in an energy crisis. Nor will I question the need for conservation, or for the further exploitation of our vast coal resources. Conservation can, and probably must, ease us through today's difficulties.

But the energy crisis will become increasingly serious as long as we are chained to a dependence on fossil fuels. For the midterm, say, through the year 2000, a mix of many sources will help us meet our needs. These may include coal, oil, natural gas, nuclear, ground solar, and wind.

It is on our long-term survival that we must place the emphasis. We must find new, nondepletable, basis-load energy sources if we are to guarantee continued energy growth. I see only three potential candidates; breeder reactor, fusion, and space solar power.

None should be ignored. And, obviously, I have my favorite candidate. This was not always the case. When Peter Glaser first proposed the idea in 1968, I had, to put it politely, serious doubts. So did the engineers to whom I gave the assignment. But the more they attempted to punch holes in the concept, the more it became apparent that there were no insurmountable technological stumbling blocks.

Perhaps, the turning point to us was the realization that we were examining an energy program rather than a space program. It still was a mighty big elephant, but it wasn't a white elephant. There were 220 million people out there with very real energy needs.

We went to work. Slowly at first, but as the data accrued, the tempo increased. A future space transportation systems study firmed up the foundation. Conceptual studies for heavy-lift launch vehicles, space freighters, if you will, followed, as did investigations into the creation of large space structures and ion propulsion devices.

For most of the last 2 years, we've been refining our data under contract to NASA's Johnson Space Center. We carefully have weighed system reqirements against existing technologies and have found, on paper, at least, that solar power satellites appear to be technologically, environmentally, and economically promising.

But, I repeat, this is what it says on paper. The time has come to take the first careful, cautious steps from the drawing board. We've done the studying, amassed enough words and numbers. What is needed is proof, of concept, of environmental acceptability, of economic viability.

Or, more bluntly, can we do it? Can we live with it? Can we afford it? S. 2860 will lead us toward answers to these questions. The $25 million it authorizes will take us from paper studies to material and subsystem testing. We suggest that these funds be spent on development and hardware testing in 10 specific areas. They are:

Solar cells: Two and one-half million dollars should be spent developing low cost, high performance, light weight solar cells. Cost reduction through automated production should be invesigated. Advanced cell types such as thin film gallium arsenide cells should be further developed. Techniques aimed at refurbishing radiation damaged cells should be investigated.

Solar cells are proven providers of spacecraft power; they must be developed to the point when they can produce reasonably priced electricity for consumers here on Earth.

Thermal engines and thermal systems: Another $2.5 million should be invested in development of materials needed for controlling temperatures on either thermal engine or photovoltaic satellites and, for a time at least, for the development of materials for engines for thermal engine satellites. Our studies tend to show that photovoltaic satellites have certain advantages over the thermal engine approach.

However, we feel that developmental work in both areas should proceed until a firm decision can be made between the two.

Microwave power transmission system: The Department of Energy and NASA are investigating the biological effects of microwaves and the development of standards and specifications for microwave exposure. We recommend that $6 million be spent to determine what effect solar power generated microwaves will have on our ionosphere.

Research and technology development in the areas of microwave power amplification and phase control also would be pursued. This work is necessary to begin a meaningful assessment of the environmental aspects of the satellite's power transmission system, both on living things and on our communications systems.

It will provide the foundation for broader terrestrial environmental studies into the effects of the beams on migrating birds, plant growth, land use under the receiving antennas, and the like. No environmental peril has been uncovered in our preliminary studies. However, this is an area of vital importance and must be investigated thoroughly before we embark on a satellite demonstration phase.

Space structures: A relatively modest $750,000 is recommended here. This will augment already existing space structures technology efforts in the specific areas of thin gage structural elements and joining and fastening techniques. Rigidity of deployable structure would be investigated; the advantages of ultrasonic welding versus mechanical fastening would be weighed.

Materials: We believe that $1.5 million should be spent to define and better understand the properties of materials proposed for construction and long-term exposure in space. For instance, we should subject composite materials suggested for satellite construction to the rigors of simulated space in large vacuum chambers.

Flight control system: Another $750,000 should be invested in the development of means to control large flexible systems in space. This would include the development of algorithms and software to provide stability when control frequencies and structural frequencies overlap, and the fine pointing of large structures using multiple actuators.

Construction systems: Three million dollars should be spent for technology development and analysis of semiautomated construction equipment needed for a satellite space construction base. Structure fabricators, solar cell deployers, men and equipment transporters, controls and displays are but a few of the needs.

Transportation systems: Much work must be done in this field. The space shuttle will be the backbone of the solar power satellite verification program, but, further down the line, new generations of space transportation craft will be needed. Booster engines for large space freighters capable of economically carrying large payloads into low Earth orbit should be developed.

Large and efficient electric thrusters for inter-orbit transfer vehicles should be designed. We recommend that $4.5 million be spent in preliminary work in this area.

Power distribution and controls: We see the need for $1.5 million here. High priority items include development of lightweight, long life, power processors and their interfaces with thermal control systems, and the development of high voltage switch gear.

Space environment factors: Two million dollars should be invested in augmenting research now primarily applicable to smaller spacecraft, and an investigation of space plasma effects on much larger area systems.

These proposals spread the legislation's $25 million thinly over an extremely broad area of technologies.

However, we see this as an adequate first year initiative which gets us off the drawing boards and into hardware development. A 5- to 7-year verification phase would follow.

And, while this $25 million is a relatively inexpensive investment for a program with such vast potential let's not kid ourselves or the public. It's just a small down payment. The 5- to 7-year verification phase would cover the total ground and space testing of solar power satellite elements and would include at least three logical decision points:

Ground testing of components, flight testing using individual shuttle sortie flights, and scaled systems tests of a 250-kilowatt to 1 megawatt power unit in low Earth orbit. These would allow engineering and cost verification and would remove the majority of program risks. If additional tests are needed prior to full scale implementation, an intermediate sized unit capable of delivery of significant electrical power from geosynchronous orbit into our ground based electrical grid could be developed.

When, and if, we reach this stage, we'll have passed through a long series of decision gates. At each step, technologic, environmental, and economic considerations will have been weighed. Interrelationship will be the key.

This asks for little that is not already in the Department of Energy's solar power satellite long-range plan. All it does is fit into a matrix the steps which will lead to the answers to those important questions:

Can we do it? Can we live with it? Can we afford it? Hopefully the answer will be yes to all three. If not, let's find out. And I'll be the first to say, enough, let's get on to something else. But let's give it a chance.

While we are looking for alternate energy sources, our Nation is importing billions of barrels of foreign oil. Is sending billions of American dollars overseas. Is burning up our own dwindling reserves, in effect borrowing from our future.

I am not asking you for millions of dollars for some esoteric scientific pursuit in space. Nor am I asking for a blank check, we can get to the Moon, so why can't we solve our problems on Earth crash program. I'm not even asking for favorite-candidate status.

All I'm calling for is balanced funding commensurate with that given other energy program candidates. To date, space solar power has been short changed, receiving less than $5 million a year. This simply is not in line with expenditures on just about any other energy option. Nor is it enough to get on with the job.

Our studies show that the solar power satellite concept is extremely promising. But, as I've said before, promises won't light our lamps or power our machinery. We need hard facts, facts upon which we can base a rational energy development plan.

We've gone as far as paper studies can carry us. We need to get on to hardware verification. It is up to the Congress and the administration to decide whether we move forward, or spin our wheels until we run out of gas. Thank you, Mr. Chairman.

Senator MELCHER. Mr. Hedrick, can you add to that?

Mr. HEDRICK. Mr. Chairman, I have prepared testimony and essentially I strongly support the approval of the bill of S. 2860. And I felt that if I could submit this for the record, I would like to take a minute or two for a comment, if I might.

Senator MELCHER. Your prepared statement will be made a part of the record.

STATEMENT OF IRA GRANT HEDRICK, SENIOR VICE PRESIDENT, GRUMMAN AEROSPACE CORP., BETHPAGE, N.Y.

Mr. HEDRICK. The prepared statement covers the Grumman's company general interest in energy problems, as well as the solar power satellite. But I would like to first just say that I believe our Nation's search for a base load, inexhaustible, energy source deserves the sense of urgency that I feel is lacking. And I say this even though I feel sure that we will not realize any appreciable energy from such a source until after the year 2000.

We in the United States are concerned and confused about our future energy supplies, and on the nature of the supplies, how they might affect such things as our future economy, military security, and our environment. I feel sure the American people would rally in support of an effort to solve our energy concerns.

Certainly a bold, positive move by the United States to develop an inexhaustible energy resource would improve our international image. But, we just haven't done our homework that is needed to make an intelligent choice between what are probably our only real options, that is fission, fast breeder reactors, fusion, and solar power satellites. It is the work needed to make the most critical choices that I say deserves this sense of urgency.

And second, I would like to point out that there are two basic ways to approaching this concept, that is the negative and the positive. The negative approach amplifies the difficulties, real or imagined, to a level where it can be rationalized, that the concept should be rejected out of hand without benefit of any constructive effort.

The positive approach considers all suggested difficulties and separates out and rejects the imaginary ones, and then seeks by creative thinking to find acceptable solutions for the real difficult. Since we have so few real options for the long-term energy needs, and none of them are quick and easy to achieve, I believe we should approach the solar-power satellite in a positive mode, as set forth in bill S. 2860. Thank you, sir.

[The prepared statements of Mr. Boileau and Mr. Hedrick follow:]

Statement of
Oliver C. Boileau
President, Boeing Aerospace Company

Before the
Subcommittee on Energy Research and Development
of the
Energy and Natural Resources Committee

United States Senate

August 14, 1978

My name is Oliver C. Boileau and I am president of The Boeing Aerospace Company. Thank you for this opportunity to speak in support of Senate Bill Twenty-eight Sixty, the Solar Power Satellite Research, Development and Demonstration Act of 1978.

With me is Ralph Nansen, Boeing's space-based solar power systems manager. In addition to my statement, I have a supplement which I wish to place in the record.

I have a lot to say in a relatively brief time. I will describe what we've done and where we are in the development of the solar power satellite concept. I will attempt to show you why we need this legislation. And I will outline for your consideration a technical verification plan designed to meet the legislation's mandates.

Simply put, we envision the creation of a series of huge satellites which would intercept the Sun's rays in deep space, transforming them into electricity which would be beamed to Earth in the form of microwaves. Large ground antennas would reconvert this beam—in essence radio waves—to electricity which would be fed to homes and factories through utility power grids.

Simply put, yes. But not simple to accomplish. These satellites may measure in size anywhere from eight square miles to even an astounding 34—depending on the desired power output. They would be constructed in space by orbiting crews numbering in the hundreds. A new transportation system eventually would be needed, and here on Earth, a new industry would be created.

Quite a mouthful. Sort of like trying to swallow an elephant. But engineers at Boeing and elsewhere think it can be done. The elephant will have to be chopped into little bites, and a lot of it will be tough to chew. But it's possible. Costly, but possible.

Why would anyone want to do it? Let's examine the need.

I will not dwell upon the fact that we are in an energy crisis. Nor will I question the need for conservation or for the further exploitation of our vast coal resources.

Conservation can—and probably must—ease us through today's difficulties.

But the energy crisis will become increasingly serious as long as we are chained to a dependence on fossil fuels. For the mid-term—say, through the year 2000—a mix of many sources will help us meet our needs. These may include coal, oil, natural gas, nuclear, ground solar and wind.

It is on our long-term survival that we must place the emphasis. We must find new, non-depletable, base-load energy sources if we are to guarantee continued energy growth. I see only three potential candidates: Breeder reactor, fusion and space solar power.

None should be ignored. And, obviously, I have my favorite candidate.

This was not always the case. When Peter Glaser first proposed the idea in 1968, I had—to put it politely—serious doubts. So did the engineers to whom I gave the assignment. But the more they attempted to punch holes in the concept, the more it became apparent that there were no insurmountable technological stumbling blocks. Perhaps, the turning point to us was the realization that we were examining an energy program rather than a space program. It still was a mighty big elephant, but it wasn't a white elephant—there were 220 million people out there with very real energy needs.

We went to work. Slowly at first, but as the data accrued, the tempo increased.

A future space transportation systems study firmed up the foundation. Conceptual studies for heavy lift launch vehicles—space freighters, if you will—followed, as did investigations into the creation of large space structures and ion propulsion devices.

For most of the last two years, we've been refining our data under contract to NASA's Johnson Space Center. We carefully have weighed system requirements against existing technologies and have found—on paper, at least—that solar power satellites appear to be technologically, environmentally and economically promising.

But, I repeat, this is what it says on paper. The time has come to take the first careful, cautious steps from the drawing board. We've done the studying, amassed enough words and numbers. What is needed is proof—of concept, of environmental acceptability, of economic viability.

Or, more bluntly, can we do it? Can we live with it? Can we afford it?

S. Twenty-eight Sixty will lead us toward answers to these questions. The 25 million dollars it authorizes will take us from paper studies to material and subsystem testing. We suggest that these funds be spent on development and hardware testing in 10 specific areas. They are:

Solar Cells

Two-and-a-half million dollars should be spent developing low-cost, high-performance lightweight solar cells. Cost reduction through automated production should be investigated. Advanced cell types such as thin-film gallium arsenide cells should be further developed. Techniques aimed at refurbishing radiation-damaged cells should be investigated. Solar cells are proven providers of spacecraft power; they must be developed to the point where they can produce reasonably priced electricity for consumers here on Earth.

Thermal Engines and Thermal Systems

Another 2.5 million dollars should be invested in development of materials needed for controlling temperatures on either thermal engine or photovoltaic satellites and, for a time at least, for the development of materials for engines for thermal engine satellites. Our studies tend to show that photovoltaic satellites have certain advantages over the thermal engine approach. However, we feel that developmental work in both areas should proceed until a firm decision can be made between the two.

Microwave Power Transmission System

The Department of Energy and NASA are investigating the biological effects of microwaves and the development of standards and specifications for microwave exposure. We recommend that 6 million dollars be spent to determine what effect solar-power-generated microwaves will have on our ionosphere. Research and technology development in the areas of microwave power amplification and phase control also would be pursued. This work is necessary to begin a meaningful assessment of the environmental aspects of the satellite's power transmission system, both on living things and on our communications systems. It will provide the foundation for broader terrestrial environmental studies into the effects of the beams on migrating birds, plant growth, land use under the receiving antennas, and the like. No environmental peril has been uncovered in our preliminary studies. However, this is an area of vital importance and must be investigated thoroughly before we embark on a satellite demonstration phase.

Space Structures

A relatively modest 750,000 dollars is recommended here. This will augment already existing space structures technology efforts in the specific areas of thin-gage structural elements and joining and fastening techniques. Rigidity of deployable structures would be investigated; the advantages of ultrasonic welding versus mechanical fastening would be weighed.

35-994 O - 79 - 6

Materials

We believe that 1.5 million dollars should be spent to define and better understand the properties of materials proposed for construction and long-term exposure in space. For instance, we should subject composite materials suggested for satellite construction to the rigors of simulated space in large vacuum chambers.

Flight Control System

Another 750,000 dollars should be invested in the development of means to control large flexible systems in space. This would include the development of algorithms and software to provide stability when control frequencies and structural frequencies overlap, and the fine pointing of large structures using multiple actuators.

Construction Systems

Three million dollars should be spent for technology development and analysis of semi-automated construction equipment needed for a satellite space construction base. Structure fabricators, solar cell deployers, men and equipment transporters, controls and displays are but a few of the needs.

Transportation Systems

Much work must be done in this field. The Space Shuttle will be the backbone of the solar power satellite verification program but, further down the line, new generations of space transportation craft will be needed. Booster engines for large space freighters capable of economically carrying large payloads into low Earth orbit should be developed. Large and efficient electric thrusters for inter-orbit transfer vehicles should be designed. We recommend that 4.5 million dollars be spent in preliminary work in this area.

Power Distribution and Controls

We see the need for 1.5 million dollars here. High priority items include development of lightweight, long-life power processors and their interfaces with thermal control systems, and the development of high-voltage switch gear.

Space Environment Factors

Two million dollars should be invested in augmenting research now primarily applicable to smaller spacecraft, and in investigation of space plasma effects on much larger area systems.

These proposals spread the legislation's 25 million dollars thinly over an extremely broad area of technologies. However, we see this as an adequate first year initiative which gets us off the drawing boards and into hardware development. A five- to seven-year verification phase would follow.

And, while this 25 million dollars is a relatively inexpensive investment for a program with such vast potential, let's not kid ourselves or the public. It's just a small down payment. The five- to seven-year verification phase would cover the total ground and space testing of solar power satellite elements and would include at least three logical decision points: Ground-testing of components, flight-testing using individual Shuttle sortie flights, and scaled systems tests of a 250 kilowatt to 1 megawatt power unit in low Earth orbit. These would allow engineering and cost verification and would remove the majority of program risks. If additional tests are needed prior to full-scale implementation, an intermediate sized unit capable of delivery of significant electrical power from geosynchronous orbit into our ground-based electrical grid could be developed.

When—and if—we reach this stage, we'll have passed through a long series of decision gates. At each step, technologic, environmental and economic considerations will have been weighed. Interrelationship will be the key.

This asks for little that is not already in the Department of Energy's solar power satellite long-range plan. All it does is fit into a matrix the steps which will lead to the answers to those important questions:

Can we do it? Can we live with it? Can we afford it?

Hopefully, the answer will be "Yes" to all three. If not, let's find out. And I'll be the first to say: "Enough, let's get on to something else."

But let's give it a chance.

While we are looking for alternate energy sources, our nation is importing billions of barrels of foreign oil. Is sending billions of American dollars overseas. Is burning up our own dwindling reserves, in effect borrowing from our future.

I am not asking you for millions of dollars for some esoteric scientific pursuit in space. Nor am I asking for a blank-check we-can-get-to-the-moon-so-why-can't-we-solve-our-problems-on-Earth crash program.

I'm not even asking for favorite candidate status.

All I'm calling for is balanced funding commensurate with that given other energy program candidates. To date, space solar power has been short-changed, receiving less than five million dollars a year. This simply is not in line with expenditures on just about any other energy option. Nor is it enough to get on with the job.

Our studies show that the solar power satellite concept is extremely promising. But, as I've said before, promises won't light our lamps or power our machinery. We need hard facts, facts upon which we can base a rational energy development plan.

We've gone as far as paper studies can carry us. We need to get on to hardware verification. It is up to the Congress and the Administration to decide whether we move forward . . .

. . . or spin our wheels until we run out of gas.

SOLAR POWER SATELLITES

A Viable Energy Option

Supplement to statement of
O. C. Boileau, President,
Boeing Aerospace Company

Before the Subcommittee on
Energy Research and Development
of the Energy and Natural Resources
Committee, United States Senate
August 1978

SOLAR POWER SATELLITES

Introduction

Solar Power Satellites (SPS) offer a possible solution to our ever increasing energy problem. They utilize a nondepletable energy source and in addition provide a means of reversing the current unfavorable balance of payments while providing U.S. jobs. The National Aeronautics and Space Administration (NASA) and Department of Energy (DOE) have sponsored system studies performed by The Boeing Company and others which have indicated the technical feasibility of the SPS concept. It is now time to advance to a technology verification phase in order to confirm the study results and provide the data base for SPS power availability in the 1990's.

Boeing has developed an orderly three-step, five-to seven-year plan for SPS economic and technical verification. This plan begins with relatively low cost ground based laboratory studies, progresses to space testing of components, and culminates with a technical verification power unit in Earth orbit. Space verification testing will utilize the space shuttle. Economic and environmental studies will be conducted in parallel with the hardware testing to assure compliance with these important constraints. This plan and the associated costs are summarized here together with a brief SPS system description and an outline of economic considerations as they relate to the overall energy problem and an SPS solution.

Energy Economics

The United States paid approximately $200 billion in 1977 for energy and of this amount, $45 billion went overseas to purchase oil. A percentage breakdown of the total energy budget is presented in Figure 1. The outcome of this huge overseas expenditure resulted in a severe impact on our national balance of payments.

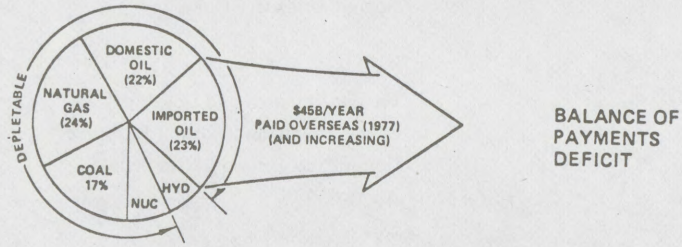


Figure 1. United States 1977 Energy Budget

The price of energy is constantly increasing, partly due to growing fuel scarcity and partly due to the actions of the international oil cartel. Energy is fundamental in the production of almost every product we use. For example, food production is dependent upon tractors and fertilizers, which both require energy. When the price of energy increases, it follows that the price of food will increase. Manufactured goods require energy for the factories that produce them. When the price of energy increases, so must the price of the goods, with the result that increasing energy cost drives national inflation. President Carter stated in November 1977 that, "The revelations about October's $2.4 billion balance of trade deficit are quite disturbing. We imported $3.7 billion worth of oil each month. This means that we have, if we don't import oil, about a $15 billion trade surplus per year. We have to cut down on the excessive importation of oil from overseas if we ever hope to get our trade balanced." The February 1978 trade balance was even worse, reaching a record $4.1 billion. It is obvious from these facts that the United States must develop a domestically controlled non-depletable energy supply if it is to stabilize and control its economy.

Figure 2 shows the historical price for three primary fossil fuels: natural gas, crude oil, and bituminous coal. Inflation is not included in this fuel price trend. The impact on a related commodity (electricity) is shown on the right. Costs of investment, operation and maintenance, etc., are shown as constant, but the increasing cost of fuel directly impacts the retail U.S. electric price as shown. Of course this simple chart cannot show the feedback effect as increasing energy cost raises the cost for new equipment in the electrical power plants.

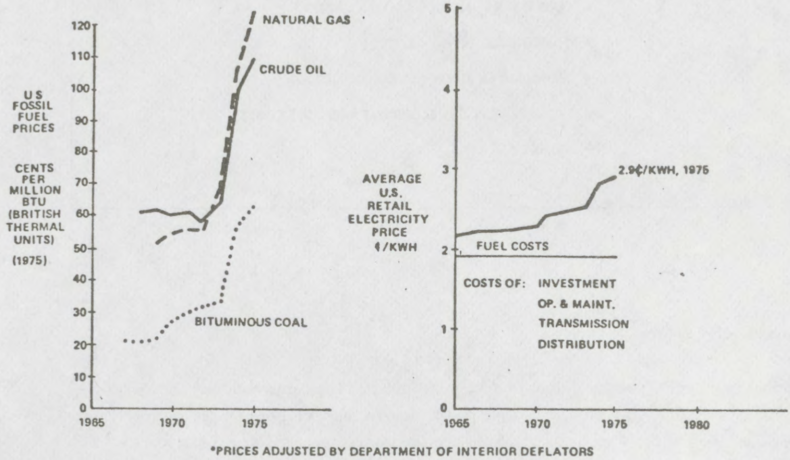


Figure 2. Symptoms of the Problem

It is clear that the energy trends shown in Figure 2 must be reversed if the United States is to cure the current balance of payments problem, stop energy induced inflation and provide the number of new jobs required to maintain a healthy economy. Table 1 lists the objectives of a long term energy solution. The primary objective of this solution is the reestablishment of a sound national economy. The table also presents the required characteristics of the solution.

Table 1. An "Energy Solution"

Objectives of a "Solution"

- REESTABLISH FAVORABLE BALANCE OF PAYMENTS
- PUT A "CAP" ON ENERGY-INDUCED INFLATION
- ALLOW CONTINUED ECONOMIC EXPANSION

Desirable Characteristics of a "Solution"

- MUST BE NONDEPLETABLE
- USE U.S. RESOURCES AND U.S. LABOR
- ADEQUATE ENERGY SOURCE
- MINIMAL ENVIRONMENTAL IMPACT
- ACCEPTABLE DEVELOPMENT AND UNIT COSTS
- TIMELY

Optional Energy Sources

A number of potential energy options to depletable oil based fuels are available. The "solutions" currently being studied are listed in Table 2. Only three of the "solutions" meet the criteria listed in the table. Two of these are nuclear options and the third is space solar. Breeder reactors are considered by many to be environmentally unacceptable, while the fusion reactors have yet to be shown technically feasible even though hundreds of millions of dollars have been expended in demonstration attempts.

Table 2. Potential Energy "Solutions"

ALTERNATIVE	NON-INTERMITTENT	NON-DEPLETABLE	NON-REGIONAL	
COAL	✓		✓	
WIND		✓		
OCEAN THERMAL	✓	✓		
GROUND SOLAR		✓		
BREEDER REACTORS	✓	?	✓	POSSIBLE "SOLUTIONS"
FUSION REACTORS	✓	✓	✓	POSSIBLE "SOLUTIONS"
SPACE SOLAR	✓	✓	✓	POSSIBLE "SOLUTIONS"

At this time, space solar power appears to be one of the most acceptable long range energy solutions from both a technical and environmental point of view. Studies have shown space solar power to be technically feasible with proven base technology and, even though all environmental issues are not resolved, current data indicate the system will be environmentally acceptable.

Based on the positive results obtained in SPS studies, it is time to proceed with an aggressive SPS technical verification program. To date, funding for the SPS program has been extremely limited (about \$5 million/yr) when compared to the nuclear alternatives (\$1 billion/yr). This lack of funding has prevented accumulation of the needed test data base and makes it impossible to accurately compare SPS to the nuclear systems. If an intelligent decision is to be made between existing alternative energy solutions, SPS research must be funded adequately through the technical verification phase.

SPS System Concept

The total SPS system concept includes provisions for transportation, satellite construction and operation, and power transmission, reception and distribution. The transportation system to be utilized during the technology verification phase will be the space shuttle. If the SPS system is shown to be economically and technically acceptable, heavy lift vehicles will be developed for the operational phase.

Figure 3 illustrates the principal of solar power satellites. The satellites would be located in geosynchronous orbit some 22,000 miles above the Earth. In this orbit they remain in one position over the equator and provide direct line-of-sight transmission of energy by radio beam to receivers on the Earth. In this orbit the satellites are almost constantly illuminated (over 99% of the time). The source of this energy is solar rays converted to electricity by an array of solar cells. The satellites are rather large, with areas of approximately 35 square miles. Their output is, however, proportionate to the size in that approximately 10 million kilowatts of power are provided by each. The power output is equivalent to about ten nuclear power plants. The satellite shown is equipped with two transmitters and serves two Earth receiving sites (5 million kilowatts per site). Satellite sizes down to approximately 2.5 million kilowatts per receiver appear economically practical. The constancy of output of the ground receivers, without the effects of night and weather, provides baseload electrical power.

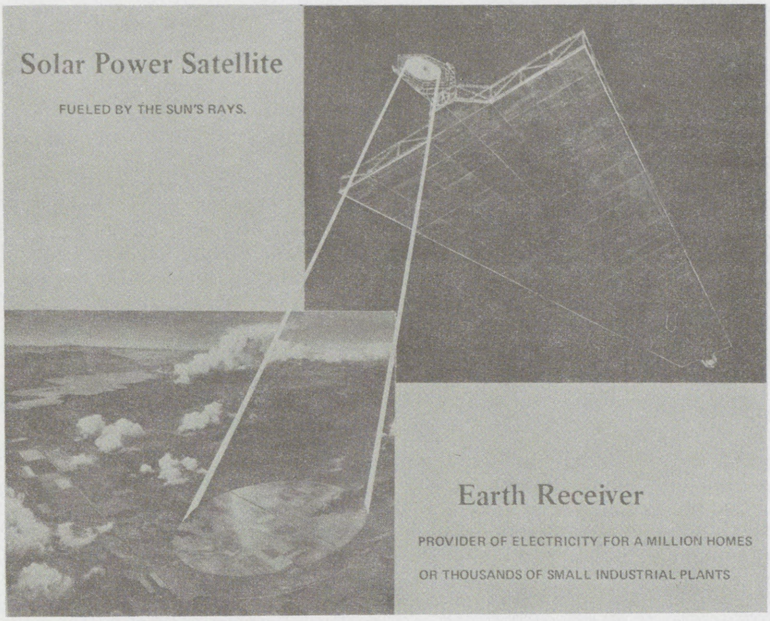


Figure 3. The Solar Power Satellite Concept

The development of an operational SPS system is a large engineering job but no major technological breakthrough is required. Most of the key hardware elements exist and are available to be scaled-up and tailored for the new SPS application. Mass production of these improved, scaled-up elements should reduce unit costs and conform to projected SPS economics. There are many examples of currently available SPS technology elements. Solar cell use on satellites has been routine for nearly 20 years, microwave transmission by radar and television has been in use for over 40 years, light-weight structures for aircraft and spacecraft are an accomplished fact as are high voltage switching gear and terrestrial power transmission facilities. The fact that SPS base technology, as demonstrated by the above examples, is available does not imply that SPS will not have to meet major technology challenges. However, the availability of SPS base technology does show that the primary elements necessary for development are either in hand or at least well within reach.

SPS Study Results

As stated earlier, Boeing has been conducting studies on SPS and related systems for the past six years. These studies are listed in Table 3. The most significant results of a recent study are shown in Table 4. The study also documented the critical technology questions that must be verified by hardware testing. By concentrating on a maximum confidence system design, the study results showed SPS to be achievable by the year 2000 and to be economically attractive. After completion of the technology verification effort outlined in the next section, and assuming success, full scale development could begin and would provide a mainstream energy system of great potential.

Table 3. Boeing SPS related Study Areas

Contracts	IR and D
Solar Power Satellite System Definition Heavy Lift Vehicle Definition Heavy Lift Launch Vehicle Definition Launch Vehicle Environmental Effects Shuttle Derivatives Tech. Req. For Earth to Geo. Trans. System Future Space Transportation System Analysis	Solar Cell Development Launch Facility Analysis Large Structures Analysis Propellants Avionics Flight Control Antenna Development Materials Evaluation Logistic Analysis Power Distribution and Control

Table 4. Synopsis of Study Results

Power Transmission
- Basic Feasibility Confirmed
- Detailed Microwave Link Error Analysis Confirmed Attainability of Adequate Efficiency

Energy Conversion
- Silicon Photovoltaic Best Overall Choice
- Potassium Rankine Backup Choice

Space Transportation Operations
- Low Cost Due To Traffic Level, Not New Technology
- Payload Volume is Launch Vehicle Design Driver

SPS System Costs
- Power Cost 4 to 5 cent/kWh; Competitive with Fossil Sources by Year 2000
- System Design Flexibility Key To Cost Confidence

Technology Advancement and Verification Program

The objective of the Technology Advancement and Verification Program is to advance required technology and provide data to confirm hardware concepts used in SPS system studies and to further verify system economics. The test data will then be available for use in making future SPS go, no-go program decisions and comparing alternative energy systems to allow informed decisions as to future energy sources.

The technology program is divided into three phases including the: (1) Ground-Base Phase, (2) Flight Test, and (3) Technical Verification Power Unit. Establishment of firm designs, performance levels, cost expectations, development requirements, and environmental acceptability, depends on the achievable characteristics of several critical technologies. Although overall success of SPS development is possible over a range of performance of these technologies, establishment of specific attainable performance levels is important to establishment of designs and system specifications. Accordingly, technology verification presently can be regarded as a key schedule constraint for potential availability of SPS-derived energy. Because of this importance of technology verification, detailed recommendations have been developed.

Funding for each phase has been estimated separately since the Phase 2 (flight test) and Phase 3 (power unit) will not be initiated until positive economic and technical results are obtained during the Phase I ground testing. Estimates of required funding for the ground tests are presented in Table 5. As may be seen, first year funding is $25 million. Since the Flight Test program can not be fully defined until some results are obtained from ground testing, the costs are less well defined but are estimated in the flight test section. The funding levels for both test phases are limited to hardware development and testing.

Table 5. SPS Five Year Ground-Based Technology Development Plan*

TECHNOLOGY AREA	YEARS 1	2	3	4	5	TOTAL
o SOLAR CELLS	2.5	3.6	3.85	3.7	2.6	16.25
o THERMAL ENGINES & THERMAL SYSTEMS	2.5	3.5	3.75	3.5	2.5	15.75
o MICROWAVE POWER TRANSMISSION SYSTEM	6.0	7.5	8.75	8.5	6.5	37.25
o SPACE STRUCTURES	0.75	2.0	2.2	2.0	1.8	8.75
o MATERIALS	1.5	2.0	2.5	2.0	2.0	10.0
o FLIGHT CONTROL SYSTEMS	0.75	0.8	1.0	0.9	0.8	4.25
o CONSTRUCTION SYSTEMS	3.0	4.0	4.5	5.5	5.5	22.5
o TRANSPORTATION SYSTEMS	4.5	7.5	8.75	7.5	7.5	35.75
o POWER DISTRIBUTION AND CONTROLS	1.5	2.0	2.5	3.5	2.5	12.0
o SPACE ENVIRONMENTAL FACTORS	2.0	2.6	2.45	2.2	2.0	11.25
TOTALS	25.0	35.50	40.25	39.3	33.7	173.75

* Does not include any required space testing
Funding in millions of dollars

Environmental and socio-economic issues will also be very important selection criteria in any comparative evaluation of optional energy systems and a need exists for additional data to fully evaluate these parameters. This is especially true of environmental effects in the area of microwave transmission. As a result, a research approach was developed to study terrestrial ecological effects of microwaves. A summary of this approach is presented in a separate section together with a program schedule and estimated funding level.

Ground-Based (Non-Flight) Technology Verifications

General areas selected for testing include solar cells, materials, structures, thermal engines and systems, power distribution controls, microwave power transmission systems, flight control systems, space transportation, space construction operations, and space environmental effects.

Solar Cells

If sufficiently low costs can be achieved, solar cells are preferred for energy conversion. Recommended solar blanket technology efforts include automated cell production by conventional and novel means, automated blanket assembly, development of prototype blanket element designs, radiation effects investigations and solar cell annealing, high voltage array operation, and advanced solar blanket (e.g., gallium arsenide) development.

These technology developments will confirm solar cell and blanket design parameters, performance and production methods and increase confidence in costs, providing a sufficient knowledge base to allow preparation of solar blanket hardware design specifications appropriate to an SPS program. Recommended funding in the first year is $2.5 million with aggregate over a five year program of $16 million.

Thermal Engines and Thermal Systems

Until near-term low cost production of photovoltaic solar blankets is assured, it is prudent to carry a backup technology program for the thermal engine energy conversion option. Recommended efforts include engine design studies and critical component testing, automated space welding/brazing techniques, solar concentrator model testing, meteoroid penetration testing, zero-g heat transfer investigations, and lightweight generator technology development. Most of these technology areas are applicable to SPS design and development even if thermal engine SPS's are never built.

These activities will establish design parameters, subsystem performance, and provide a sufficient knowledge base to allow preparation of thermal engine and other design specifications appropriate to an SPS program. Recommended funding in the first year is $2.5 million and the aggregate over five years is $16 million. Given early success in the photovoltaics effort, the thermal engine technology effort could be reduced in scope.

Microwave Power Transmission System

The power transmission system is at the heart of the SPS system. Its performance and operating characteristics are critical to establishment of the overall system design parameters as well as cost estimates. The design of the power transmitter requires integration of interacting structural, electrical, RF, thermal control, and flight control parameters. Although there is considerable design flexibility in the RF system in terms of altering design parameters to adapt to component/subsystem performance levels, successful operation of a design, once the parameters are set, is dependent on achieving specified component/subsystem performances. Therefore, technology verification in this area is particularly important.

Specific items include development of laboratory prototype RF amplifier tubes, phase control circuitry, and antenna subarray hardware, leading to a prototype integrated subarray, supplemented by ionosphere heating tests, radio frequency interference testing and design standards development, exploratory development of high efficiency, high temperature solid state amplifiers, and development of receiving antenna elements. The recommended verification program will provide the knowledge base for subsystem/component specifications and for selecting system design parameters. Recommended funding in the first year is $6 million dollars; the aggregate over five years is $37 million.

Space Structures

Fabrication and tests of representative structural elements and joining devices should be conducted to establish confidence in prediction methods for structural strength and dynamics for these thin gage lightweight structural elements. Tests and analyses are also needed to improve predictions of structural thermal response and precision in the operating environment. Achievement of very small structural responses to thermal fluctuations can greatly simplify SPS design, especially in the power transmitter. Recommended funding in the first year is $0.75 million; the aggregate over five years is $8.75 million.

Materials

Materials testing and development are recommended in the areas of plastics and composites, life and properties in the space environment, bonding and fastening techniques for space construction, moderate-to-high temperatures composites, thermal control and other coatings, and special-purpose alloy development.

These technology items are required for selection of materials, setting of allowable stresses and other design conditions, and detailing of space assembly processes, appropriate to achievement of SPS designs suitable for 30 to 100 years operating life. Recommended funding in the first year is $1.5 million and the aggregate over five years is $10 million.

Flight Control Systems

A development effort on theory, algorithms, and software is needed to add confidence to the techniques appropriate to control the large, flexible SPS spacecraft. A small effort on sensors is also appropriate. Recommended funding in the first year is $0.75 million, with an aggregate of $4.25 million over the five-year period.

Construction Systems

Construction of SPS's will involve the operation of a final assembly factory in space. Critical technologies include automated fabrication of space structures, closed life-support systems, means of in situ structure integrity verification, docking and berthing of large space systems, development of construction operator accommodations and provisions, and construction base onboard logistics systems. These activities will provide technology verification support development of construction bases and their equipment inventory. Recommended first-year funding is $3 million and the five-year aggregate is $22.5 million.

Transportation Systems

Achieving projected low costs for space transportation is important to economic attractiveness of SPS power. Studies have verified, to the extent possible by study, these low costs. Key technology verification needs include zero-g propellant transfer, a new booster engine, high-power electric propulsion, fully reusable (e.g., water-cooled) launch vehicle heat shields, oxygen/hydrogen-fueled auxiliary propulsion, and on-orbit servicing of vehicles. (The recommended work on the last item involves design studies for checkout, maintenance, and hardware changeout equipment and techniques.) The booster engine will be the schedule limiter for the advanced launch vehicle system. Upper stages can use the space shuttle main engine. The recommended technology effort will support the initiation of development of the low-cost transportation system. Recommended first-year funding is $4.5 million with a five-year total of $36.5 million.

Power Distribution and Controls

Electrical systems technology items include fast switchgear and components for RF amplifier arc suppression, high efficiency lightweight power processors (about 15% of the SPS onboard power requires processing), conductors, high-temperature semiconductors, high-power slip rings and lightweight electric power storage. These activities are needed to select and establish electrical power distributions and processing design parameters and to permit preparation of design specifications. Recommended funding in the first year is $1.5 million, the aggregate over five years is $12 million.

Space Environment

A modest study and analysis effort to improve knowledge and predictability of space environment effects is needed. Included are meteoroid, plasma and fields, and energetic radiation. Recommended first-year funding is $2 million for a five-year total of $11 million.

Flight Test Technology Verification

The recommended flight program is presented below and is illustrated in Figure 4. It includes an interferometer spacecraft experiment, shuttle sortie flights, followed by a 250 kW to 1 MW technology verification power unit constructed and tended in low Earth orbit by the space shuttle. Costs for this program are less well defined; estimated totals are $50 million to $100 million for the interferometer spacecraft, $675 million for shuttle sorties, and $2.1 billion for the power unit including design, development, launches, construction, and the complete experiment program.

Fabrication Tests

Objective–Demonstrate in the space environment all critical fabrication processes to be used in the space construction of SPS's:

Specific Tests–

- Structure (beam) fabricators
- Mechanical fastening
- Fusion welding and brazing
- Ultrasonic welding of composites
- Bonding

Implementation–Shuttle sortie flights.

Environment

Objective–Improve definition of space environmental factors important to SPS construction, operation, and life.

Specific Tests–

- Metals, plastics, and composites outgassing and properties changes under representative SPS conditions.

Implementation–Shuttle sorties and geosynchronous long duration exposure facility (LDEF). The latter could be placed at geosynchronous orbit by an Inertial Upper Stage (IUS) and samples later retrieved by a manned geosynchronous sortie when the latter capability is developed.

35-994 O - 79 - 7

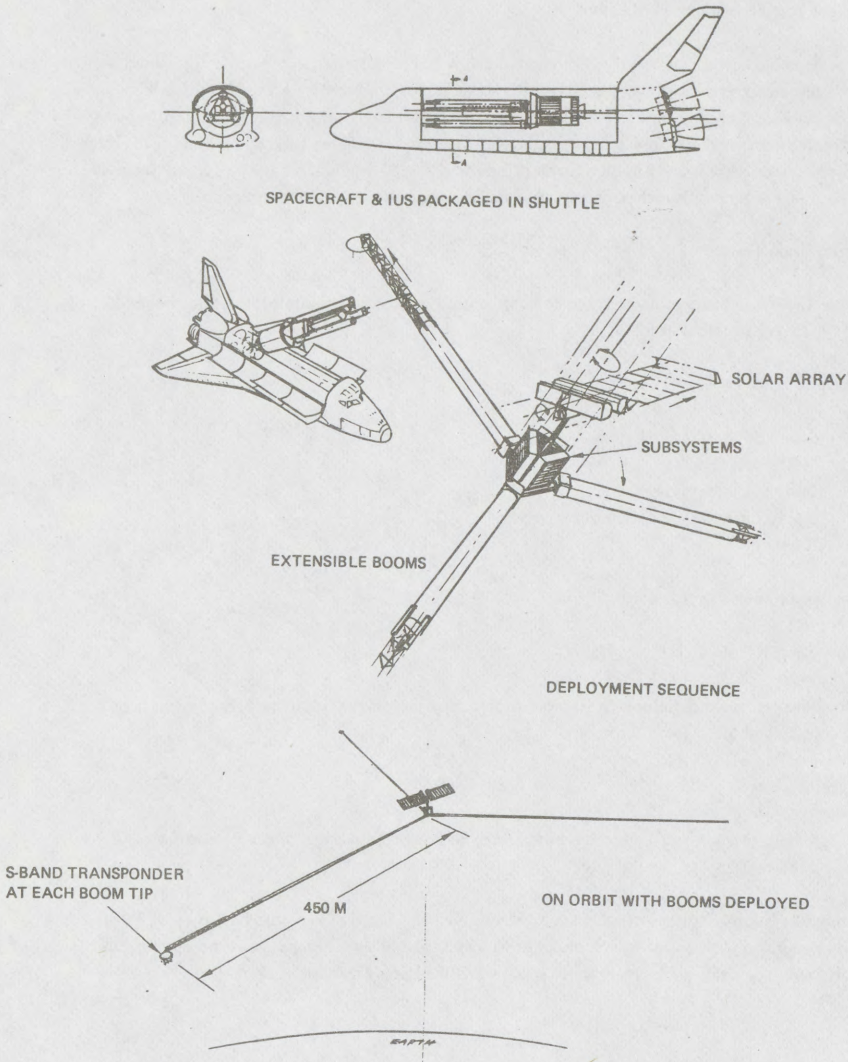


Figure 4. Interferometer Spacecraft Concept

- Space plasma and radiation environments–emphasis on better definition of low to moderate energy radiation environments and plasma effects.

Implementation–Measurements aboard suitable spacecraft. Existing programs such as the Space Charging Test at High Altitude and the International Sun/Earth Explorer programs can provide much of the needed information.

- RF/microwave propagation–Signal-power-level simulation of power transmitter beam steering and phase control over actual geosynchronous range.

Implementation–Shuttle/IUS-launched geosynchronous microwave interferometer spacecraft. The spacecraft concept is shown in Figure 4. RF transponders on the boom tips would simulate the large aperture of the power transmitter. The transponders would be synchronized and phase controlled by methods being tested for power transmitter application. Ground measurements of the interference patterns produced by the interferometer transponders would determine the performance of the phase control techniques.

SPS Power Generation and Power Transmission

Objective–Demonstrate critical technology applications and operation in the space environment.

Specific Test–

- Power generation–operate large solar arrays at moderate to high voltage.

- Power transmission–operate prototype klystron modules in space conditions. Test open and closed envelope tubes. Measure and assess RF arcing problems in evacuated waveguides under various temperature and outgassing conditions.

- Electric propulsion–test high power (approximately 100 kW) thrusters. Measure thruster plasma/solar array interactions.

- Space-based solar cell annealing tests.

Implementation–

Initial–Shuttle sortie flights.
Culmination: 250 kW to 1 MW power unit in low Earth orbit.
(Thermal environment tests may require operation of up to nine 70 kW klystron modules requiring about 500 kW_e) Array voltage switchable up to 3,000 volts. "Test bench" configuration to allow conduct of various power generation, power transmission and propulsion tests.

Annealing tests could be preceded by electric-propelled power unit sortie into lower van Allen belts with return to 450-500 km orbit for tests.

The Technical Verification Power Unit test program will primarily be automated with support by periodic shuttle sortie flights.

The total ground and flight program is summarized in Figure 5.

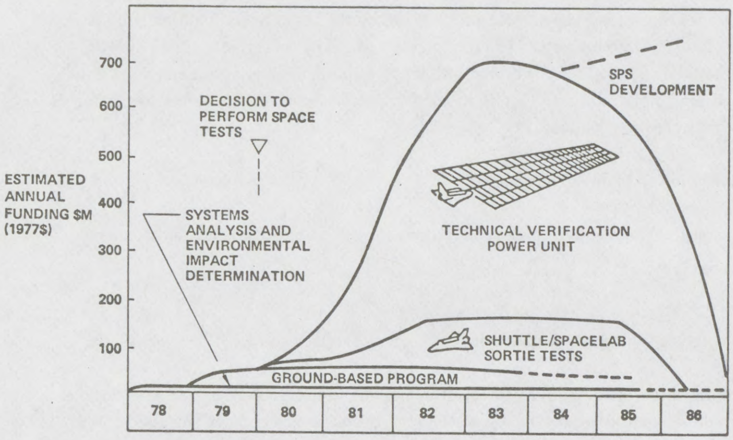


Figure 5. The Verification Phase: First Step to SPS

Microwave Environmental Study Approach

Funds have not been included for terrestrial environmental studies within the first year's $25 million. Additional funds should be made available. Environmental questions on microwave transmission are some of the more important considerations that must be addressed during development of a Solar Power Satellite (SPS) system. Possible environmental effects extend from satellite operation to atmospheric transmission and terrestrial ecological interactions. Significant SPS environmental effects are not anticipated because of the relatively low microwave energy levels being considered; however, all possible effects, both good or bad, must be reevaluated in the context of the SPS design to resolve outstanding environmental questions. Information on terrestrial environmental effects of microwaves is extremely limited. A summary is presented here outlining an approach to obtaining required terrestrial environmental data. This approach includes a facility concept for use in conducting pertinent research together with estimates of costs and schedule. First year funding is estimated at $4 million.

Experimental Approach

Limited data are available on biological effects of microwaves at the intensities and frequency required for a total SPS ecological assessment. Further research is required to expand the data base and obtain information in a form that is adaptable for inclusion in an SPS environmental impact report. Most of the available data obtained from past studies are fragmented since they were obtained under widely varying experimental conditions with diverse types of dosimetry. Also, the studies were usually of short duration measured in hours or days and did not evaluate long-term exposures of weeks or months.

The approach recommended here is believed to be the most direct and economical method of providing the information needed for the SPS program. This approach involves a total environmental simulation to determine first, if any problems actually exist when diverse groups of organisms are exposed to the relatively low level microwave fields produced by the SPS system. The simulation will be conducted on a large enough scale and for a long enough time period to determine if measurable effects occur under actual field conditions. The investigation will allow for the study of individual organisms as well as heterogeneous groups of organisms to determine group interactions. If, under actual field conditions isolated effects are observed, then laboratory studies can be initiated to determine the cause. The experimental objective of this approach is to determine if any significant environmental effects occur, whether benificial or harmful, under conditions expected at an SPS rectenna site.

Two basic types of simulations are required to implement the approach just outlined. The first (Type I) simulation will be a study of microwave exposure levels expected on the ground both in and around the rectenna site. This study should provide all of the required plant data and at least 95 percent of the data required for animal exposures. The test will be conducted at a frequency of 2.45 GHz and an exposure level of 1 mW/cm^2. One milliwatt per square centimeter is selected because it is at least an order of magnitude above the calculated ground exposure level under the rectenna, or at the exclusion fence line or at the "1st side lobe Peak".

The Type II simulation will be conducted at the same frequency as Type I but at a microwave beam intensity of 23 mW/cm^2. This simulation will be designed for studies of flying insects and birds. Nesting bird studies will be conducted under the Type I conditions. Type II exposure times will be relatively short in duration since bird flight through the six-mile diameter beam will be on the order of minutes. Longer exposure periods may be required for specific insect studies.

Simulation Facility

A simulation facility will be required to implement the outlined research program. Figure 6 illustrates one such facility with which the research objectives can be achieved. The facility shown is designed for Type I simulations but can be readily modified to accomodate Type II work. Microwave exposure is provided by microwave oven magnetrons strung on poles over an experimental field. Other types of microwave sources may be used; however, the illustrated concept appears to be a reliable and relatively inexpensive method of conducting the investigation and will be used here at the 1 mW/cm^2 exposure level as a baseline for discussion. The important point to be illustrated in Figure 6 is not so much the particular microwave generation technique as it is the integrated approach to the research.

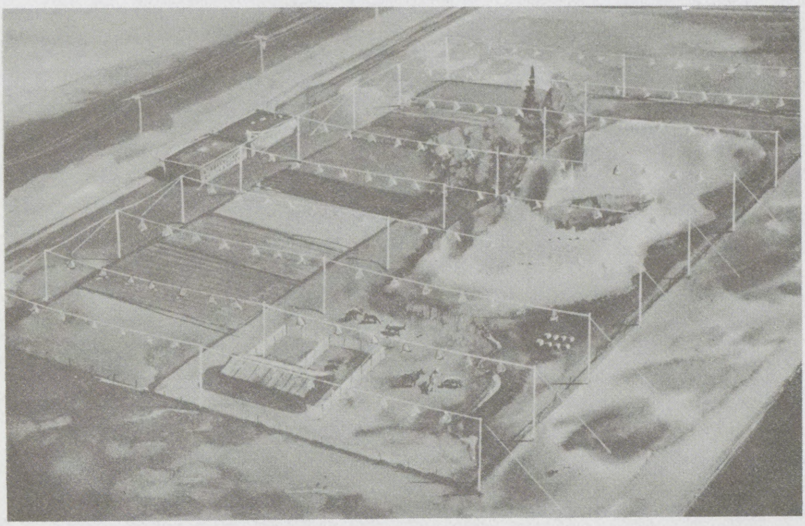


Figure 6 Microwave Environmental Simulation Facility

System Concept: The Type I simulation concept is one of a large outdoor area with agricultural provisions and corrals for animals. The area is "flooded" by a fairly uniform incident electromagnetic "field" (the term in this case means "region of influence"). The electromagnetic field is obtained from a multiplicity of microwave power sources (magnetrons) which derive their power from a high voltage distribution system. The microwave sources, (or tubes) are supported overhead by a lattice of wires which also supports the high voltage distribution system. Engergy from each microwave oven magnetrons is directed by a horn which "focusses" the energy in a roughly vertically downward direction.

It is proposed to provide an environment of 1 mW per sq. cm at a frequency of 2.45 GHz. To accomplish this, each microwave source (or magnetron) will irradiate an area ten meters on a side, from a height which is somewhat optional –say four meters. By the nature of the configuration, the actual exposure area to be covered by the facility is very flexible with cost being roughly proportional to the experimental area. The size can be determined by the biological considerations of the experiment. The concept provides "incoherent" illumination of the area with overlap or fringing of the energy from each magnetron as it reaches the ground. The net effect will be to provide an average level of intensity of $1 mW/cm^2$ with slight variations as one moves across the field. DC high voltage power and AC filament power for the magentrons are supplied from a power building located at the side of the facility. Distribution is by wire along with support lattice, which itself is supported by wood telephone poles around the perimeter.

Experimental Method

A reasonable start toward answering the SPS environmental questions can be made by constructing a four acre Type I exposure facility. Because of the flexibility of the approach just described, this facility can be expanded in size at any time if required. Initial experiments can be conducted at $1 mW/cm^2$ at a frequency of 2.45 GHz on both plants and animals. An additional Type II facility, based on the wind tunnel concept for flight experiments, can also be constructed at the same time. The latter exposures will be at $23 mW/cm^2$.

Careful controls must be maintained during all microwave exposure experiments. These controls would be conducted for both plants and animals in a four acre unexposed field adjacent to the exposure facility. A bird flight tunnel, without exposure equipment, would also be required to control this portion of the experiment. Additional controls, such as infrared exposure facilities to simulate microwave heating, would initially not be required during simulation since the experimental question being asked is, "do changes occur." If changes are observed, the causes would be determined in later experiments, if deemed necessary.

The time period for which the exposure experiments should be conducted is a complex question. The appropriate experimental time period will vary widely depending on the organisms being studied. Ideally, each experimental organism would be studied over several generations. This is not a problem where microorganisms, many insects and some plants are concerned. However, the criteria of "several generations" may be impractical for many higher plants and animals. It is suggested that a three year field simulation will be adequate to answer most of the questions required to complete an SPS environmental impact report.

Program Approach

The objectives of this program can best be met by a team of experts assembled from universities, government and industry. This team can supply the expertise required to design and conduct a research effort of this complexity. In addition, a diverse team of this composition will be able to interpret the wide range of data generated and will provide credibility to the results.

The program can be conducted in five phases. These phases include:

Phase I - Experimental Design and Baseline Data

Experts in various biological fields will design experiments that then will be integrated into a total test matrix to maximize data from the research facility. For example, honey bee experiments would be integrated with those being conducted with flowering plants. Limited baseline laboratory work would be conducted to assure adequate field measurements and control. Additional personnel such as soils experts would also be included on the research team.

Phase II - Facility Design and Construction

This phase would be conducted in parallel with Phase I. A site would be selected that is representative of an SPS rectenna site and preferable on government land to reduce the program costs. The facility would be designed, constructed and checked out during this phase.

Phase III - Field Simulation

The simulation tests would be conducted under the supervision of the research team, data collected and upon completion, a report prepared.

Phase IV - Laboratory Confirmation

This phase may or may not be required. If effects are observed during Phase III that require clarification before an environmental impact report can be prepared, the studies would be conducted during this phase.

Phase V - Environmental Impact Report

Data obtained during the test program will be incorporated with other pertinent environmental information to complete the report.

Program Schedule

Regardless of the amount of time devoted to this type of research program it is impossible to answer all questions. There is always another "what if". It is believed that adequate time has been allowed to obtain sufficient data to determine if major terrestrial environmental obstacles are present in the SPS program. The six and one half year program schedule is presented in Figure 7.

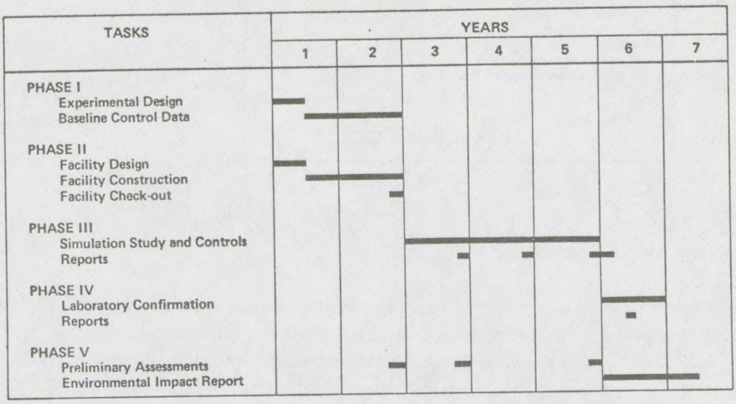


Figure 7. Program Schedule

Program Costs

Microwave exposure facility costs estimates are presented in Table 6. These costs are considered good planning numbers. Table 6 also contains estimates of the total program costs. Since the experiments are not yet fully defined nor the facility site selected, accurate estimates are difficult. If the critical environmental questions are to be answered for SPS, contract dollars of the magnitude presented in the table will be required. The terrestrial microwave environmental study is separate from the hardware Technology Verification Program and will require additional funding not included in Table 5.

Table 6. Program Cost Estimates

ITEM	ESTIMATED $ X 1000
PHASE I	
Experimental Design	500
Baseline Control Data	2,000
PHASE II	
Facility Design	250
Facility Construction	1,500
Facility Check-out	250
PHASE III	
Simulation Study	9,000
Reports	500
PHASE IV	
Laboratory Confirmation	1,000
Reports	100
PHASE V	
Preliminary Assessments	400
Environmental Impact Report	1,000
Sub-Total	$16,500K
Contingency	2,000
TOTAL	$18,500K

Solar Power Satellite Program Conclusions

The SPS concept was proposed approximately ten years ago. Boeing has been actively engaged in SPS studies for the last six years. System studies performed by various government agencies and industries have shown SPS to be both technically feasible and potentially economical. Based on these studies, Boeing has developed a SPS program plan that can lead to a fully operational SPS by the mid 1990's. This plan, summarized in Figure 8, has the required key features for assessment, design, development and construction and includes appropriate decision points for program advancement.

The plan begins with an Environmental and Social Assessment task that will be conducted concurrently with a ground based Technology Advancement task. The concurrent phasing is important since each of these tasks may provide input to the other. While much of the assessment of environmental effects of the microwave power transmission system will depend on analyses and tests conducted expressly for that purpose, certain aspects of SPS technology advancement will also influence this assessment. Examples of these aspects are: (1) the determination of phase control precision capability, which influences the amounts of scattered microwave energy, both relating to biological effects of low level energy and radio frequency interference effects, and (2) achievable spectral purity and associated noise and harmonic suppression.

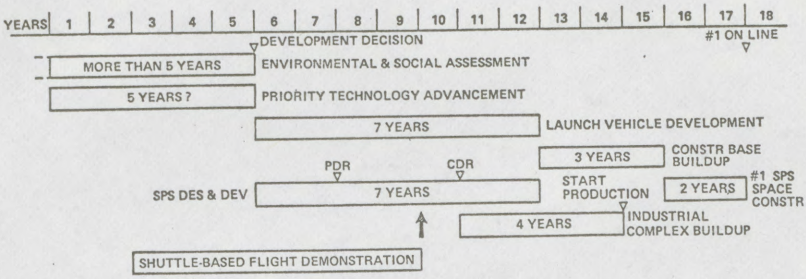


Figure 8. Key Features of an SPS Program

The plan also includes a Shuttle-Based Flight Demonstration program that will start near the completion of the Environmental and Social Assessment phase and extend into the Design and Developmental phase. The major flight projects involve space flight experiments and demonstrations conducted using the space shuttle to confirm and verify technology for SPS. Since these projects are basically of a confirmatory nature, it is presumed that their results may be fed into the SPS development activity as late as two years after the preliminary design is established. This approach will accelerate the overall SPS program while assuring an acceptable level of technical risk.

The previous SPS studies have shown that the required base technology is available today. It is now time to start an active technology advancement program and to initiate system verification and environmental testing at significantly increased funding levels. The data resulting from these tests will be used for further economic confirmation of the SPS system. After testing has answered many of the technical, environmental and economic questions, a decision point will be reached. The point will be the determination of whether or not to move into a developmental phase of a full scale SPS, thus allowing for delivery of usable electrical power to the United States in the 1990's.

TESTIMONY

OF

GRANT HEDRICK

SENIOR VICE PRESIDENT - GRUMMAN AEROSPACE CORPORATION

BEFORE THE

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

AUGUST 14, 1978

Mr. Chairman and Members of the Committee:

My name is Grant Hedrick and I am a Senior Vice President for Technology Development of the Grumman Aerospace Corporation.

I am pleased to have the opportunity to speak in support of Bill S-2860 for the exploration of a Solar Power Satellite concept (Figure 1). We at Grumman have been working with A. D. Little, NASA, Boeing and others since the early 1970's on the development of this concept for supplying power from space, and we are encouraged by the progress that has been made during these years.

Our nation's energy resources are not limitless. Our President has already expressed concern regarding the degree of dependence on Mid-East oil. We are not alone in this regard. Japan and the NATO countries are equally dependent. Moreover, there is serious concern regarding our mutual ability to guarantee the security of the sea lanes to these resources in the event of an unexpected crisis. The very existence of such vast amounts of Mid-East oil reserves and our continued dependence on this supply is a temptation to any aggressor and a liability to our national security. In order to meet the continued demand for greater amounts of power, we need not only to manage our resources carefully and eliminate waste using modern conservation techniques, but also we need to develop alternate energy sources to replace our dwindling supply of domestic liquid fossil fuels.

We at Grumman have been applying aerospace technology to programs in support of these principles for several years. We have performed energy conservation studies for the Federal Government, schools and commercial industries that will produce annual savings of 65 million gallons of fuel oil. We are currently producing and marketing solar collectors for hot water heating systems for homes (Figure 2) and industrial use (Figure 3). We have designed, developed and sold, to a limited market, several windmill designs in the 25' diameter, 20KW power range (Figures 4 and 5). We have proposed to design, build and operate a modern waste disposal plant that will produce useful steam energy for industry in the greater Louisville area. We have recently completed the initial preliminary design studies of this plant (Figure 6) under contract to Jefferson County, Kentucky, and are awaiting a go-ahead for detailed design and construction.

We are teamed with the Ebasco Company to design and develop the Tokamak Fusion Test Reactor (Figure 7) for the Princeton Plasma Physics Laboratory. This Tokamak is scheduled for completion in the early 1980's and could become the first device to produce substantial quantities of fusion energy by burning deuterium-tritium fuel.

The energy programs we are engaged in are at different stages of their development. The solar collectors, windmills, waste disposal plants and energy conservation services are available on the market today. Our programs on nuclear fusion and Solar Power Satellite are in the exploratory stage and may not reach a commercial stage for some time to come. Nevertheless, we believe that continued systems studies, technology demonstrations and detailed program planning are essential to making the best decisions for our country's long range energy supply. Senate Bill, S-2860, which we are discussing today takes a positive approach toward solving the problems associated with the Solar Power Satellite concept that must be overcome in order to design an economically attractive electric energy system.

I am aware that there is serious concern in some quarters regarding potential adverse environmental effects of the SPS system such as atmospheric contamination or the effects of microwave exposure on communication and on growing things as well as humans. Much work has been done in these fields and additional studies should be performed to quantify these effects so that we may understand their true impact. Program costs have also been a matter of some concern. As is the case in most large scale high technology development programs, the ultimate program cost cannot be clearly determined at early stages of the concept. We believe that this points up the importance of proceeding in a step-wise fashion according to a well defined program plan to develop the proper confidence before proceeding to a large scale demonstration program.

The House Bill recently adopted and the Bill before us today provide these assurances and at the same time provide the support for a more vigorous overall exploratory program.

Several key issues should be resolved in the next few years. The development of solar energy conversion techniques should be aggressively pursued in order to improve efficiency and reduce costs. Methods of fabrication and assembly of large space structures (Figure 8) should be developed, tested on the ground where feasible and plans made for in-flight verification. The transmission of microwave power (Figure 9) and its interface with the ground electrical grid require a more detailed understanding. Materials research is required to continue development of new lightweight high strength materials capable of withstanding long duration exposure in geosynchronous orbit. Additional studies should be undertaken to better understand the environmental impact of Solar Satellite Systems on the atmosphere, human health and valued natural resources. Development program planning, shuttle payload definition and operational prototype system studies should be continued. In short, an aggressive effort is required on a broad technological front to provide insight for our future decisions.

Many of the near term objectives can be achieved with a ground based program, and will strengthen the base from which predictions of the SPS system performance can be estimated. These early program activities will provide the foundation for downstream shuttle sortie missions and later, an end-to-end demonstration in space assuming experimental results at each intermediate milestone continue to be encouraging.

We recognize that good work is now underway by DOE and NASA in performing some SPS studies and examining some of the environmental issues. We believe that this work should be continued vigorously and that the additional vital technology effort should be included in the program plan.

We are impressed that the SPS Program offers a unique opportunity for international cooperation during early development stages as well as during actual deployment. Individuals in Japanese government and industry have shown a keen interest in the development of a Solar Power Satellite System.

I visited Japan in the spring of this year at the invitation of the Keidanren (Federation of Economic Organizations). The Keidanren is an association of major Japanese companies that plays and active role in determining Japanese world trade policy.

These people met with us for two days to discuss in considerable detail the status of the technologies and overall concept development of the SPS. They clearly indicated their interest in exploring Japanese participation in SPS evaluation. As a measure of their

35-994 O - 79 - 8

interest they have applied for membership in the Sunsat Council, a non-profit U.S. organization organized to foster SPS development through educational programs.

I had the opportunity to visit a Japanese industrial plant engaged in solar cell production. Their efforts aimed at increasing production rate at low cost showed considerable promise and reflected Japanese interest in developing alternate energy sources.

I believe that the SPS development program plan as called for in the Senate Bill would aid in defining tasks that could be undertaken by foreign countries in a manner similar to the nuclear fusion cooperative efforts now underway between the DOE and its foreign counterparts.

In summary, we believe that S-2860 will maintain program momentum by providing a focus for the supporting technology development, providing more vigorous funding and developing an overall program plan against which progress can be measured and more refined cost estimates can be determined. We join with the distinguished sponsors of the Bill and other supporters in urging its approval.

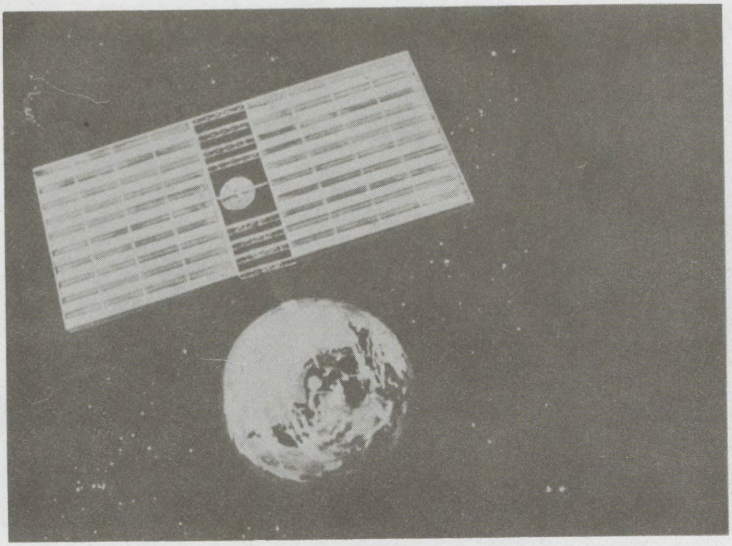


Fig. 1 Solar Power Satellite

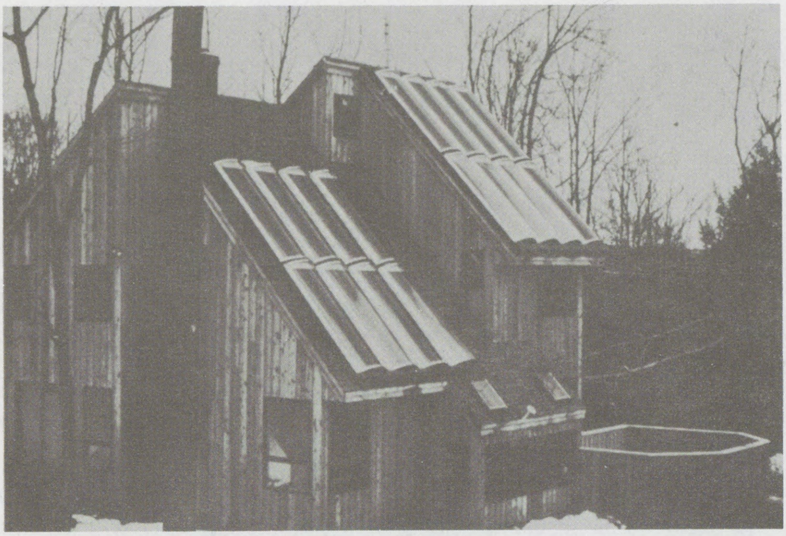


Fig. 2 Solar Collector, Domestic

Fig. 3 Solar Collector, Industrial

Fig.4 Windmill, New York State

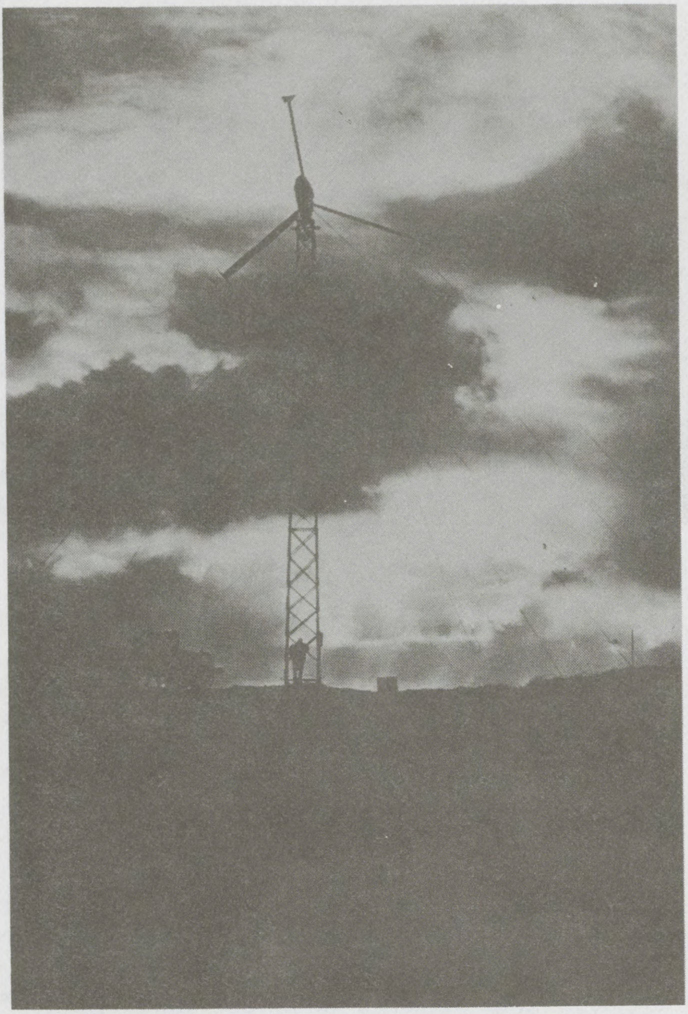


Fig. 5 Windmill, Alaska

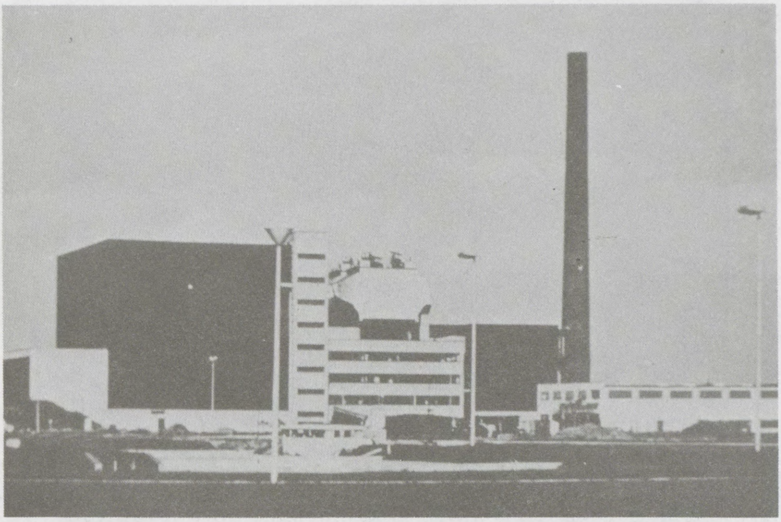


Fig. 6 Waste Disposal Plant

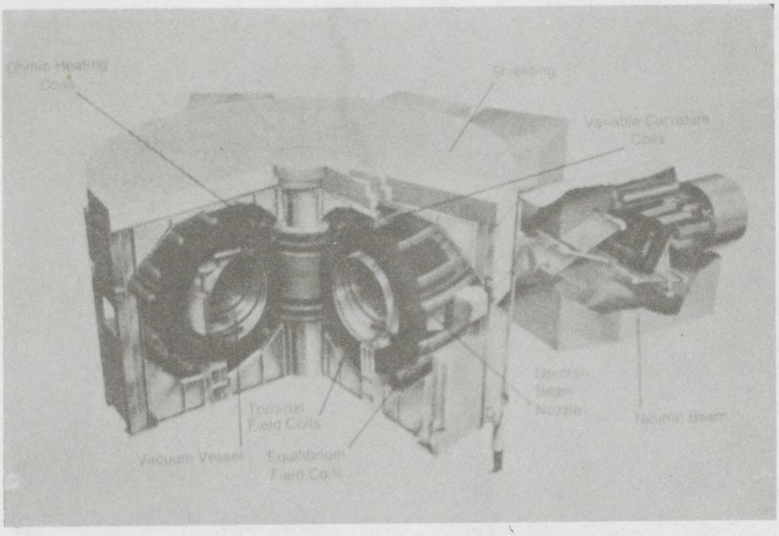


Fig. 7 Tokamak Fusion Test Reactor

Fig. 8 Large Space Structures Simulation

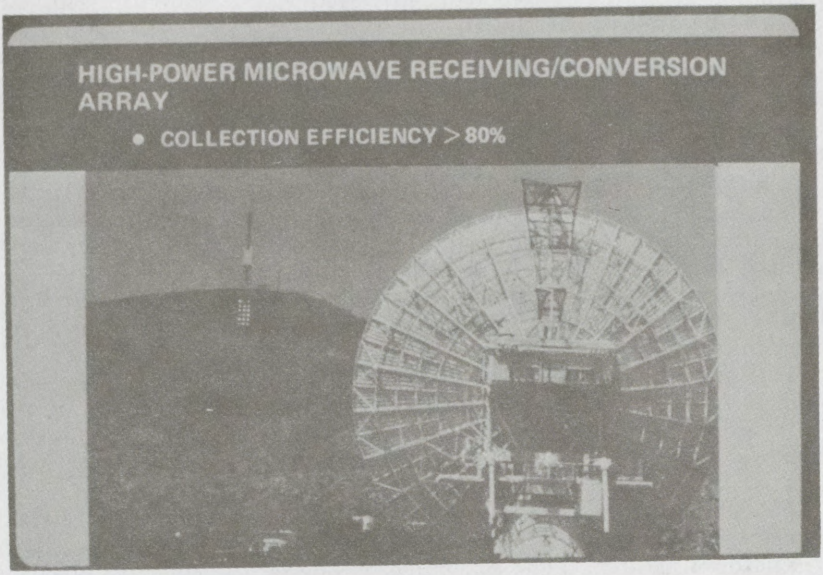


Fig. 9 High Power Microwave Receiving Conversion Array

Senator MELCHER. Thank you, Mr. Hedrick. I want to briefly say that the breakdown of the specific funds for different parts of the puzzle is very helpful. We have a little problem with solar cells getting adequate funding. We have $106.8 million in the Senate authorization bill for fiscal 1979 and in the National Energy Act, still not completed in conference, is $98 million over 3 years in addition to the $106.8 million for solar cell work during the coming year.

Some of these other items, of course, have a like treatment in the authorization act already passed, and would assume, for instance, that for materials, for power distribution controls, part of the necessary funding is already there, and perhaps all of the funding would be there. So, we are not really starting from scratch on the breakdown that you recommend, Mr. Boileau, but it is very helpful to have the breakdown.

Mr. BOILEAU. May I make a comment on that? I'm aware of the solar cell research. I would suggest that the administration in their program add the unique features that make solar cells useful for this type of power concept. We're talking about lightweight, very thin solar cells.

Dr. Deutch said earlier that we are still trying to pick between single crystal silicon and gallium arsenide features.

Senator MELCHER. This, of course, is one of the concepts that the Department of Energy is studying, and one of the concepts that we want them to look at, speaking for this committee.

Mr. BOILEAU. I might add that any production mechanism that would come up with low-cost solar cells would benefit whatever solar cell application we have on Earth also.

Senator MELCHER. Absolutely. If you find out some basic scientific fact that contributes to our broader knowledge of everything, then I'm sure that some of the same work will benefit other work. Some of this work would benefit other work.

Conversely, other work would benefit solar satellite. Mr. Boileau and Mr. Hedrick, your emphasis on let's find out, let's answer these questions, is shared by me, and I know from speaking to Ralph Nansen that it is shared by him. I happened to have had the pleasure of sitting next to Mr. Nansen at a space meeting, what did we call that, the Washington Space Club.

I thank you all very much. I appreciate your being here today, and we appreciate your concise and very much to the point testimony. Dr. Peter E. Glaser, vice president of Arthur D. Little, Inc. of Cambridge, Mass., and president of Sunsat Energy Council of Washington, D.C.

STATEMENT OF DR. PETER E. GLASER, VICE PRESIDENT, ARTHUR D. LITTLE, INC., CAMBRIDGE, MASS., AND PRESIDENT, SUNSAT ENERGY COUNCIL, WASHINGTON, D.C.

Dr. GLASER. Mr. Chairman, thank you very much for inviting me to testify. I am greatly honored to present testimony at the hearings of the Senate Subcommittee on Energy R. & D. in support of the bill that is before you. I would like to request that my formal testimony be included in the record. I will just briefly comment on some of the issues that I see before us.

Senator MELCHER. Your entire testimony will be made part of the record.

Dr. GLASER. I had the pleasure of testifying before Senate committees in October 1973 and January 1976, and to outline the concept of solar power satellites. I urged at that time that the development of this major option of power generation in space for use on Earth receive serious consideration as a matter of national interest.

In the intervening years, considerable work has been carried out, first under NASA, and subsequently under joint DOE and NASA program management. This work dealt with technical and economic feasibility as well as environmental and societal issues. The results of these studies have confirmed the cedibility of solar power satellites as an option that could provide power on a global scale.

Mr. Chairman, that is essentially the objective that I believe we should bear in mind when discussing the development of solar power satellites. I have listened with great interest to the testimony presented this morning, and find that many of the questions that have been raised should be considered and deserve very thoughtful answers. I would like to address myself to a few of the issues that have been raised, and try to deal with them in the time available.

First, if we look at the allocated funds for SPS and compare these funds with other solar energy programs, we see a significant discrepancy. I believe I do not have to stand either before this committee or the public and explain my active support for solar energy applications over the last 25 years, since my record speaks for itself.

I urge that when funds are allocated along the lines of the testimony presented today, that these do not come out of the solar energy budget, but rather that they come out of the budget for the development of central power generation methods.

The solar power satellite is not a near-term possibility. And yet its magnitude and its potential represents the kind of challenge which in this year, in this month, the 10th anniversary of my first presentation of the SPS concept, appears now to be within our capabilities to meet.

As far as the SPS operational life, I believe 30 years was mentioned. This is just the beginning of the life of a solar-power satellite. As we found out on the Moon, the rocks up there are billions of years old. Thus we do not have to concern ourselves with replacing our satellites after 30 years in the benign environment of synchronous orbit. We expect the SPS to have infinitely long life, with appropriate maintenance.

We must acknowledge that during the past 10 years, only a limited amount of work has been carried out on the SPS. Thus, it is easy to find that this hasn't been done, and to point out flaws in the work that has been carried out. I have been very conscious of these flaws, and that is why I support this bill, because it will provide us with the opportunity to start to go into more depth where we know detailed investigations are warranted.

We have to understand the benefits of solar-power satellites, and how they can fit into utility systems. Limited work along these lines has already been carried out. I am pleased that several utilities are supporting the development of the SPS.

We also need to understand how other nations can benefit from this particular solar energy conversion concept. I believe there is an excellent opportunity for solar energy to be the prime energy source in the 21st century. Therefore, it is not appropriate to advocate only the distributed or only the centralized solar energy conversion methods but rather the best combination of the conversion methods we now have or will in the future be developed. We must acknowledge, when discussing economics, of solar energy conversion for baseload power generation with the SPS, fusion power or fast breeders, that the cost of displacing fossil fuels in terms of primary quads of energy lies within narrow limits.

It does not matter whether we displace our fuels with nuclear power or with solar power on Earth or in space, the cost will run into the hundreds of billions of dollars to generate comparable amounts of baseload power. We have, of course, to continue with our energy conservation efforts. I expect that these will continue and accelerate.

We require that energy storage methods be developed for terrestial solar energy conversion. The work being carried out on the SPS indicates that we do not need a large amount of energy storage to meet utility-load management requirements. Reports to that effect have been prepared, one by Arthur D. Little, and others are underway.

As far as the international aspect is concerned, the SPS is not just of interest to the United States. Speaking as the president of the Sunsat Energy Council I am pleased that the council has members from Japan, including an organization representing major Japanese corporations. In addition, we have participants from Europe and people who are interested in the SPS from all walks of life, industry, labor, and government.

The public interest in the SPS is high, as indicated by TV and radio broadcasts, newspaper articles, scientific and technical papers, and inclusion in books, not only in this country, but in Europe, Japan, and even in Russia. The technical community is interested in the solar power satellite. For example, later this month there will be a major meeting on energy conversion in San Diego arranged by the professional engineering societies where two sessions are devoted to discussions of the SPS technology.

The European Space Agency is discussing the SPS at a meeting next month in Holland. The Royal Aeronautical Society is devoting attention to the SPS in the meeting, to be held in London in December, and the SPS will be discussed at the International Solar Energy Society meeting in Denver this month.

I suggest that the SPS is not just of interest to industry, but also to labor. In this month's issue of the Machinist, published by the International Association of Machinists, strong support for solar power satellites is expressed. I believe that we are on the verge of a new evolution, an evolution which can take us into space in ways which we have dreamed about for many years. Not only space exploration for national prestige, but space for commercial use.

We certainly do not expect to have all the answers to SPS development in a short time, however, unless we take the trouble to try and obtain these answers, we may miss a unique opportunity. Although space will be there forever, our resolve may lie fallow, and at a time when we may wish to utilize our space capabilities they may not be available to us in the full measure that they are today.

I believe that going ahead with the type of program outlined in this bill represents a reasoable approach and one which would address the economic and environmental issues which are being raised. If the technical development is successful, it should then be possible to make deliberate decisions regarding the next steps.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Glaser follows:]

SOLAR POWER SATELLITE DEVELOPMENT — THE NEXT STEPS

Testimony of Dr. Peter E. Glaser
Vice President —Engineering Sciences
Arthur D. Little, Inc.
Cambridge, Massachusetts

President, Sunsat Energy Council
Washington, D.C.

at the Hearing of the Subcommittee on
Energy Research and Development

of the

Committee on Energy and Natural Resources
United States Senate

August 14, 1978

Arthur D. Little, Inc.

TABLE OF CONTENTS

35-994 O - 79 - 9

I. INTRODUCTION

I am greatly honored to be invited to present testimony at the Hearings of the Senate Subcommittee on Energy R&D of the Committee on Energy and Natural Resources in support of the Bill on the "Solar Power Satellite Research, Development, and Demonstration Act of 1978." In my testimony before the Senate Committee on Aeronautical and Space Sciences in October 1973 and again in January 1976, I outlined the concept of solar power satellites and urged that the development of this major option for power generation on Earth receive serious consideration as a matter of national interest. In the intervening years, considerable work has been carried out, first under NASA, and subsequently under joint DOE and NASA program management. This work dealt with technical and economic feasibility, as well as environmental and societal issues. The results of these studies have confirmed the credibility of solar power satellites as an option that could provide power on a global scale. They have also suggested that this energy source has great promise of being cost-competitive, resource conserving, compatible with the environment, and of benefit to society. The objectives of the Senate Bill S.2860 — both to pursue a vigorous research and development program aimed at confirming the potential of solar power satellites as a major source of energy to satisfy our national needs, and also to provide for the development and demonstration of practical means to deploy solar power satellites — are firmly based on the significant technological advances which we have witnessed since the lunar landing demonstrated man's capacity to explore space.

Our national space program is unquestionably the most successful major effort, fully meeting its announced goals, which the United States has undertaken in the past 20 years. We must acknowledge that the spur to our first entry into space 20 years ago was the successful launching of Sputnik, which was seen at that time as a test of different ideologies. Today, our space program is primarily applications-oriented, and commercial motivation is beginning to compete with the view of space activities as a matter of national prestige. Soon, the space shuttle will make it possible to embark on activities, including those with an industrial profit motive, in orbit around the Earth on a scale and frequency which promise to make commercial uses of space possible in this century. As a result, concepts such as advanced communication satellites, the processing of materials in space, and solar power satellites are taking on a new reality.

The space program has moved off the television screen and out of the public view into government, academic, and industrial offices, laboratories, and test and production facilities. This is an appropriate change at the present stage of space technology development. Today, a successful space launch — and even activities of man in space, whether carried out by the United States or the Soviet Union — barely make the back pages of our daily newspaper. What this means is that accomplishments in space are being viewed by the public as commonplace. The glamour of being an astronaut may soon be replaced by work requirements akin to those of airline operations, which safely and quickly deliver passengers and cargo to their desired destinations. The space shuttle will carry people who do not have to undergo the rigorous training or medical screening of astronauts, but who are selected for their ability to perform the important and largely routine functions which are essential in crossing the threshold into commercial uses of space.

This reality of space as a frontier for industry is significant to the development of solar power satellites. The transition from space as an arena for projects with strong overtones of national prestige, to a setting for projects with a commercial motivation will take time. This transition also implies that the project management would move from control solely by government to the involvement of the private sector, as has already occurred in the area of communication satellites. It should also be conducive to international participation, leading toward cooperation between nations on space projects of mutual benefit.

In my view, federal government support, which is crucial during the early development, demonstration, and operational period, should be planned to phase into a commercial venture which also would involve ownership by industry and the public. Thus, I see Senate Bill S.2860 not as a commitment to finance an operational solar power satellite system, but rather as an evaluation of whether to proceed with its development and demonstration, and if so, how best to accomplish this purpose. Although technical feasibility of the SPS is being increasingly accepted, the program and plans outlined in S.2860 are necessary to provide the basis for rational decision making regarding what next steps, if any, should be taken to implement the SPS.

Solar power satellite development, which not so long ago was considered as esoteric preoccupation of space buffs, is gaining much wider recognition and support. It is notable that most of the technically competent people who have seriously studied the SPS concept have seen its merits, even if initially they considered it unreasonably ambitious.

Moreover, most of the criticism stems from opposition to centralized power: We should not postpone the SPS on this ideological issue unless we are also ready to give up development of other centralized power generation technologies, including nuclear fission and fusion, fossil fuel plants, ocean thermal power among others.

The public and particularly the younger generation, senses that here is an option which, if successful, would significantly help meet the energy challenges that will be faced by society as the shrinkage of our resources becomes more acute. Despite opposing claims, the public does not perceive the solar power satellite development program as a sandbox for aging space technologists to play in, or as a near-term panacea for the ailing aerospace industry, but rather an opportunity to serve both this and succeeding generations. We will not serve them well if timidity hampers us in our search for new solutions.

Since Sputnik and Vanguard, we have achieved a partial conquest of space. The question was once raised: to what end? There was a point not long ago when our answers were vague and unresponsive to needs that were felt by the earthbound man or woman on the street. But now we can say that the largely uncharted course on which we embarked with our space program has begun to intersect with our need for energy — a need that is at the same time economic, societal, and fundamentally related to the national goals and international tranquility.

In brief, it is back on Earth where our ultimate vision of solar power satellite benefits should now be fixed. The electricity it could supply will be, of course, identical to that generated by other baseload power plants. The only fundamental difference is that the SPS will tap the sun's energy in space instead of diminishing subterranean reserves of petroleum, natural gas, or coal. We find it difficult, I think, to make the linkage in our mind's eye between terrestrial power stations and orbiting solar collectors. Yet, the technology for constructing the latter is at least as well established as several terrestrial power generation methods now under development. There is growing consensus that: The SPS is technically feasible; the basic research and experimental phases are now past, and there remains what is essentially a challenging engineering task which is well within present capabilities. The time has arrived when we can say with confidence that the question of whether to supply SPS generated power is no longer one of space technology but of energy technology and its attendant relevant issues — with utilization of space as the means rather than the end.

II. THE SPS CONCEPT AND ITS POTENTIAL BENEFITS

When the SPS concept was first proposed in 1968,[1] its technical feasibility seemed highly questionable. Its objective of developing an approach for the large-scale generation of power in space to be beamed back to the Earth was considered irrelevant. Since then, we have become conscious of the limits to growth and the limits of available nonrenewable terrestrial energy resources. Our lack of control over imported liquid petroleum resources has demonstrated how unrealistic was the confidence of the industrialized countries that energy supplies would always be available in the required amounts to feed their growing energy economies.

We now know that the energy problem has no short-term and simple solutions, and we are seeking to define the options open to us. As we investigate these options it is becoming clear that no one energy source will, by itself, meet all future demands, that the quest for new sources of nonrenewable fuels can only extend the day of their ultimate exhaustion, and that the uncertainties inherent in achieving the potential of known energy conversion methods are considerable.

As a result of more realistic appraisals of the various energy resources and conversion options, emphasis is being placed on the development of renewable energy sources. Among these, solar energy is the most widely distributed and has a seemingly unlimited potential to meet future requirements if cost-effective applications can be developed. The degree to which these applications will be successful will depend to a large extent on the economic feasibility of solar energy technological advances and their competitive position compared to those of other energy options.

As solar energy technologies and their benefits and limits are better defined, solar energy conversion in space for use on Earth is being increasingly recognized as a major power generation option. In comparison to a terrestrial central solar power station, there are significant advantages to converting solar energy in geosynchronous orbit (22,300 miles above the Earth), where solar energy is available 24 hours a day during most of the year and a satellite is stationary with respect to a desired location on Earth. In this orbit, the SPS will be illuminated by the Sun more than 99% of the time, receiving from 4 to 11 times the solar energy available in areas on Earth with copious sunshine.

Furthermore, dedication of the large areas required for converting the solar energy — on the order of tens of square miles — and assembling the lightweight structures and large numbers of conversion devices, such as solar cells, are much more feasible in the vast emptiness of space at orbital altitude and under its conditions of zero gravity and the absence of rain, snow and wind than on Earth.

In the SPS, the electricity produced by this solar energy conversion will be fed to microwave generators forming part of a planar, phased-array transmitting antenna. The antenna is designed to precisely direct a microwave beam of very low power density to one or more receiving antennas. At the receiving antenna, the microwave energy will be safely and efficiently reconverted to electricity and transmitted to users. A large number of SPS's can be stationed in geosynchronous orbit, each beaming power to receiving antennas placed at the desired locations on Earth. Each SPS in orbit could produce from 2.5 to 10 million kilowatts at its receiving site on Earth.

At first, the SPS concept was considered "pie in the sky," but a series of system studies[2,3,4,5,6,7] confirmed that there are no known technical barriers to the design, deployment, and operation of the SPS. Economic studies show that projected capital and SPS electric power generation costs are within the competitive range of the costs of future terrestrial power generation methods, and risk analyses provide economic justification for proceeding with the initial phases of an SPS development program.[8]

Since the inception of the United States Space Program in 1958, one of its major objectives has been the development of technology that would effectively use space to contribute to the improvement of life on Earth. As already demonstrated by the existing network of communications and Earth-observation satellites, space technology and associated activities have so matured that we have already achieved this objective to some degree and thus demonstrated that expanding activities in space could be increasingly beneficial to all people on Earth.

Although the SPS is a huge undertaking by any contemporary standard, the past ten years' investigation of the concept in the United States as well as in other countries[9] indicates that its development would have far-reaching benefits. There is an increasing consensus that the SPS has the potential to provide an economically competitive and environmentally and socially acceptable option for continuous power generation on a scale substantial enough to meet a significant portion of future global energy demands.

If the SPS were implemented on a significant scale, a variety of additional benefits could arise because of its particular characteristics as an energy source. For example, the SPS is obviously an enterprise which would stimulate the development of the nation's capabilities in high technology. As has been noted by Dr. Frank Press[10] : "The social returns from investment in high technology can be extraordinarily great. Over the past years, high technology industries have grown almost three times as fast, increased their productivity twice as fast, expanded their employment nine times as fast, and at the same time raised their prices only one-sixth as much as low-technology industries." The SPS is especially remarkable, however, in that its need for high technology is complemented by a need for mass production of very large numbers of repetitive elements (solar cells, microwave power amplifiers, dipole rectifiers, etc.) so that it can provide an important stimulus to employment at the level of skills required for operation of a production line or in the construction industries as well as at the professional engineering level.

The SPS can also be of very great benefit to the U.S. balance of payments, making our nation again an energy exporter rather than an energy importer. The export trade created by the SPS might involve the sale or lease of power stations in orbit, sale of services such as launch, construction and maintenance for SPS's, or export of microwave power to receiving antennas (perhaps locally built) in other countries.

III. CURRENT SPS DEVELOPMENT STATUS

The increasing confidence in the SPS concept is the result of Department of Energy and NASA sponsored system definition studies, and economic and environmental evaluations by more than 30 U.S. industrial organizations, academic institutions, and government agencies.[11] The major technological and economic uncertainties and constraints are being assessed and the steps that will have to be taken to further develop the SPS concept are being identified.

The progress that has been made in defining key issues is highlighted in the following paragraphs:

- Solar energy conversion based on the use of solar cells has been identified as a preferred approach. For example, single-crystal silicon solar cells with a thickness of 0.002 inch and an efficiency of 14%, have been produced in a pilot production line. The continued progress is quite dramatic: only three years ago the production of thin silicon solar cells with acceptable efficiencies was considered to be a very unlikely development. Production processes for thin film gallium arsenide solar cells have been identified.

- Microwave power rectification was shown to be feasible when in tests in 1975 at Goldstone, California, microwaves were directly converted to electricity with an efficiency of 83%. Prior to that demonstration, some authorities had considered it unlikely that microwave conversion efficiencies at the receiving antenna would be higher than 20%.

- Results of space transportation system studies indicate that transportation costs to geosynchronous orbit could be reduced from present levels to $40 per pound when large and reusable space transportation vehicles are developed. The development of such transportation vehicles, although a major step in terms of annual launch capacity, would be based on the experience gained in space shuttle flights and represents a relatively modest extrapolation of booster technology. Much of the expected reduction in cost arises simply from economics of scale which are predictable with frequent, routine launches.

- The continuous fabrication of large lightweight structures has been demonstrated with an automated beam-making machine. This capability, combined with increasing sophistication in the design of tele-operators and methods of assembly of large structures in space, indicates that solutions to the assembly of SPS structures in orbit are forthcoming.

- Recent experiments at Arecibo, Puerto Rico have indicated that exposure of the ionosphere to microwave beams does not result in heating effects which would interfere with communications.

- The microwave transmission system can be designed so that microwave exposure of the public at the perimeter of the receiving antenna site will be 100 times less than the present United States standard for continuous exposure to microwaves, and will meet guidelines for microwave exposure adopted by the Eastern European countries.

- Convergence of cost projections indicates SPS capital costs ranging from \$1600 to \$3500 per kW, leading to electricity costs (based on a 30-year lifetime and a 15% return on investment) ranging from 3 cents per kWh to an upper bound of 12 cents per kWh, with a nominal cost of 6 cents per kWh. These costs are within the competitive range of costs of future terrestrial power generation methods.

- Risk analyses have provided an economic justification for proceeding with the next phases of an SPS development program to obtain the information on which future decisions can be based.

- The successful development and commercialization of the SPS will require neither technological breakthroughs nor a search for new scientific principles. Instead, the challenges are primarily in the development of known technology and the application of engineering know-how and mass production experience.

The scope and direction of the next steps in the SPS development program should be such as to provide more detailed information on the following:

- Solar Energy Conversion Technology,
- Microwave Generation, Transmission, and Rectification,
- Advances in Key Technology Areas,
- Space Transportation Systems,
- Fabrication and Assembly of Large Structures in Space,
- Interface of the SPS with Utility Systems,
- Economic Competitiveness,
- Environmental Constraints, and
- Institutional and International Issues.

IV. THE NEXT STEPS IN SPS DEVELOPMENT

Although most of the components which are to be produced for the SPS can be presently demonstrated on a laboratory scale, it will be crucial to develop them further, to adapt them for mass production, to test their functions, assemble them into subsystems, and demonstrate their functions both on Earth and in space.

The SPS Concept Development and Evaluation Program Plan for the conduct of studies to August 1980, issued in February 1978 by the Department of Energy and NASA,[11] is primarily concerned with system definition and studies of economic, international and institutional issues and comparative assessments of the SPS with terrestrial energy systems, with only a minor fraction for technology development or testing.

S.2860 recognizes the need to supplement the existing SPS development program. To advance the understanding and the credibility of the SPS concept, it will be necessary to perform key terrestrial tests to support ongoing systems studies, to define SPS development and operational issues, and to initiate supporting space experiments that will provide crucial information on which to base decisions concerning the implementation of required technology.

S.2860 will be supportive of the objectives of a near-term SPS development program, which are:

(1) To identify and assess issues that could constrain successful SPS development; and
(2) To seek ways to resolve these issues by a combination of analyses, system studies and experiments on Earth and in space.

The critical issues that need to be resolved in the SPS development program can be grouped according to the following priorities:

(1) Issues that could prevent successful development:

- Interactions of the microwave beam with the ionosphere;
- Effects of launch vehicle emissions on the upper atmosphere;

- Microwave beam biological effects;
- Radio frequency interference; and
- International agreements, e.g., frequency assignment, allocation of synchronous orbit positions, limitations on power generation levels in satellites.

(2) Issues that must be settled to proceed with SPS system design:

- Microwave transmission parameters, e.g., frequency, beam intensity and distribution;
- Microwave exposure standards;
- Space vehicle emissions;
- Space radiation exposure standards; and
- Construction and assembly sites in Earth orbits.

(3) Issues that affect implementation of SPS:

- Large-scale low-cost space transportation;
- Orbital construction and assembly;
- Launch sites;
- Receiving antenna sites;
- Interfaces with utility power production and distribution;
- Risks and uncertainties of achieving operational goals;
- Level and timing of capital investments; and
- Cost of SPS-supplied power.

These issues are closely interrelated and must be addressed in a system context. However, studies alone without experimental data cannot resolve these issues. Orbital tests will be required for which the space shuttle will be invaluable as a launch vehicle and to support test programs including:

(1) Exposing materials such as solar cells, electronic components, coatings, and structures to the space environment in geosynchronous orbit for long periods of time and then recovering them to obtain data on their suitability for SPS applications;

(2) Building structural elements with automated fabrication equipment, forming a structure with these elements, developing methods to install solar cell arrays and other components, and testing the characteristics of subsystems; and

(3) Testing microwave generation and beam transmission and SPS station-keeping techniques and functions.

A flight test program with the space shuttle will provide opportunities for SPS-related experiments to be performed by other nations which may wish to participate in the SPS development program. Such an involvement will set the stage for international cooperation which will be essential to the success of the SPS development program and subsequent commercialization.

V. IMPLEMENTATION OF THE SPS DEVELOPMENT PROGRAM

The SPS development program can be divided into three overlapping phases.

PHASE 1: Concept Feasibility Studies — The objective of these studies which started in 1972, is to establish the overall feasibility of the SPS concept through system definition studies and environmental and socio-economic evaluations so that development program directions can be defined. These studies are based on existing and projected information and will be concluded by 1980.

PHASE 2: Technology Advancement — Significant advancement of the technology for the SPS will require laboratory investigations, terrestrial testing, limited space experiments, and continuing in-depth evaluation of environmental effects, economic factors, and institutional arrangements to reduce program risks and uncertainties and to define future SPS development program directions. This program should be started as soon as possible within the context of S.2860 and should extend over a five-year period.

PHASE 3: Demonstration Projects — Demonstratons of the functions of critical elements and operational readiness of the SPS will require space projects to be carried out on an appropriate scale and with increasing space capabilities to provide information necessary for a decision to proceed with a full-scale implementation of the SPS.

The SPS Concept Development and Evaluation Program Plan of the Department of Energy and NASA, with a budget allocation of $15.6 million until 1980, is primarily concerned with Phase 1 feasibilities studies. I recommend that the budget for Phase 2: Technology Advancement within the framework of S.2860 be established for a five-year SPS development program on a scale appropriate to this major option for baseload power generation, with the funds allocated as shown in Table 1 to address the critical issues.

On an annualized basis, the projected funding levels would be only about 10% of the present annual funding for each of the advanced nuclear energy options. At this funding level, it should be possible to achieve the necessary momentum for an effort which is of increasing national interest and to reach the stage where decisions to proceed with Phase 3 of the SPS development and demonstration program could be

TABLE 1

PROPOSED FIVE-YEAR SPS DEVELOPMENT PROGRAM BUDGET

		($ In Millions)
Technology Development		120
System Studies	20	
Space Technology	30	
Terrestrial Experiments	20	
Space Experiments	50	
Environmental Effects		55
Analytical Studies	12	
Terrestrial Experiments	18	
Space Experiments	25	
Economic Factors		10
Industrial Arrangements		15
		200

made. The SPS development program funding should not diminish the funds allocated to other solar technologies but rather should be an added budget line item.

There is a broader context in which the implementation of the program envisaged by S.2860 can be viewed. Achievement of the SPS development program goals will lead to the intensive utilization of the space shuttle, the performance of Spacelab experiments, demonstration of the capability to construct large space structures, and the generation of significant power levels to support future space activities.

The SPS development program will focus development efforts on space processing, fabrication, assembly and maintenance; human habitations in orbit; space transportation efficiency, and the possible uses of extraterrestrial resources, thus setting the stage for achievements which may transcend anything that heretofore has been accomplished by the human species.

VI. SHORT-TERM BENEFITS OF THE SPS DEVELOPMENT PROGRAM

Although studies to date have indicated that the SPS may indeed be one of the most promising options for generating electrical power which could be available in the post-1990 period, it would be premature to propose today a national commitment to actual deployment and operation of the system on a scale commensurate with energy needs. All that is needed now is a limited development program, as discussed above, aimed at resolving those outstanding issues which will determine the eventual priority to be given the SPS in the overall national energy plan.

In addition to providing the information needed for timely decisions, this program could contribute significantly to the achievement of much more immediate policy goals. Even in its early phases, a serious study of the SPS would be a most dramatic energy initiative. Unlike other energy R&D efforts, the SPS development program would capitalize on the international prestige generated by very successful U.S. space programs, especially Apollo. Although the scale of the SPS challenges the imagination, few will doubt the technical capability of this nation to deploy such systems in orbit. Like Apollo, the SPS is a major technological enterprise which can fire the spirits of men everywhere, engage international participation and cooperation, and, if it is successful, provide a powerful stimulus to economic growth, here and abroad. It is not a panacea, but it does offer a combination of desirable characteristics unmatched by any other proposed energy source.

Because of these factors, a development program of the type envisioned in S.2860 could yield these short-term benefits:

(i) Slowing oil price inflation.

By giving notice to oil supplying nations that a viable and significant alternative to dependence on oil was under investigation, the SPS development program could lead to some restraint in continued escalation of the world oil price. It should be noted that the cost to this nation of imported oil is such that deferment of an annual increase of only 0.1% (or about a penny per barrel) would pay for the program proposed here.

(ii) Changing public perceptions of the future.

Because of its dramatic character and profound implications, the SPS development program can help engender positive attitudes towards the future in a way that could not be expected from, say, a commitment to coal gasification. In particular, it could modify the common opinion that nothing much is being done about the energy crisis. Moreover, a prerequisite for deployment of the SPS is development of a truly economical capability for transportation to orbit and for large-scale construction in space: the possibility therefore arises of other forms of space industrialization and, eventually, of human settlement off Earth. The consequences for the future of man may include the indefinite postponement of limits imposed by terrestrial resource exhaustion. Even in its early stages, the SPS program may thus help dispel the current gloom and restore the classic American confidence in the future. Like Apollo, the SPS can serve the social purpose of "getting this country moving again"; but, unlike Apollo, the program can be justified in quite pragmatic terms.

It is difficult to quantify these types of benefit, but it is clear that they may be sufficient to justify the level of funding I have proposed for the next several years, even without regard to the longer-term promise of the SPS. However, these benefits can accrue only if the SPS program is credible: it must be funded at a sufficient level to demonstrate convincingly that this is a serious program. Present expenditures, approximating one percent of the total DOE solar energy budget, or of the budgets for other advanced energy sources, cannot be expected to achieve these goals.

35-994 O - 79 - 10

VII. THE SUNSAT ENERGY COUNCIL

The recognition of the significance of the SPS development program has led to the formation of the Sunsat Energy Council, a nonprofit organization, which endeavors to bring together representatives of academic institutions, industry, labor and public interest groups to achieve the following objectives:

- Foster the development of the SPS for the purpose of providing an inexhaustible energy source for the public benefit;

- Encourage cooperation and research and development of the SPS technology among federal government agencies concerned with the problems associated with the development and use of the SPS, develop solutions for such problems, and provide such solutions and related information to the appropriate agencies of the federal government for the benefit of the public;

- Foster communication among the public, environmental organizations, industry, government agencies, and all other groups interested in the development of the SPS; and

- Foster international cooperation, education, and communication in the development of the SPS and regulation of the SPS for the public benefit.

The Sunsat Energy Council concludes that:

- There is increasing confidence in the technical feasibility, economic promise and environmental acceptability of the SPS.

- The SPS is one of the major power generation options which could meet global energy demands in the 21st century.

- Implementation of the SPS in conjunction with terrestrial solar energy conversion and other promising energy technologies could lead to the elimination of energy-related concerns after the turn of the century.

- The SPS represents a major and significant step towards extending peaceful human activities beyond the confines of the Earth's surface.

- S.2860 would permit the SPS to be developed on a scale large and significant enough so that it can be ready to meet the challenges that will have to be faced during the inevitable transition to renewable sources of energy.

- S.2860 provides the opportunity to make the best use of past investments in space capabilities so that the soil and rock brought back from the Moon will be not only a symbol of the capabilities of man but a demonstration of the potential for changing the course of human evolution.

REFERENCES

1. P.E. Glaser, "Power from the Sun: Its Future," SCIENCE, Vol. 162, November 1968, pp. 857-886.

2. P.E. Glaser, et al., "Feasibility Study of a Satellite Solar Power Station," NASA CR-2357, NTIS N74-17784, February 1974.

3. Boeing Aerospace Company "Solar Power Satellite System Definition Study, Part I and Part II," NASA JSC, Contract NAS9-15196.

4. Rockwell International, "Satellite Power System (SPS) Concept Definition Study," NASA, MSFC, Contract No. NASA-32475, Final Report, April 1978.

5. ECON, Inc., "Space-Based Solar Power Conversion and Delivery Systems Study," NASA MSFC, Contract NAS8-31308, Final Report, March 1977.

6. NASA, Lyndon B. Johnson Space Center, "Solar Power Satellite Concept Evaluation," Activities Report, JSC-12973, July 1977.

7. NASA, George C. Marshall Space Flight Center, "Satellite Power System Study Status," July 1976-June 1977.

8. G.A. Hazelrigg, "The Economic Viability of Pursuing a Space Power System Concept," AIAA/EEI/IEEE Conference on New Options in Energy Technology, San Francisco, August 1977.

9. AEG-Telefunken, "Sonnenenergie-Satelliten," Summary Report, Contract No. RV11-V67/74-PZ-BB74, May 1975.

10. Dr. Frank Press, press conference reported in N.Y. Times, March 30, 1978, p.51.

11. U.S. Department of Energy and National Aeronautics and Space Administration, "Satellite Power System (SPS) Concept Development and Evaluation Program Plan, July 1977-August 1980," February 1978.

DR. PETER E. GLASER, Vice President, Engineering Sciences, Arthur D. Little, Inc.

Dr. Peter E. Glaser heads Arthur D. Little's activities in the field of solar energy. He is the inventor of the solar power satellite and was awarded a patent for his concept in 1973. Dr. Glaser serves as president of the Sunsat Energy Council, a non-profit organization of scientists, industrialists and public interest groups formed to encourage the development of solar power satellites. He is past president of the International Solar Energy Society and is currently serving as Editor-in-Chief of the Society's journal. Dr. Glaser has published and spoken widely on the potential of solar energy to meet future energy demands.

Since joining the staff of Arthur D. Little, Inc., in 1955, he has directed numerous advanced engineering development projects in thermodynamics, space and lunar science instrumentation, and the utilization of solar energy. These projects have involved research on methods of generating high temperatures, including the construction of solar and arc imaging furnaces; thermal insulation systems; and properties of postulated lunar surface materials. Dr. Glaser was responsible for the development of scientific experiments for the Apollo lunar landing missions, including measurements of the heat flow from the lunar surface, lunar gravity and the earth-moon distance. He also directed Arthur D. Little's international multiclient program to develop a solar climate control industry. He currently is directing projects on the feasibility of solar power satellites, solar climate control systems for buildings, photovoltaic conversion and integrated systems for rural electrification.

Dr. Glaser received his undergraduate training in mechanical engineering at Leeds College of Technology, and Charles University, Prague. He obtained his M.S. and Ph.D. degrees in mechanical engineering from Columbia University in 1955.

Dr. Glaser served on Committees of the National Academy of Sciences, and is a member of the American Association for the Advancement of Science, the New York Academy of Sciences, the American Institute of Aeronautics and Astronautics, American Society of Mechanical Engineers, the American Society of Automotive Engineers, American Ordnance Association and Sigma Xi. In

1974, Columbia University awarded Dr. Glaser the Carl F. Kayan medal for his contributions in the field of engineering. He has over one hundred publications, books and patents in the fields of solar energy applications, solar power satellites, thermal insulation, thermal properties measurements, thermal imaging techniques, lunar surface characteristics, extraterrestrial resource utilization, and technology transfer.

Senator MELCHER. Thank you, Dr. Glaser.

Dr. Glaser, you are the first witness who has mentioned this morning the international aspect of solar power satellites. What work is going on in other countries, and what nature is it?

Dr. GLASER. Work that I am familiar with has been going on, for example, in Germany, where reports have already been published in 1974 and 1975.

I have recently visited Europe, and I know that in Germany several industrial organizations are very interested in the SPS because they believe that as far as Europe is concerned, they do not have the options that we have for solar energy conversion because they do not have sunny locations as we do in Arizona. Furthermore, there is great interest in the SPS in Japan. The Japanese industry recognizes that their options to secure energy sources are very limited. The land availability for receiving antennas in Japan is restricted, but there is a possibility that solar power satellites with receiving antennas offshore could have a dual purpose to provide power and for aquaculture, which would have a major impact not only on the Japanese energy supply situation, but also on food production.

I have had discussions on the SPS with representatives from India, and was told that the Prime Minister expresseed an interest in solar power satellites. In the May 1 article in the Christian Science Monitor an Indian scientist was quoted that India is greatly interested in solar power satellites because it will enable them to provide the power that they will desperately need to meet the needs of their growing population and industry.

In addition to the industrialized nations of the West, there is work in progress in Russia. I have met with several of the Russian representatives at various conferences and found that they are well acquainted with our work. Again the Christian Science Monitor quoted in the January issue that the designer of the Soyuz spacecraft has expressed an interest in the SPS.

The United States has a major opportunity to lead in this effort and to recapture the spirit of accomplishment which the world applauded as a result of our efforts in space during the Apollo program.

But this time our objective is not just to land a few men to explore the Moon, but to be pragmatic and to undertake industrial activities in space, which already are beginning to grow in importance as the space shuttle is readied for flight.

Senator MELCHER. None of the countries are at a stage yet to exchange ideas, or results, I take it.

Dr. GLASER. I am not aware of it. It may well be that as their work will progress, some of the results will be reported, for example, at a conference organized by the European Space Agency, to be held in Holland on September 11 through 13.

Senator MELCHER. When is that?

Dr. GLASER. The Conference starts on September 11. I plan to attend and several papers on the SPS will be presented.

Senator MELCHER. Have the Russians freely engaged in prompt publication of their findings in energy matters?

Dr. GLASER. I really couldn't comment since I don't follow the Russian literature, but I would think people in the Department of Energy would know that.

Senator MELCHER. Are you aware that a few years ago, perhaps 2 or 3 years ago, we arranged with the Russians an exchange of information regarding MHD technology, which has been beneficial, I think, for the United States, and perhaps we can return any information regarding the value of the information we have gained from their work.

They even used one of our magnets, I understand. It was airlifted to Russia a few months ago. So some of our experimentation was done with MHD.

Dr. GLASER. I hope, Mr. Chairman, that the results from the Soviet Soyuz experiments will be available to us because the men working in space are carrying out experiments that will shed more light on the kind of activities which we will have to carry out as we prepare to develop the solar power satellite.

Senator MELCHER. I found it extremely helpful to get your assessment on how long the satellite would last. Now, when you say reasonable maintenance or prudent maintenance, what are you speaking about? That's a little bit mystifying to me.

Dr. GLASER. First let me again say that the 30 years that was quoted is strictly a number that is used for economic analyses because a discount rate carried beyond this period doesn't make sense. As far as maintenance is concerned, we need several types.

One is to supply material, and equipment, which may wear out. We recognize that some of this has to be done periodically. Second, we have to supply propellants for station keeping, for example, argon, which would be used to keep the solar power satellite fixed in relation to the Sun, and transmitting the antenna in relation to the Earth.

Several studies are already considering the type of maintenance procedure that we would have to use.

Senator MELCHER. It doesn't make a great deal of difference then in estimating cost effectiveness of this source of energy, if it is feasible.

Dr. GLASER. Maintenance requirements have been taken into account in establishing SPS operational costs. Ongoing system studies include considerations of maintenance, and of course, assembly. But much more work ought to be carried out to define these costs more precisely.

Commenting on the receiving antenna locations, we are undertaking now a study which builds on a previous study which NASA has carried out. We have identified at least 100 potential antenna sites. Arizona and South Dakota already have expressed their interest in having receiving antennas located in their State. For example, the State of South Dakota, under the sponsorship of the Governor, organized a symposium on solar power satellites in June 1974 and at that time arranged for us to review potential sites in South Dakota.

Senator MELCHER. The Governor should talk to Senator Abourezk.

Dr. GLASER. I guess the Governor may not have informed the Senator about that. Mr. Chairman, I might say that the SPS program tends to invite some sensationalism. I hope that as we carefully study the various aspects of the SPS development program, the facts will be better defined and not subject to widely differing interpretation.

Senator MELCHER. Do you think we'll need another international space treaty to assign rights to synchronous orbit?

Dr. GLASER. Mr. Chairman, I was privileged to be asked to attend a conference organized by the American Bar Association, in Montreal in 1975, at which time the 1967 space treaty was being considered by a panel including NASA and Soviet representatives. During the discussion I asked a very specific question: If we construct a solar power satellite, would that fall under the 1967 space treaty? The answer by the Soviet representative was yes, it would. This is a significant answer indicating that the existing legal framework will apply.

Senator MELCHER. Under that treaty, isn't the available synchronous orbit somewhat limited?

Dr. GLASER. The 1967 space treaty provides the legal basis for obtaining synchronous orbit positions. The United Nations Committee on the Peaceful Uses of Outer Space is the body responsible for orbit position allocatious.

We have a large amount of territory up there, which will allow us to orbit all of the satellites that we would conceivably place in operation. Once an SPS is in orbit, it is very likely that we could combine the functions of several satellites with the SPS, thus reducing the number of required orbit positions.

Senator MELCHER. Under the treaty, if you have something in synchronous orbit at the present time, is that a right of ownership?

Dr. GLASER. The treaty respects rights of ownership. Furthermore, the President of the United States, in a pronouncement release on June 24, has made it clear that any object in space will be considered to have the same rights of ownership as any object on the surface of the Earth.

Thus, a solar power satellite, just as a ship at sea, or a powerplant on Earth will be vulnerable but protected by national and international legal rights.

Senator MELCHER. The same vulnerability as a U-2 or a Pan American 747.

Dr. GLASER. It would be the same. Any interference with commercial installations would have significant consequences.

Senator MELCHER. By vulnerability, do you mean the results are vulnerable, and the results would be applicable in a similar way?

Mr. GLASER. Right. I believe that the solar power satellite must be considered an object which can be destroyed, but there are very few objects nowadays in this world which could not be destroyed. It would be much harder, of course, to take hostile actions in synchronous orbit, because only a few nations possess that capability.

My hope and expectation is that solar power satellites would be utilized internationally, on a global basis, with many nations enjoying their benefits. If this is the case, then why should nations destroy each others satellites?

Furthermore, I would like to comment on who would own solar power satellites. The most unlikely owner would be the Boeing Co., or Con Edison in New York. I do not foresee ownership by any one large company or utility, but rather as is the case with communications satellites, there would be joint ownership between governments, industry, and the public. In Comsat Intelsat we already have an analogy to such institutional ownership. The ownership issue by the way, is to be studied in the program being undertaken now in the DOE.

Senator MELCHER. That is one of the studies.

Dr. GLASER. Yes.

Senator MELCHER. Thank you very much, Dr. Glaser, you have been very helpful to us.

Dr. GLASER. Thank you, Mr. Chairman.

Senator MELCHER. That concludes our hearing.

[Whereupon, at 1 p.m., the hearing was adjourned.]

APPENDIX

Additional Statements and Communications Submitted for the Record

---

Statement of Hon. Gaylord Nelson, a U.S. Senator From the State of Wisconsin

Over the last several years, the Senate Small Business Committee, which I chair, has actively promoted the development of solar energy. Our hearings have shown that solar energy can provide a substantial percentage of our nation's energy needs in a clean and economical manner. Ironically, however, it seems to us that one of the greatest threats to the development of solar energy is the solar energy system envisioned in S. 2860, the Solar Power Satellite Research, Development and Demonstration Act of 1978. This bill commits the United States to the development of solar power satellites even though we have not even completed initial concept evaluation studies. If we ultimately develop solar power satellites, we may well find ourselves stuck with an enormously expensive and uneconomical source of energy which has cost us too much money to abandon. We may also find ourselves facing serious and widespread health hazards from microwave radiation, since the satellites use microwaves to transmit energy from space. Most disturbingly, we may find ourselves having to defend the satellites from military attack, something to which they could be very vulnerable, adding to the already fantastic costs. Even if we can solve these problems, however, successful solar power satellites will still pose tremendous problems to society, for they would concentrate the control of a substantial percentage of the nation's energy needs in the hands of a few industrial giants. Massive government regulation would be required. At the same time, expenditures for developing the solar power satellite would have dwarfed and probably severely restricted funds for solar development on a more human scale—funds for incentives for installing solar devices in homes and businesses, funds for building windmills and installing generators at small hydroelectric sites, funds for developing photovoltaic cells for industry, funds for all the diverse and innovative solar approaches we already know require nothing more than our commitment. We would have denied funds for these projects in order to pursue a massive single-mode energy path whose failure could lead to a crisis many times more severe than the energy crisis we face today.

Other witnesses will address the environmental, military and cost problems raised by this bill. Suffice it to say here that at this point we know that microwave pollution is a very serious matter, having been implicated in genetic changes, changes in the central nervous system, and cataracts, and possibly causing cancer or sudden infant death. We also know that the industry's own cost estimates for this program are $40–80 billion dollars for the next two or three decades for research and development alone, with eventual costs totalling one and one-half trillion dollars for a system providing 20–30 percent of the nation's energy. At these costs, the energy delivered would be competitive, but the aerospace industry has a notorious record for understating costs. A brief look at the costs projections reveals enormous differences in assumptions—the estimated repayment time varies from 3 to 46 years, for instance. Finally, no one has seriously addressed the question of whether we would need to defend the satellites. Soviet technology has already advanced to a point where the satellites would be seriously threatened. To avoid energy blackmail, we would need a reliable defense system, the costs of which would surely be enormous. These and other questions need to be answered before we commit ourselves to development and demonstration, as this bill does. There is such a study already underway at the Department of Energy and NASA, due to be completed in 1980. At the very least, we should await the completion of that study.

Even if satisfactory answers to these questions can be provided, however, we still question the advisability of this program.

Using the industry's own estimates, research and development of solar power satellites will itself cost $2–4 billion per year over the next two or three decades, to be followed by well over one trillion dollars to deploy the satellites, each of which would be as big as Manhattan. Future administrations, no doubt, would include these expenditures in their solar energy budgets. Money for smaller scale solar developments would consequently be much less available. This would represent, we believe, a tragic confusion of priorities.

The Council on Environmental Quality has concluded that with a serious commitment by the year 2000—around the time we would be ready to send up the satellites—we could supply 25 percent of our energy needs through conventional solar power, and by 2020—when the satellites would be in use—50 percent. Much of this energy would be electrcity—the same energy provided by the satellites. Since the nation will consume well under half its energy in the form of electricity at that time, it is clear that the solar power satellites would have to preclude other forms of solar energy, such as hydroelectric power, windmills, photovoltaic cells, biomass conversion, and other promising developments.

If we used the money committed to the solar power satellites for providing incentives for solar development, we believe we could achieve the CEQ's goals. For instance, by installing hydroelectric generators at existing small dam sites around the country, we could create as much power as that generated by over $125 billion worth of solar satellites. While the cost of such installations cannot be predicted, it seems very doubtful that they would even be a fraction of the solar power satellite cost. Money spent on solar satellites could be used to build windmills—in Europe, there are already windmills producing many kilowatts of electricity at costs much below current energy prices for other kinds of electrical generation. For one-third the cost of the satellite program, we could install comprehensive solar systems on every house in the country, without the homeowner paying a cent.

All these solar developments could lead to a solar society in which a large variety of approaches was implemented by a competitive, diverse industry. Failure of one segment or approach would not be a societal disaster. By contrast, the solar power satellite approach would be a militarily and economically vulnerable system controlled by a few giant companies—and representing mind-boggling prior investments. Problems with this system would be of crisis proportions. Given these choices—and realistically, we must see them as choices—it seems obvious that what we should be doing is making a serious commitment to human scale solar technology now.

I therefore urge that this bill should not be considered until this concept has been thoroughly evaluated by the DOE–NASA study.

Statement of Charles Domm, President, KingDOMM Improvements, Inc., Baltimore, Md.

Mr. Chairman, it is an honor to appear before your committee to discuss opportunities for our nation's growth and well-being. Decisions and policies considered from this meeting will undoubtedly be wise and improve the welfare of this generation and all future generations of Americans and others.

Allow me to present but just a few thoughts to this honorable panel regarding my position as a trainer and developer. I help train disadvantaged persons in marketable job skills especially for the home improvements industry. I am particularly favored towards aiding those persons most frequent to our welfare roles, those of the poorest educational achievement in our major cities, and those who foster little hope for a positive future. This training is both time consuming and costly, but it is also able to be productive for the recruited trainee, the trainer, and eventually for the society-at-large. Such programs for personal and collective development are analogous to the establishment of a "Solar Power Satellite Program" where the future wellbeing of our nation in particular and all nations eventually must be considered in long term packages rather than with expectations of immediate cost-effective returns.

I am speaking here of survival-planning for the human species where we, as intelligent and foreseeing creatures, make adequate plans for sustaining life and the quality of life that we are accustomed to living. It is clear to many contractors and developers that much of our national planning in terms of energy and natural resources has been less than adequate from many years ago. In recent years, however, there has been an increasing trend in Washington towards developing long term and life-sustaining policies, regulations, and general guidelines. This effort is saluted, but now is the time to emphasize that we need even greater foresight and effort than ever before.

As a developer of both human and ground resources, I see the proposed Senate Bill 2860 as another opportunity to help build a stronger nation and world. First in terms of training people for the ground level construction of "energy collectors" placed strategically throughout the country to best meet urban energy demands. Second, I see these "trained workers" as continuing in our labor force in both domestic and global residential and commercial markets for solar energy. The builders of the ground stations would gain an education regarding energy, supply and demand, space technologies, and a true spirit of teamwork. Plus, a new national pride is most likely to be experienced similar but better to what was felt during the Apollo missions and the landing on the moon.

This Bill proposed by Senator Melcher (S. 2860), is what we need to bring a greater unity amongst American people. We need to close the existing gaps in attitudes regarding "elitist technologies" and "down home strugglin' ". We need programs and a national impetus for bringing all Americans into a recognized new life—a life of long term hope and promise. Space, energy, and technology are not elements of existence to be feared by any of us. These are elements to be understood and made useful for all of us. The great gap existing between knowledges held by our leaders and knowledges held by our masses or unemployed, uneducated, and unskilled—can be effectively bridged in a relatively short space of time through careful staging of programs geared towards Space systems and Space/Earth systems. There are many methods for progress, and some are much better than others. In this case, I see the opportunity for research and development that combines long term energy planning, long term job training, long term economic productivity, long term growth of American Spirit and pride, and long term satisfaction through developing a unified effort of a non-military nature.

I urge this committee to consider these areas of human development along with the considerations for the overall development of solar power satellite programs. And, I will deeply appreciate the committee's transmission of these concerns to the appropriate legislative and executive bodies.

As is usual for me in helping others to plan for long terms, I hope each of you have a nice eternity. Thank you.

TESTIMONY IN SUPPORT OF THE SOLAR POWER SATELLITE RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAM ACT OF 1978 - DR. BRUCE FRIEDMAN, CHAIRMAN, DISTRICT FIVE ENERGY COMMITTEE OF B'NAI B'RITH

The District Five Energy Committee of B'nai B'rith sincerely appreciates this opportunity to testify in support of the Solar Power Satellite Research, Development, and Demonstration Program Act of 1978. District Five comprises the Washington, DC area, Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida.

In addition to testimony directly pertinent to this power satellite legislation, it has been deemed appropriate to make some general remarks pertinent to the entire energy problem in this nation and indeed relevant to other problems which this nation faces. The motivation for these general remarks arose as a result of comments made by some Congressional staff people in the course of conversations dealing with the power satellite bill.

The author was told that there are people involved in the development of solar heating for homes who are apparently opposed to this power satellite legislation because it would divert funding from their field of endeavour. Along the same lines, the view was expressed that perhaps work on power satellites should not be expanded beyond the current meagre level because the federal research and development budget for all solar energy work is approaching an upper limit and consequently power satellite development would proceed at an accelerated pace at the expense of sacrificing other solar energy projects. These remarks are based on certain unstated assumptions.

One assumption is that the work to be performed under the power satellite program has nothing to do with earth-based solar energy applications. This is certainly not the case. The research and development program which is necessary to attain eventually a successful, economical power satellite system is of such a broad-based nature that it can be used to improve the performance of all other solar energy systems. Consider, for example, the situation with respect to photovoltaic solar cells. A power satellite system based on the use of such cells could very well utilize hundreds of square miles of such cells. For maximum economy, these cells would have to be as efficient as possible with respect to energy conversion in order to reduce the size of the satellites and also be capable of being manufactured with a minimum of expense. Certainly, these characteristics are also highly desired by the homeowner and industrialist who would like to help run their home and factory complex using solar cell arrays on their land and buildings. True, there are differences between the survival characteristics of solar cells for space use as opposed to those for use down here on the earth but the knowledge gap could be readily closed by appropriate additions to the federal solar cell technology research and development budget.

Another example of the commonality between the requirements for space-based solar energy and earth-based solar energy arises from the possibility of interposing between the solar energy stream itself and the energy conversion devices such as solar cells or Brayton cycle steam engines, some auxiliary apparatus and/or materials to increase the collection efficiency and/or energy conversion efficiency of the overall system. One might want to utilize mirrors and lenses to concentrate the incoming radiation and make it more intense. These sort of concentrators could be used down here on earth for both solar heating panels and solar cells. There are materials that could be placed in front of solar cells which materials could modify the spectral intensity distribution of the incoming solar radiation so as to put more of the radiation into that spectral region wherein the solar cells could most efficiently transform the radiation into electricity. These materials, too, could be used both on the ground and in space.

Another example of how results from the power satellite program would aid in the further development of earth-based systems is in the area of tracking and attitude control. Devices derived from this aspect of the program would certainly be of benefit in those ground applications where the sun has to be tracked more or less continuously to obtain the maximum amount of solar radiation.

It is thus readily concluded that most of the research and development to be undertaken under the power satellite bill will be of great utility in terms of contributing to the enhancement of ground based solar energy systems. However, in no way could the current inadequate power satellite studies in addition to the other current Department of Energy solar energy programs lead to a timely assessment as to the viability of a power satellite system to be used to augment the energy posture of the nation.

Now, consider that other statement that the proposed power satellite program could essentially only be implemented to the detriment of other solar energy projects. This remark apparently stems from a feeling that the overall federal budget must be balanced so that the growth of this budget is essentially severely limited. Why must the federal budget be balanced? The popular thinking is that this exercises a significant restraint on the rate of growth of inflation while, of course, increasing unemployment. Is this true? Popular thinking is apparently quite shakey in this area. Some economists who have studied this assumption have come to the conclusion that cutting federal government spending by an amount that would have a truly significant effect on inflation would produce such terrible unemployment that it could well lead to the political suicide of the elected officials involved. It is quite possibly true that many Senators, Representatives, and Congressional staff people are aware of this analysis. However, because of the feeling that "politics is the art of the possible," and that one should go along with the popular will, few political figures are willing to go counter to the beliefs of the public.

B'nai B'rith, after long and serious consideration, has come to the conclusion that this "either or" way of thinking is self-defeating and is courting eventual long term disaster for the nation. New investments of many billions of dollars over many years should be invested in order to bring to fruition all of the viable energy options. The economic well being of the nation and the quality of life of the individual is very dependent upon a dependable supply of energy which supply should

35-994 O - 79 - 11

continue to grow over the years so as to assure a plentiful supply of goods and services equitably distributed among the citizens of the nation. A plentiful energy supply will fight both inflation and unemployment. Thus continuous new investments for research, development, and deployment of all of the viable new energy sources, which investment avoids the dangerous possibility of putting all of our energy eggs into one basket, will yield results quite different from the popular misconception about federal government spending. If the nation does not follow this course of investment, the result may eventually be, among other possible spectres, a severely energy deficient society wherein a minority power elite hoards energy for its own use and pleasure while doling out a bare minimum to the majority of the populace which populace would essentially be surviving at a subsistence level.

B'nai B'rith feels that the only limitation on the sum total of investments to be devoted to energy development, and to other productive areas, should be the availability of trained personnel and of resources and equipment, and of the rate at which new trained people and resources and equipment can be generated and put into the economic system. By this criterion, much more can be accomplished in the area of energy research, development, and deployment by the federal government than is now being done. B'nai B'rith hopes that as time goes by, more people in the political arena will take this more expansive viewpoint concerning investment to safeguard the future of the nation.

In case anyone is worried about the nation devoting too many engineers and scientists to the energy area to the detriment of other important fields of endeavour, it is instructive to consider an analogous situation from the not-so-distant past of the nation. When President Kennedy announced his decision that the United States would send men to the moon, some critics expressed the very same fears about a shortage of engineers and scientists for other, nonspace projects. This shortage never materialized. In fact, upon the completion of Project Apollo, many of the people employed by it could not obtain other meaningful positions compatible with their background and training. Careers and even lives were destroyed. What a waste!

Some people, it should be noted, when they think of energy think only in terms of energy conservation. By itself, energy conservation can add nothing new to our energy supplies but merely postpones the day when our present depletable energy sources are consumed. Energy conservation does buy time in which to develop new energy sources among which one possibility is the power satellite system.

B'nai B'rith is not yet prepared to advocate the "full speed ahead" construction of a system of solar power satellites. Because of the present lack of knowledge and experience in this area, it would be both premature and irresponsible for B'nai B'rith to take such a position at this time. It is for this very reason that B'nai B'rith wholeheartedly supports the Solar Power Satellite Research, Development, and Demonstration Program Act of 1978 so that the gaps in science, technology, and engineering can be eliminated in a more expeditious manner than with the present totally inadequate funding. Further, B'nai B'rith feels that if the proposed power satellite program can usefully absorb such funds, the amount of money allocated to this program for the first year should be greater than twenty five million dollars and that the funding in following years for this work should be commensurably higher. The sooner the nation has the requisite data to make a decision as to the viability of power satellites as an energy option, the sooner the nation can undertake more sensible planning for its long term energy development.

B'nai B'rith wants to make it clear that it does not regard any particular energy source, including power satellites, as a panacea. In any event, even an aggressive program based on a positive decision to go ahead with the construction of a power satellite system as a result of the expeditious completion of the power satellite bill program under discussion in this testimony here could not lead to any significant contribution to the energy posture of the nation until after 1995. B'nai B'rith feels that the nation should never rely completely on just one energy source. This means that even if a commercial power satellite system is put into operation, nuclear fusion and ground-based solar energy should, among other energy sources, be playing major roles in the long term energy posture of the nation.

It is now appropriate to consider the nature of the work that B'nai B'rith expects to see performed under the proposed legislation. The Final Report of the ERDA Task Group on Satellite Power Stations published in November 1976 presented seven options with comments as to the pros and cons for each approach of which the selection of an option was intended to get some work started (aside from the first option which required no work whatsoever) on power satellites. (It was, by the way, this report which noted that the power satellite concept was the only solar electric approach to energy production that appears to yield the possibility of generating a significant amount of base-load power without suffering from major drawbacks with regard to geography.)

The third and fourth options were recommended to the Administrator of ERDA. The third option required funding of twelve million dollars over a three-year period. This option would have had quite modest consequences for the total ERDA solar energy budget while it would have increased the data base with regard to environmental factors (including those criteria to be used as a basis for system definition studies), institutional and training factors, the siting of receiving antennae and the technical and economic feasibility of the overall system. Option three had the drawbacks of not producing more knowledge in the areas of alternate thin-film arrangements, microwave radiation transmission, assembly techniques and methodology, and space transportation, although it would have been of some aid in determining the economic viability of the system and the energy payback to be expected from it and the material resources required for its construction and maintenance. The fourth option would have had a slightly greater impact on the ERDA solar budget since it involved the allocation of nineteen million dollars over a three-year period. As in option three, the data base would have been increased in the areas of environmental, institutional and training factors and receiving antennae siting. It would have increased the feeling that no major technical or economic problems would block power satellite development and possibly allow a high risk initiation of advancement in technology. It was felt that a possible objection to this plan was that it would raise funding early before the feasibility of the program was determined. B'nai B'rith would not have objected to a high funding level.

The most ambitious option presented by the task group was the sixth one which would have involved the allocation of thirty-four million dollars within a timespan of three years. This option would have been in accord with the Draft Plan of the NASA Office of Energy Programs and would have increased systems-definition and microwave transmission studies. Again, it was noted that some critics might have objected to this option because it would increase funding early before program feasibility was established. Option six is the plan that B'nai B'rith would have wanted to have implemented immediately after the issuance of the task group report. However, even this option might have been deficient in the areas of studying transportation (earth to orbit and orbit to orbit), receiving antenna siting, productivity of people in space, planning for phased experiments, economics of the power satellite system and institutional and international factors and implications.

The currently underway joint NASA/DOE Solar Power Satellite Concept Development and Evaluation Plan which was started in fiscal year 1977 and will terminate in fiscal year 1980 calls for the expenditure of about sixteen million dollars over a four-year period. This averages out to four million dollars per year which is the same average which is obtained from option three of the ERDA task group report. The current project suffers from all of the drawbacks mentioned in the ERDA report with regard to option three. Even from the point of view of strictly theoretical studies, this plan is grossly inadequate. Space related technology studies were funded only for the first year of this plan. Certain possibilities and modes of implementing a power satellite system have apparently been rejected prematurely under the ongoing plan. For example, consider the prospect of constructing a power satellite system utilizing largely nonterrestrial materials such as might be obtained from the moon or the asteroids with the aim of reducing construction costs and of reducing the enormous launch rate required from earth bases if only terrestrial materials and components are utilized. At this time, no one could truly say yes or no to the validity of this proposal. No amount of strictly theoretical studies can yield a sound determination as to this concept being the way to go although many more theoretical studies into all respects of a power satellite system are certainly warranted and should be undertaken. But above and beyond theoretical studies, many experiments both on earth and in space must be performed, hardware for space and earth must be constructed and put into operation, and actual entire complex orbital test facilities implemented and utilized to gain data and operational experience before many questions can even be properly phrased and meaningful decisions can be made. Suppose that all of this is done within the next five years as could be reasonably expected under the proposed legislation. (Five years seems to be a reasonable period of time within which to undertake each a research, development and demonstration program because after all, assuming that the results of the program, including environmental considerations, are such that it is decided to proceed with the construction of a full scale commercial power satellite system, in order to get the first satellite on line by 1995 would probably mean the project would have to start by about 1985.) At this point, five years from now, it would be much more realistic to make decisions about various aspects of the construction of the commercial system than can be done presently. It should be pointed out that the decision making processes, including those involving the nonterrestrial materials utilization route, could very well be accelerated if the proposed program under discussion here is undertaken as part of a generalized space industrialization implementation program which space industrialization is firmly supported by B'nai B'rith.

This power satellite bill is urgently necessary and desirable because so many questions must be expeditiously answered and so many factors understood and mastered. B'nai B'rith recommends that this program include the deployment of at least two orbital solar power satellite test facilities utilizing a maximum of modular construction so as to assure the most flexibility in a thorough investigation of the factors involved in the construction and operation of a power satellite system.

These orbital facilities should also be capable of having their orbits altered as required.

Consider some of the factors and questions that have to be addressed. Should all of the satellites of the system be maintained in geosynchronous orbit or should other types of orbits be considered? What are the environmental consequences involved with transmission of many microwave beams from space to the surface of the earth? Are there alternatives to microwaves for the transmission of satellite energy to the earth which would be more efficacious and have less environmental impact? What is the best way of converting solar energy in space into electricity on a power satellite? Possibilities include photovoltaic systems, thermal electric schemes utilizing Brayton cycle engines, and dielectric conversion systems. What sort of impact could be expected upon the environment from a high rate of launching of heavy lift launch vehicles? What kind of protection can be provided for a power satellite system in the event of attack by a hostile nation? What kind of deterioration can be expected by many years of exposure to the space environment and what is to be done to maintain a system against this contingency? How are such very large space structures to be constructed in an efficient manner? For example, what proportion of the work is to be undertaken in low earth orbit as opposed to being done in geosynchronous orbit? This, in turn, is a function of whether or not and how much the nonterrestrial materials approach fits into the picture. How is satellite solar power to be integrated in with other sources of electrical energy for the nation?

How is waste heat on board a power satellite to be managed? What sort of stabilization and orientation systems are required for these orbital power plants? How much of the orbital construction operations must be performed directly by space suited people and how much by automated and remote control equipment? These questions and the many myriads of others can be answered satisfactorily and in a timely manner only by this proposed legislation. It is definitely in the national interest to ascertain as soon as possible whether or not solar power satellites would be a viable and valuable addition to the energy sources of the nation.

Consequently, the District Five Energy Committee of B'nai B'rith fully supports the passage and vigorous implementation of the Solar Power Satellite Research, Development, and Demonstration Program Act of 1978.

ABSTRACT OF TESTIMONY IN SUPPORT OF THE SOLAR POWER SATELLITE RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAM ACT OF 1978 - DR. BRUCE FRIEDMAN, CHAIRMAN, DISTRICT FIVE ENERGY COMMITTEE OF B'NAI B'RITH

The United States of America faces the possibility of suffering from a severe energy shortage at sometime in the future. This means that new energy sources must be expeditiously developed. The solar power satellite is a promising energy source concept. Current work on the concept is totally inadequate as to yield a timely determination as to the viability of this concept as a major contribution to the energy posture of the nation. The proposed legislation will allow such a timely decision to be made. Consequently, the District Five Energy Committee of B'nai B'rith fully supports the passage and vigorous implementation of the Solar Power Satellite Research, Development and Demonstration Program Act of 1978.

BIOGRAPHICAL DATA

Born June 21, 1939, Brooklyn, New York. Graduated Brooklyn College, Brooklyn, New York, June 1960, B. S., Physics. Graduated Syracuse University, Syracuse, New York, Ph. D., January, 1969, Physics. From July 1967 to January 1970, worked in Naval Applied Science Laboratory, Brooklyn, New York. Most of the time between that job and my reporting to my present job at the David W. Taylor Naval Ship Research and Development Center, Annapolis, Maryland in September, 1974, I worked at the American Institute of Physics, New York, New York. Here in the Annapolis R&D Center, most of my time has been spent in the Pollution Abatement Division.

Testimony of Myron W. Burr II

University of California, Berkeley

Department of Mechanical Engineering

Student

before the Subcommittee on

Energy Research and Development

of the Committee on

Energy and Natural Resources

United States Senate

August 14, 1978

My name is Myron Burr. I am a mechanical engineering student at the University of California, Berkeley. I recently had the outstanding experience of working with the National Aeronautics and Space Administration's Ames Research Center as a research assistant on the SOLARES Project. The SOLARES concept proposes a system of reflectors orbiting the earth to provide continuous and slightly concentrated sunlight to be collected and converted to electricity or to be used directly as a heat source for various uses. Through this project, I was introduced to the related Solar Power Satellite (SPS) idea and learned a great deal about its potential capabilities and how it compares with other systems. I am returning to school this fall and, therefore, am no longer employed by Ames Research Center. Consequently, my testimony is not of an individual who has any financial gains or rewards at interest. My testimony is solely that of a concerned private citizen who has a little knowledge in the field.

Most of us realize now that there are no simple solutions to the energy problem. We realize that many different technologies will have to provide us with solutions and that we must take a broad-based approach towards examining each alternative. We must also start to develop our nondepleteable resources so that we can conserve as much as possible the remainlng nonrenewable resources for non-energy needs.

One of our most promising nondepleteable options is that of solar energy, because of the relative ease in harnessing it and its widely distributed nature. If cost-effective applications can be developed solar energy can provide the needed resource on an unlimited basis. It has been determined, though, by technology assessments of solar energy and its potential for our future energy needs, that without strong government support and incentives, the tapping of solar energy and its cost-effective usage on a widespread basis has very little chance.

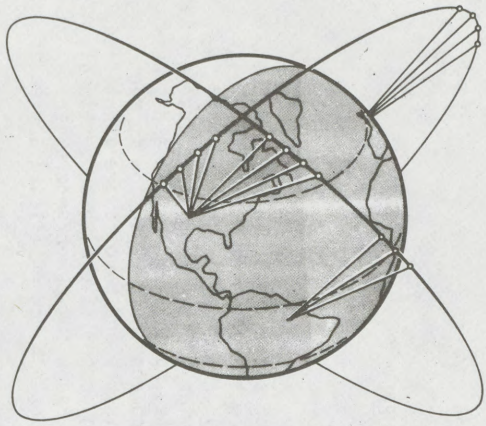
We see, therefore, that if we wish to contribute to the solution to the energy problem by exploiting this nondepleteable resource, passage of legislation such as S. 2860 is necessary.

The passage of this bill at this time is needed for other reasons, also. Dr. Jerry Grey, Administrator of Public Policy for the American Institute of Aeronautics and Astronautics, in testimony before the House Subcommittee on Advanced Energy Technologies on H.R. 10601 (April 12, 1978), provided an excellent statement of these reasons. These reasons will be summarized as follows:

The Department of Energy is scheduled to define a "baseline" SPS system before the end of this year. This definition should be postponed until it can be based on an extensive "technology verification program" which would include not just one SPS concept, but many. This would enable comparison studies to be made and a mixture of the best components of each concept would determine a preferred concept. This also would avoid premature decisions on a preferred concept that might not produce the system with the best potential. Only when this technology verification program is complete and extensive comparison studies have been made between the various concepts should a prudent attempt be made to define a "baseline" system or preferred concept. The bill's provision for "ground-based research leading to a solar power satellite total system definition" indicates that there is a provision for this type of program.

Recognizing this bill's provisions for the thorough investigation of the SPS idea and its possible beneficial impact on the future energy situation, I wholeheartedly favor it. An SPS concept would also have the potential to reduce the huge trade deficit caused by the large disparities in our import and export of energy. Additionally, a re-escalation of the aerospace program brought about by the SPS would, as it has in the past, bring about many technological advancements that would benefit mankind. It is for these reasons that I strongly encourage the Committee to work to obtain passage for this bill within the Committee and within the Senate, and thereby, take a strong leadership role towards solving the energy problem for this Nation and possibly for this World. Thank you.

SPACE **O**RBITING **L**IGHT **A**UGMENTATION **R**EFLECTOR **E**NERGY **S**YSTEM



AMES RESEARCH CENTER

K.W. BILLMAN
W.P. GILBREATH
S.W. BOWEN

35-994 O - 79 - 12

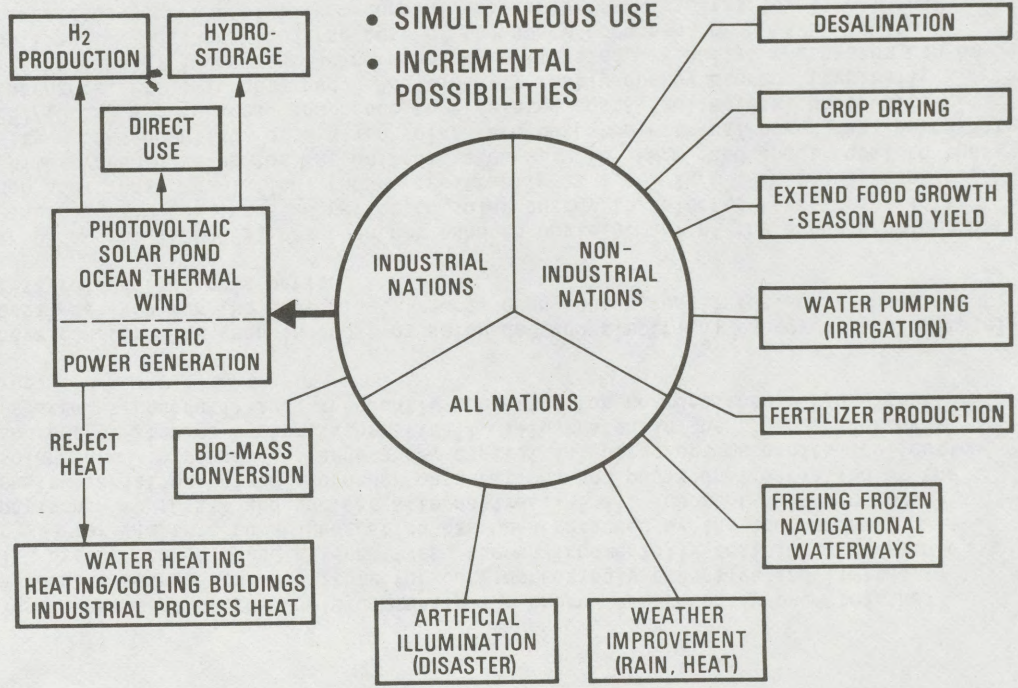
ORBITING MIRRORS FOR TERRESTRIAL ENERGY SUPPLY

A system of orbiting reflectors, SOLARES, has been studied as a possible means of reducing the diurnal variation and enhancing the average intensity of sunlight with a space system of minimum mass and complexity. The key impact that such a system, providing <u>continuous</u> and slightly <u>concentrated</u> insolation, makes on the economic viability of solar farming and other solar applications is demonstrated. New developments in solar sailing are incorporated to reduce space costs, namely mirror mass and transportation. The system is compatible with incremental implementation and continual expansion to meet the World's power needs. Key technology, environmental, and economic issues and payoffs are identified. SOLARES appears to be economically superior to other advanced, and even competitive with conventional, energy systems and could be scaled to completely abate our fossil fuel usage for power generation. Development of the terrestrial solar conversion technique, optimized for this new artificial source of solar radiation, yet remains.

It is clear at this time, however, that the SOLARES system could provide solar energy to any number of traditional uses such as those shown in the figure. Most importantly, these could be <u>simultaneous</u> applications wherein those mirrors over industrial nations could be producing electrical power while those over agrarian nations could be providing energy for such needs as desalination and pumping of water, etc., again with the economics attendant to continuous and concentrated insolation. Indeed, some such uses may prove economically unattractive when further analysis is made. But it does indicate a flexibility of applicability possessed by no other advanced system and one of more general attractiveness to the World community than the exclusive production of electrical power.

SOLARES APPLICATION

- MULTIPLE USE
- SIMULTANEOUS USE
- INCREMENTAL POSSIBILITIES

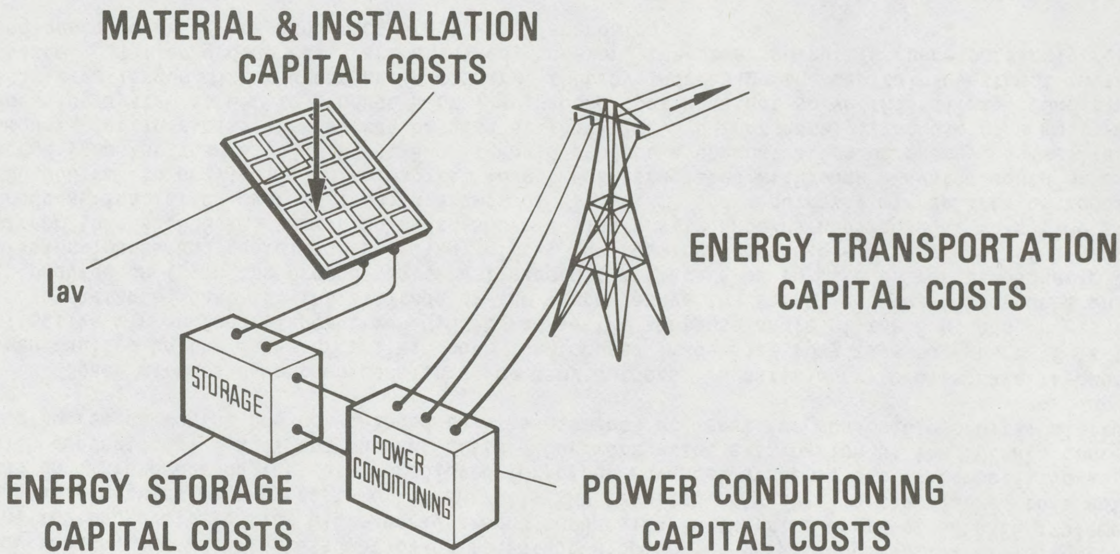


The seemingly insatiable need of the world community for energy has recently prompted the examination of many alternate sources to substitute for our increasingly expensive and limited supply of fossil fuel. Use of one of these alternatives, the environmentally desirable, renewable resource - solar energy - for electric power generation has been retarded by the economics of solar farming in comparison with fossil and nuclear alternatives. Small inherent solar energy density, diurnal intensity variation, cloud and other obscuration, and positional variation of the source require the "solar farm" to possess a large area, capital intensive optomechanical collection or conversion array and energy storage system, schematically illustrated in the figure. Furthermore, this expensive system is underutilized, frequently operating for no more than 6 h/d without and 12 h/d with storage.

These factors have conspired to keep the cost of solar-derived electrical energy at approximately five times that of fossil-derived for the past ninety years, even though fossil fuel costs have increased more than fiftyfold during this period.

The orbiting mirror system, SOLARES, has been designed to obviate many of the above problems by providing continuous and slightly concentrated reflected solar energy to selected terrestrial solar conversion sites. Such additional insolation, chosen arbitrarily as $I_o \approx 1$ kW/m^2, is significantly higher than the best time-averaged value for the United States of 0.25 kW/m^2 and about equal to the peak, noontime intensity. Consequently, for a given solar farm output electrical power, an approximate reduction of $(1 + 0.25)/(0.25) = 5$ in area, and hence area-related costs (collectors, photovoltaic converters, land, maintenance, etc.) is obtained. Additionally costly energy storage (typically one-half of the solar farm capital investment) can be nearly eliminated. Finally, the system can be nearly continuously utilized. Thus, provided the cost of the space component of SOLARES is low enough, substantial reductions (ca. 5 to 10) from conventional solar farm capital investment and resultant electrical energy cost may be realized.

SOLARES
IMPACT ON ECONOMICS OF SOLAR ENERGY PRODUCTION

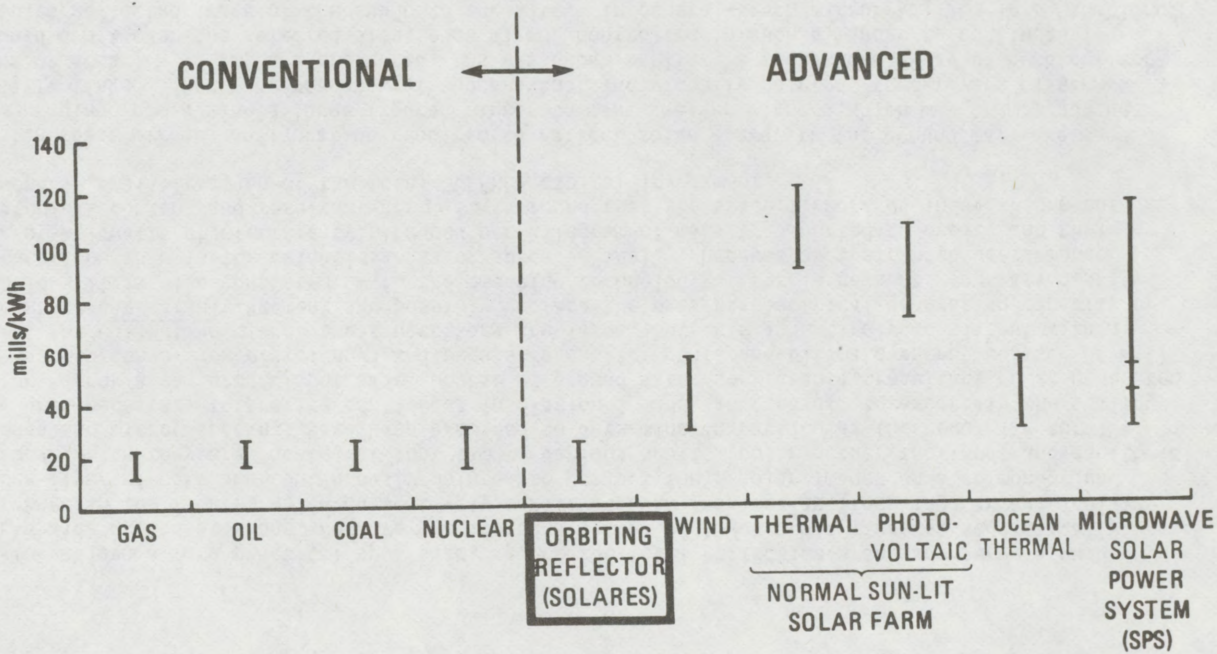


CONCLUDE: FROM 1890-1977, COST OF SOLAR ENERGY HAS REMAINED FIVE TIMES THAT OF FOSSIL ENERGY

Indeed the initial assessment of this concept did show that space costs could be low enough, and with the assumption of modest development of mass-produced, 15% efficient cadmium sulfide photovoltaic flat plate array ground conversion in the time frame of SOLARES implementation, busbar electrical energy costs of 10-20 mills/kWh resulted. As seen in the figure, this not only was an improvement on the costs predicted for other advanced systems, but is competitive as well with conventional fossil and nuclear costs. Our more exact examination of the SOLARES concept during recent months has not changed this assessment, at least for reasonable orbital altitude.

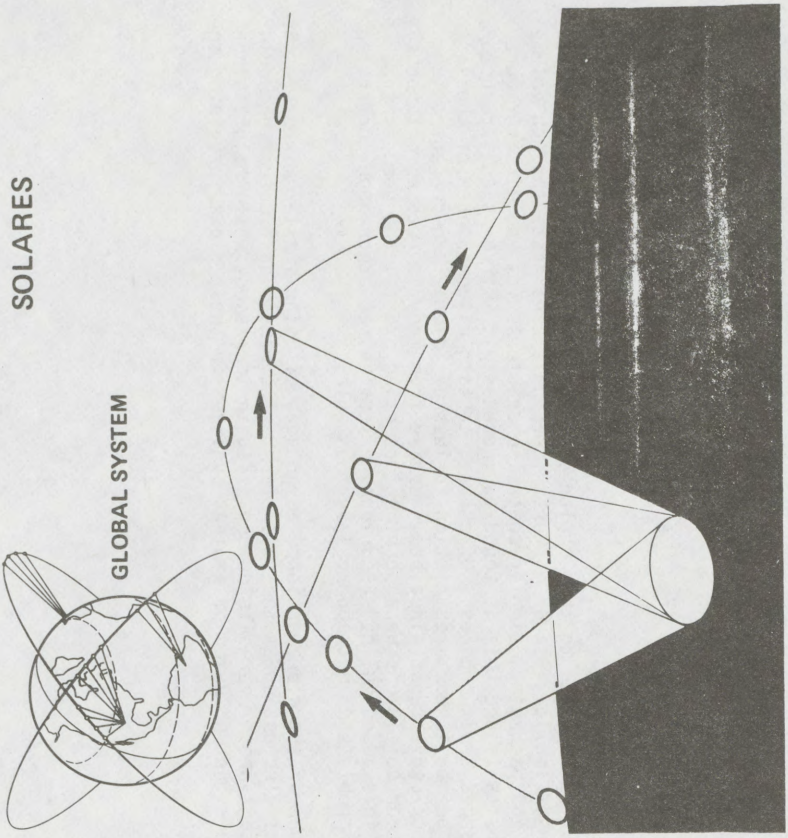
Space mirrors have been considered by many authors. Geostationary orbits have frequently been faulted on the basis of scale: both the focused image size ($D = f\alpha = h\alpha$, where f is the effective mirror focal length, $\alpha = 0.0093$ rad is the subtense angle of the Sun, and h is the image distance, that is, the altitude of the mirror above the Earth) and the mirror area which, to provide an I_o in the ground spot, must exceed the image area to make up for atmospheric transmission losses and geometric spreading. Thus, the seemingly desirable arrangement of a geostationary mirror ($h = 35,800$ km) remaining fixed above a single site appears nonviable at this time since it produces insolation over an area in excess of 87,000 km^2 and requires a mirror area of about 200,000 km^2 to provide I_o! The capital investment associated with such a system would be exceedingly large (greater than \$4.5 x 10^{12}), and it would produce a concentration of energy, as well as an amount, far in excess of what can be used at this time. Unfortunately, the use of a multi-mirror focusing system at GEO to produce a smaller ground spot does not solve this dilema. One finds that even larger mirror areas are necessary, thereby increasing the capital investment in the space system. Smaller ground costs are attained; however, the power output is correspondingly reduced and hence, overall the economics are further acerbated.

SOLARES
ELECTRICAL ENERGY BUSBAR COST (1976 DOLLARS)



To achieve a more practical spot size, reduce the total reflection area, and serve a number of world-wide ground stations, we have considered a system of lower orbit mirrors, schematically illustrated in the figure, which collectively constitutes an Archimedian (focusing) array; individual free-flyer mirrors are continuously pointed to project their solar images on a common ground spot above which they are located at that time. Various orbits (polar, other inclined, and equatorial), altitudes and mirror spacings have been examined to determine in particular the requisite total mirror area necessary to provide continuous insolation I_o and, in general, to ascertain the scaling laws for mirror area, ground spot size, number of ground sites serviceable, resultant power generated (with assumed conversion efficiency) and requisite capital costs and ultimate energy costs. As will be seen, the collective mirror areas necessary are large, but this is entirely consistent with a system which can sizably augment and possibly replace the present electrical generating capacity of the World. It is also consistent with the emerging technology of the large area, low mass density structures possible in the weightlessness of space. Finally, because of their high performance factor of kilowatts of electricity produced per kilogram of mass transported to orbit, and their low materials content and resultant cost, it is found that the space mirrors do indeed represent a reasonably small fraction of the total SOLARES capital investment.

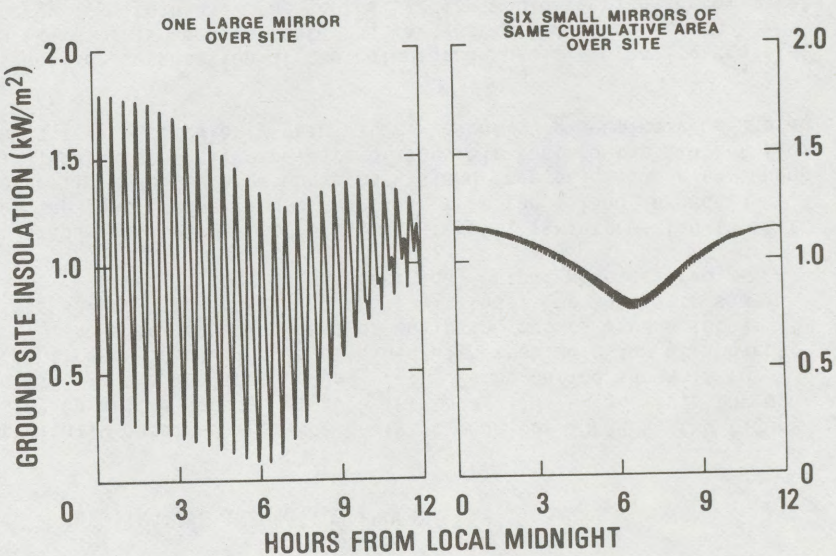
The space mirror configuration required to reflect solar energy to the ground may take many forms, ranging from a single large figured mirror to many smaller mirrors which may or may not be physically linked. For many reasons, it appears that individually pointed, free-flyer, planar mirrors of area 1 - 10 km^2 are preferred. As was shown earlier, a continuous array of such reflectors would orbit over the selected site, each mirror controlled in such a manner to continuously direct its reflected image of the sun onto the site. In general, each mirror will be in a "tumbling" mode, i.e., rotating about its diameter, as it orbits around the Earth. As will be seen, slight accelerations will suffice during the "over site" operational period (the time for the reflector to move from 30^o at one horizon to 30^o at the opposite horizon) to modify this free rotation angular velocity so that the reflected image of the Sun remains fixed on the site.


SOLARES
GLOBAL SYSTEM
FOCUSING MIRROR ARRAY

There are many factors which have led to this choice of a free-flyer focusing mirror array: easier mechanical fabrication of smaller, planar mirrors, lower unit area costs through volume production, easier deployment and packaging, simpler control characteristics and mirror figure maintenance, reduced areal density (since this is found to <u>increase</u> with mirror size), reduced insolation variation, and expanded orbit choices. Of course, certain disadvantages of the large number of mirrors also should be mentioned: restriction to less efficient, non-concentrating, flat plate terrestrial collector/converters (since beams arrive from many sources simultaneously); the need to avoid possible mirror collisions because of intersecting orbits; the need to track and control many objects; and possible added "glint" (spurious reflection) at other, non-conversion site global locations. These problems do not appear insurmountable.

The figure illustrates one of the aforementioned advantages of using smaller mirrors: the reduction of intensity temporal fluctuation at the solar farm. The remaining fluctuation would be further reduced as the instantaneous over-site number is again increased, while maintaining constant cummulative area. Note the inclusion of ambient sunlight in these plots, providing the increase between hours 6 to 12.

SOLARES
TEMPORAL VARIATION OF INSOLATION
WITH MIRROR SPACING



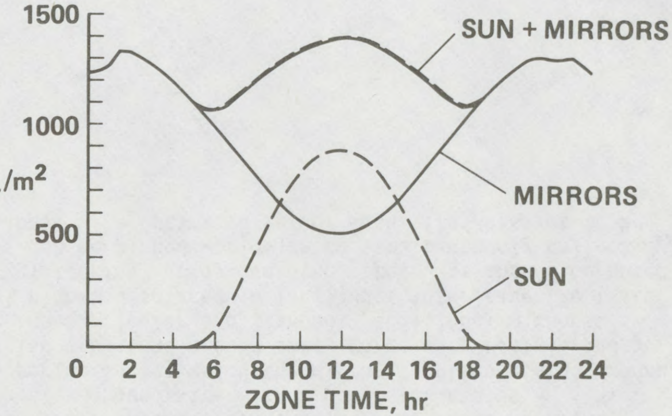
ILLUSTRATIVE INSOLATION PROFILE

To illustrate the results typically obtained from the analytic model of SOLARES, the figure shows the temporal radiant intensity on a site located at 29^{o}N latitude, 118 ^{o}W longitude for our benchmark orbital case. (Altitude 4146 km and inclination 45^{o}) The 24 hr period shown is for 1 July; it is seen that a rather continuous insolation is attained with the inclusion of ambient sunlight. In winter, for this orbit and site, about 3 hours of eclipsing occurs around local midnight. This problem becomes less severe with increasing orbit altitude. For this site some buffering conversion system would be required if continuous electrical output were desired.

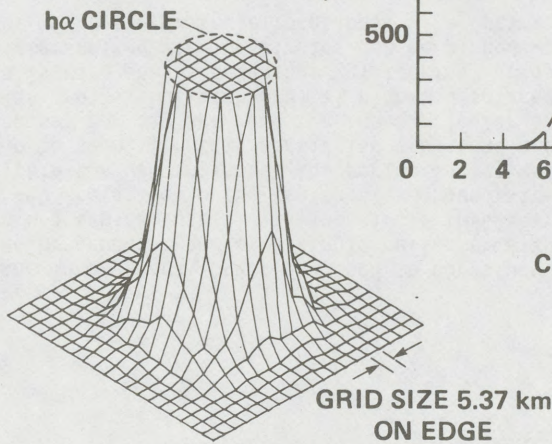
The site chosen, Guadalupe Island, located west of Baja, California, is interesting in that Gemini photographs have shown that the gentle upwelling of warm air from the island, produced by solar insolation, serves to generally keep the area above the island free of clouds even though the surrounding ocean is covered. Thus, a controlled release of sensible heat to the ambient from the site may allow the use of many sites, particularly near water, which would seemingly be unusable because of normal cloud obscuration.

We also show a three dimensional representation of the calculated spatial intensity profile; a circle of diameter $h\alpha$ = 38.6 km (24 mi.) is seen to contain a large fraction of the energy. Approximately 60% of the total energy is within $h\alpha$. The central region would receive approximately 42 Q = 4.4 x 10^{19} Joules/yr for I_o = 1 kW/m^2 and I_{Av} = 0.2 kW/m^2. If the entire radiant input were converted to electrical energy with a conversion efficiency of 15%, this single site would produce an average power P_e = 210 GWe which is to be compared with the current U. S. usage of ca. 250 GWe. Five such sites, located around the world, appear possible for this orbital benchmark case; the total power would exceed current world usage, which is estimated to be 10^{12} We.

SOLARES



CENTRAL INTENSITY



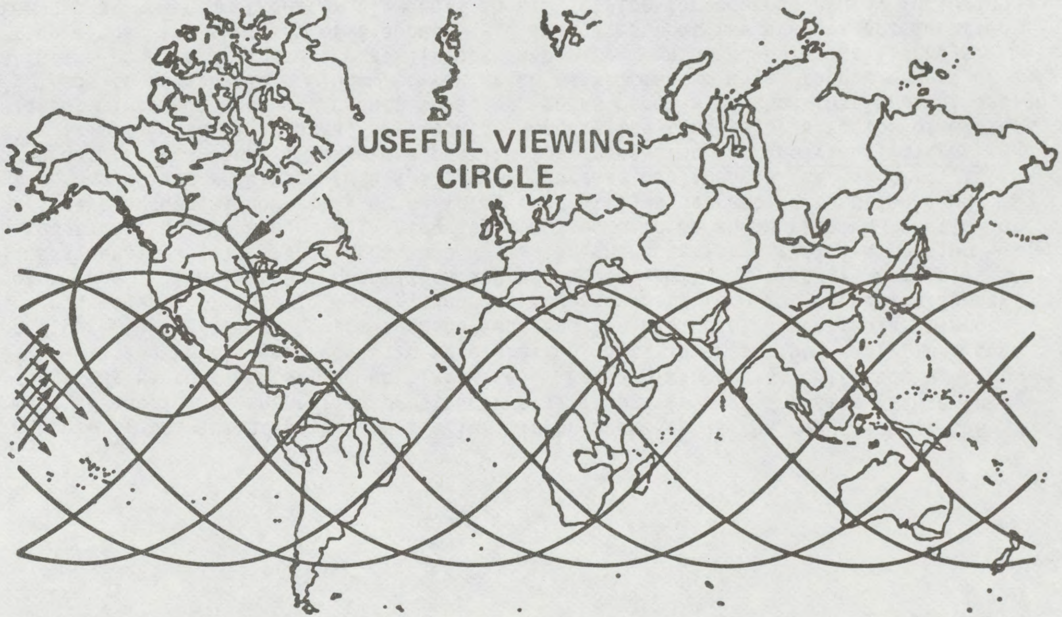
INTENSITY PROFILE

Typical of the more general orbit examined in our study is that shown in the figure which illustrates the 24 hr ground trace of a single reflector with $i = 45^o$ and $h = 4146$ km ($P_o = 3$ hr). Here is also shown a typical useful viewing circle (UVC), i.e., the intersection of a right circular cone of $\pm 60^o$ relative to the zenith of a ground site with a sphere of radius $R_e + h$. A mirror track within the UVC indicates the period during which the mirror supplies useful ground insolation; as can be seen, for this particular orbit and ground site, three very useful, and a fourth less so, passes per day are made for the particular orbit shown. Additional mirrors, placed into similar orbits, but with orbital planes displaced in longitude, interleave the trace shown to essentially make an instantaneous "glittering" array over the site. It should be noted that other, non-intersecting viewing circles can be placed worldwide to simultaneously collect radiation from the mirrors over these locations. The optimized set of such sites has yet to be determined.

SOLARES

TYPICAL SINGLE MIRROR GROUND TRACK
FOR 24 HOURS

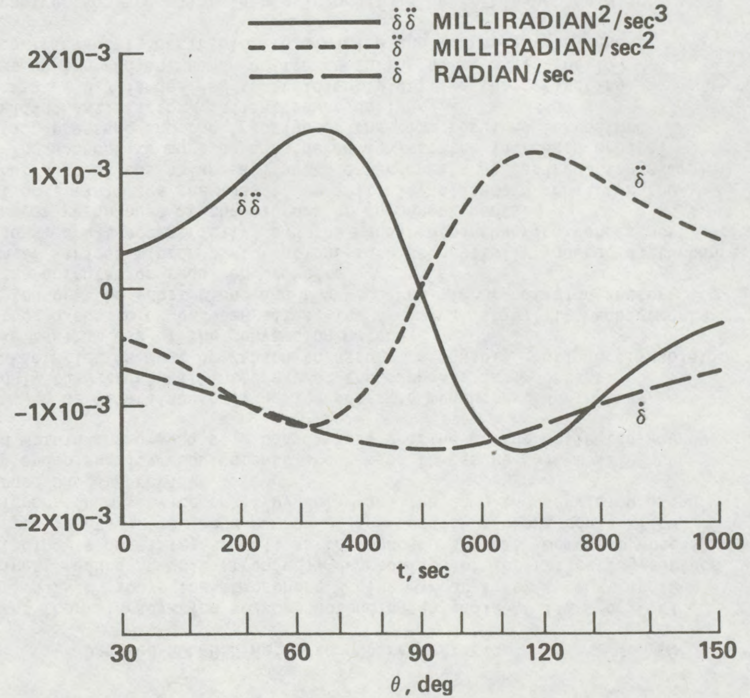
ALTITUDE: 4146 km INCLINATION: 45°



Another example of the advantage of the smaller mirror approach is the reduction of the torques which must be applied to the reflector structure as it passes over the site (since the mirror orbits about the Earth's center and not the site). For a given orbital altitude h, the angular velocity variation $\dot{\delta}(t)$, and requisite acceleration $\ddot{\delta}(t)$ is prescribed; a typical case is shown in the figure for h=2500 km. From such curves, and the choice of a particular mirror configuration, i.e., moments of inertia I_x, I_y, and I_z, the requisite torques, mechanical power, etc., may be determined. Clearly these quantities therefore scale with $I_i \sim \sigma A R_i^2$ where σ is the average areal mass density, A is mirror area, and R_i is the characteristic radial dimension along the i'th rotational axis. Structural integrity requires σ to be an increasing function of R_i (other authors have argued, incorrectly we believe, that it is a decreasing function) and hence I_i, and the torques and required mechanical power increase nonlinearly (ca. as $A^{2.5}$ to A^3) with mirror area. Thus, there is a severe penalty for increasing the individual mirror area; an increase from 1 km to 15 km area, say, would increase the torques by a factor of 870 to 3,340. More elegant mirror designs may reduce this; our point here is to show that present design, with $A \sim 1$ km^2, leads to reasonable $\sigma = 10$ gm/m^2 for which peak momentum wheel torque powers of only tens of kilowatts are required. These are easily obtainable from on board solar cell arrays. Note also from the figure that the symmetry of δ about $\delta = 0$ indicates that the average acceleration is zero, and the use of momentum transfer flywheels should suffice for control needs, including the necessary reorientation between ground sites if the latter are judiciously chosen.

SOLARES

ANGULAR VELOCITY $\dot{\delta}$, ACCELERATION $\ddot{\delta}$, AND PRODUCT $\dot{\delta}\ddot{\delta}$



35-994 O - 79 - 13

Desired SOLARES Reflector Characteristics

The sun is an incoherent thermal radiation source subtending an angle of $1/2^{\circ}$ or 0.01 radian and delivers about 1.4 kW/m^2 above the atmosphere. The mirror lifetime must include meteor damage to the guy wires(redundant multistranded), degradation of the reflecting surface (in situ evaporative resurfacing is possible) as well as the onboard systems (momentum wheels, thrusters, computers, solar cells etc.). A large number of low density mirrors could allow periodic removal of some mirrors from service orbit by solar sailing down and servicing using the operation and maintainence budget provided.

The pointing, tracking and planarity requirements are needed to assure that most of the radiant energy is delivered within the ground site boundaries; phasing of the reflected energy is not required.

The mirror figure needs to be maintained only during oversite maneuvers; during re-orientation between sites only the structural integrety of the supports is important.

The mirror orbital characteristics must be chosen to assure reasonably continuous insolation at the site in order to make maximum use of the conversion method.

During maneuvering either oversite or between sites, the dynamical stability requirements between the mirror inertia tensor, the orbit plane and the required mirror rotation vector must be met regardless of the orientation required oversite.

The frequency spectrum of various mirror purturbations such as orbitally induced disturbances (gravity gradient oscillations, orbit eccentricity) and the required maneuvering forces must avoid the very rich spectrum of resonances of the mirrors or component parts.

A low area density not only minimizes the mass to be initially placed in orbit for the required collective area, but also allows solar sailing to other orbits as desired, for example servicing as noted above. These benefits must be considered against the increased orbital perturbations due to radiation pressure and the fraction of the time required to restore the mirrors to an orbit yielding satisfactory radiant power delivery.

A high specular reflectance 0.9 is desired to efficiently utilize the collecting area placed in orbit interms of the radiant power delivered to the site, while the low, 10^{-4} , diffuse scattering coefficient is desirable to minimize the mirror intrusiveness off site.

Automated assembly, construction and maintainance in orbit is desirable not only to reduce the considerable cost of manned orbital operations, but also to allow more flexibility in orbit selection with respect to the radiation belts around the earth.

Costs of between 2 and \$4 per square meter or \$200 to \$400 per kilogram and an overall operation and maintainance budget of 4 mill/kWhe will allow very favorable competition with even current energy sources.

SOLAR REFLECTOR CHARACTERISTICS

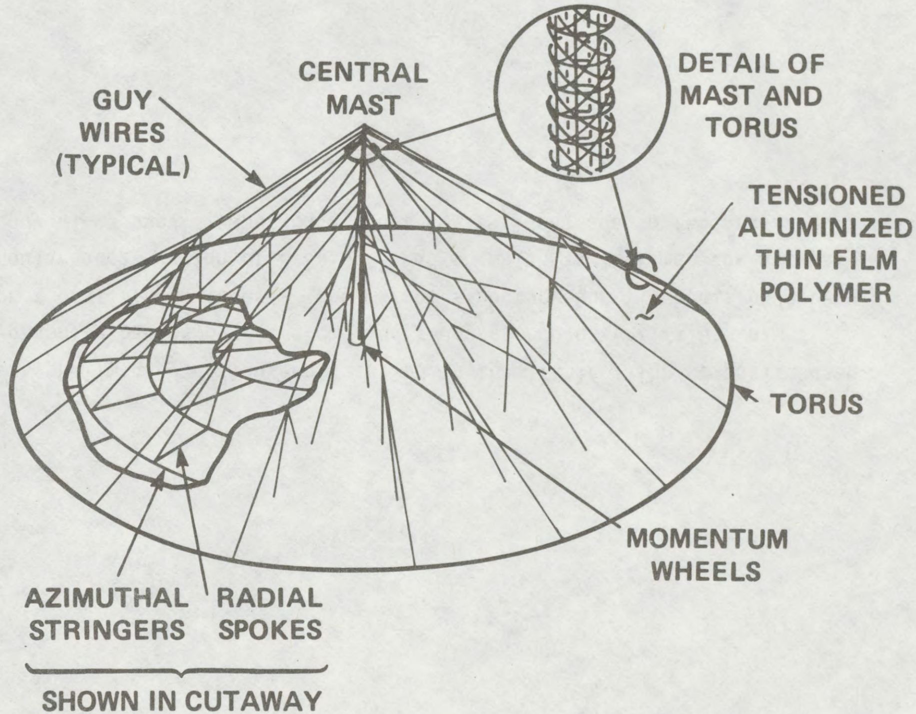
ITEM	REQUIREMENT
• LIFETIME	30 YEARS
• POINTING ACCURACY	250 μrad
• TRACKING	ALTITUDE/10000
• PLANARITY	125 μrad, WRINKLE FREE OVER SITE
• MANEUVERING	TORQUING OVERSITE 2×10^{-7} rad/s^2 REORIENTATION BETWEEN SITES 2×10^{-6} rad/s^2 (4000 km ALTITUDE)
• SITE COVERAGE	CONTINUOUS
• CONFIGURATION	DYNAMIC STABILITY DURING PASS OVER SITE
• STRUCTURAL RESONANCES	AVOID COUPLING WITH ORBIT INDUCED AND MANEUVERING LOAD FREQUENCIES
• AREA DENSITY	10 g/ m^2
• SURFACE PROPERTIES	HIGH SPECULAR REFLECTANCE, LOW DIFFUSE SCATTERING
• COST	2-4 \$/m^2, (200-400 \$/kg)
• MAINTAINANCE	4 mill/kWhe
• GROUND/SPACE, MANUFACTURE/ASSEMBLY	AUTOMATE
• SIZE	CONSISTANT WITH DESIRED INSOLATION, ORBIT ALTITUDE, # MIRRORS, AREA DENSITY

Current Structural Reflector Design

At this time we are in the early stages of assessing the possibilities in the realm of large area, low density structures for space usage. However, to realistically assess the feasibility of SOLARES, both on technical and economic grounds, it has been necessary to design a mirror structure which, in principal, can work. Such a design is shown schematically in the figure. The reflector is a polymeric film of 2.5 μm thickness with 0.1 μm aluminum evaporated onto each face; overall reflector areal density is 4.09×10^{-3} kg/m^2. The film is tensioned onto a supportive structure, consisting of an outer torus, radial spokes, azimuthal stringers guy wires. Such tensioning and support is necessary to maintain the reflector planarity, or "figure" despite the perturbing radiation pressure, gravitational gradient, and angular acceleration forces acting on it. The rim torus must have sufficient buckling strength to provide this tension. The central mast and guy wire system is required to support the spokes and stringers and prevent out-of-plane buckling. The principle demand placed upon the mast structure is to withstand buckling under the requisite torques which must be used for mirror pointing and tracking. The current design postulates centrally located momentum wheels to provide these torques; near term examination will be made of rim-located ablative thrusters which may reduce the mirror masses derived below. We have modeled the mast and torus as thin shells of aluminum matrix carbon fiber composites ($\rho = 2.2$ gm/cm^3 density and Young's modulus of $E = 2.7 \times 10^{11}$ nt/m^2). Substantial reduction in the mast and torus mass will accrue from the use of a stiffened open-weave composite structure, as shown in the figure insert, however, such improvements have not been included in this report. We are thus presenting results for a reflector structure which, by careful mechanical design, will indeed function for the SOLARES needs but which is a "Mark I" device upon which further improvements are possible.

It will be impossible to detail here the mathematical model developed for Mark I which determines the overall average areal density σ as a function of service altitude, h, the radius, a, of the reflector, and other parameters such as densities of materials comprising the subelements and the allowable stresses. Suffice it to say that the first consideration is the evaluation of the requisite tension, as a function of altitude and maneuvering requirement for the polymeric film in order to maintain a flatness or figure which will allow a distorted, increased ground spot area of no more than 5% above that which would be obtained with a perfectly flat mirror. It is found that the film stress required never exceeds 2% of the yield stress. The torus cross sectional radius and thickness to give this stress is derived from the in-plane buckling of the torus ring together with the thin wall local buckling formulas. The optimized stiffener and guy wire dimensions and masses required to support the mirror surface are then determined along with the momentum wheel, motor-generator couplers and the solar cell mass required to replace the transfer losses in the energy stored in the counter rotating flywheels. The mast wall thickness is then determined essentially from the moment induced stress required for pointing with smaller contributions from supporting the mirror stiffeners and the torquing. An iterative numerical analysis results in the Mark I structure required for various altitudes.

SOLARES
SCHEMATIC OF PLANAR MIRROR



The results of the current preliminary design are detailed in this table. The composite used for the torus and mast is Al-graphite having $\rho = 2.2\ g/cm^3$ and Young's modulus $E=2.7 \times 10^{11}\ n/m^2$. This material is also used for the stiffener tubes. The mirror structure and flywheels have been sized to produce a maximum angular acceleration of $2.2 \times 10^{-6}\ rad/s^2$ which is 10 times the nominal pointing requirements. The guy wires should experience about 10% failures due to meteors in 30 years.

NOMINAL MIRROR

Orbit Altitude 4146 km, Mirror Radius 500 m, Useful time over site 28.2 min.

MIRROR (2.5 μm polymer + 0.2 μm Al)
- Area density 4.09 g/m²
- Edge ripple angle 1/8000 rad
- Film tension 0.46 n/m
- Mass 3212 kg

GUY WIRES (Al) and STIFFENERS (Al-graphite composite)
- Spacing 1.23 m
- Stiffener tube diameter 2.44 mm
- Stiffener wall thickness 0.122 mm
- # of guy wires 2.06×10^6
- Guy wires 500 m long, 3*10 μ dia
- Stiffener mass 1314 kg
- Guy wire mass 657 kg

TORUS (Al-graphite composite)
- Cross-section diameter 0.96 m
- Effective wall thickness 23 μm
- Mass 480 kg

MAST (tapered, Al-graphite)
- Overall length 300 m
- Base diameter 10 m
- Effective wall thickness 0.111 mm
- Mass 1151 kg

FLYWHEELS (graphite-epoxy)
- Diameter 2.97 m
- Thickness 1.48 cm
- Mass of four 677 kg
- Mean flywheel power 133 kW
- Angular rotation rate 1101 rad/s

MOTOR-GENERATOR COUPLER
- Mass 33 kg

SOLAR CELLS+POWER CONDITIONING
- Mass 200 kg

TOTAL MIRROR MASS 7725 kg

MEAN AREA DENSITY 9.84 g/m²

As shown in the figure, for a given reflector radius, the (overly robust) structure demands very large average areal densities σ for low orbit operation, decreasing to much lower values for altitudes where the mechanical perturbations are smaller. As also seen, for a given altitude, the mass density increases with mirror area, as contended earlier. In general then, the desire to reduce the number of mirrors in orbit, for a given ground site insolation and hence necessary collective reflector area, must be paid for by a corresponding increase in total mirror mass in orbit (cost) as one increases the individual mirror area.

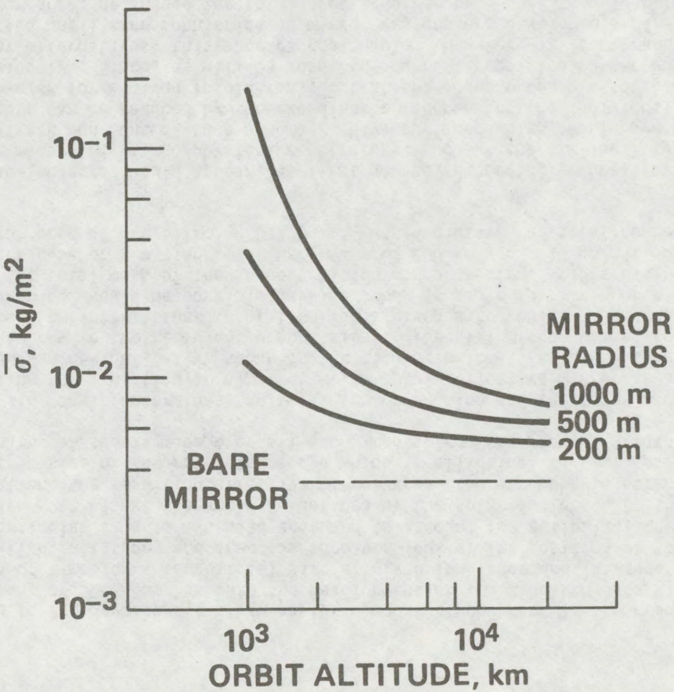
For illustrative numerical purposes throughout this report, it will be useful to discuss a "benchmark case". We choose this to correspond to a reflector altitude h = 4146 km, corresponding to an orbital period P_o 3 hrs, and a reflector radius a = 500 m. The figure then shows $\sigma = 10$ gm/m^2.

Solar Sailing

As was discussed in the initial SOLARES assessment, the low areal density of the reflectors not only minimizes the payload mass which must be transported to orbit, per unit radiant energy provided to the world-wide network of conversion sites and hence per the subsequent electrical busbar energy developed, but it also serves to reduce subsequent space costs and allow additional flexibility. For these densities it is found that mirrors deployed, or constructed in orbit from modular units, have solar radiation forces approximately ten times that of drag for altitudes above 800 km. Thus, the mirror can be solar sailed from this low Earth orbit (LEO) to the desired operation orbit without the need of the development of an orbital transfer vehicle and the subsequent fuel costs. Furthermore, flexibility in modifying orbits is allowed, either to bring a mirror to a lower repair and maintenance facility or to raise the orbit, as will be discussed later, to increase the power output of SOLARES to keep pace with world energy demand. Again, this option is particularly consistent with the smaller mirror scheme since the rather long orbital transfer time (ca. 34 days to sail from 800 km to 2000 km) is tolerable when compared with the much longer time (perhaps 15 years) needed to assemble the complete array. It is recognized, of course, that the radiation pressure will modify the operational orbits with time; however, the possibility of dedicating part of each orbit, when not over serviceable ground sites, to orbital correction exists. Alternately, the allowed accumulation of orbital error can be corrected by routinely removing a small fraction of the mirrors from ground insolation service and dedicating their entire orbits to solar sailing back into the desired orbit.

SOLARES

MIRROR AVERAGE SURFACE DENSITY VARIATION WITH ORBIT ALTITUDE AND MIRROR RADIUS



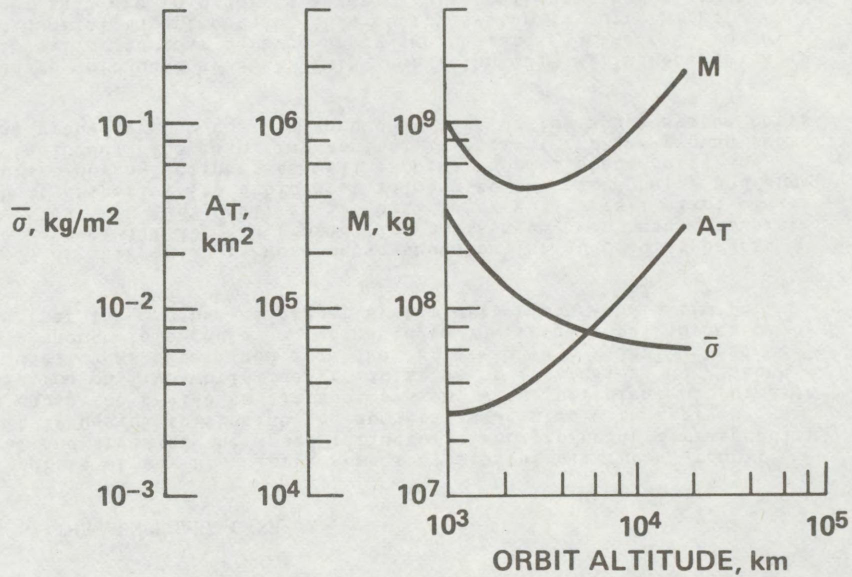
Of equal importance to the development of an analytic model of the Mark I mirror for the accurate and quantitative assessment of SOLARES, has been the development of the model to determine the solar insolation as a function of time for a terrestrial site at given longitude and latitude and a mirror of given orbital inclination, altitude, and area, as seen previously. The position of the sun relative to the mirror for the particular time is assessed and used to account for eclipsing, the determination of the mirror normal which must bisect the angle 2δ defined by the solar incidence to the mirror and the current ground site location, the resulting effective mirror area, the atmospheric attenuation discussed and the geometric size of the reflected image which is elliptical for all cases where the mirror is not at the zenith. A sum is made over all such imputs from the mirrors within the UVC.

The detailed analytic model determines the total area over site and the total mirror area in orbit by direct calculation for a particular altitude h the total collective mirror area A_T which must be distributed world-wide , as is shown in the figure, which is required to provide <u>continuous</u>, 1 kW/m^2 average radiant energy to the recipient ground sites. (Special mirror usage, for example extension of daylight hours or intermittent insolation for a given site would, in general, require less than A_T since mirror "bunching" would be possible.) Also shown is the σ for a mirror of radius a = 500 m. The product $\sigma A_T = M$, is the total mass of the space orbiting mirror system. Interestingly, it has a minimum near our benchmark case of h = 4146 km. Here $A_T = 63{,}000\ km^2$, $\sigma = 10\ gm/m^2$, and $M = 6.35 \times 10^8$ kg. The individual mirror area of $\pi(0.5)^2 km^2 = 0.785\ km^2$, would dictate the total number of mirrors in orbit to be 80,000.

This number of "space objects" would appear, at first glance, exceedingly unrealistic. However, certain points should be made. First, no physical constraints, such as the availability of orbital space or the ability to track and control such a number, have surfaced which would preclude this number. Second, the number can be reduced by the expedient of increasing the individual mirror size (A_T must remain fixed however for a given insolation), but at the added expense associated with increased σ as seen previously. Since, as will be seen, the current predicted busbar energy costs are low compared with current alternatives, this appears reasonable. However, it is premature to speculate how far this may be carried until more sophisticated mirror designs are developed. Finally, a proper perspective on this mirror area, or indeed the total area required by SOLARES should be maintained relative to the task at hand. As will be seen, this system would supply an amount of electrical energy in excess of that currently used worldwide. It can be viewed therefore as an equivalent to the extensive worldwide system of hydro, nuclear and fossil plants estimated to be of value in excess of 10^{12} \$. As such we should indeed be surprised if SOLARES were smaller than calculated!

SOLARES

ALTITUDE VARIATION OF MIRROR AREAL DENSITY, AND TOTAL MIRROR AREA AND MASS REQUIRED TO GIVE $1kW_r/m^2$



THE BENCHMARK CASE

Although SOLARES can operate at any of a large number of orbital altitudes, requiring corresponding structural and areas of the space reflectors, and producing corresponding terrestrial power output, it is useful to examine the numbers associated with a given SOLARES configuration. We chose the h=4146 km altitude system, with sufficient mirror area to produce an average insolation on five worldwide ground sites of 1 kW/m^2, as our "benchmark case." Mirror areal density is determined from the curves shown earlier; we assume the mirror radius as 500 m although this could be increased to lower the total number of space objects but, of course, at the expense of higher system mirror mass and ultimate energy cost.

The space costs assumed for this analysis were those shown on the succeeding pages. This leads to a total space cost of $117B. The ground site costs have been assessed using $500/peak kWe photovoltaic cells (DOE 1985 Goal) at 15% efficiency and overall plant efficiency of 11%. The cost of heat dispersal (to avoid heat release to the atmosphere) and energy storage (to avoid power outage during eclipse) as well as other normal plant costs and efficiencies has also been included. The resulting capital investment for the ground conversion system is 675 B$. Hence the ground system cost is about 6.8 that of the space system costs for the benchmark case.

The ultimate cost of energy produced by SOLARES is seen to be 23.8 mills/kWhe which is comparable with alternate fossil or nuclear derived energy which ranges between 15 to 30 mills/kWhe. Of course, the capital investment for this energy system is quite high; 792 B$. A few comments about this are in order, however. This configuration is for a full-operation, world electrical energy supply (ca. 720 GWe) system. As will be discussed later, initial system startup would be on a smaller scale, using lower orbital altitude, and thus less mirror area, probably a single conversion site. This would lead to substantially lower initial capital investment while yet providing some revenues. (A single site providing 20 GWe average power should return ca. $4.2B/yr.) As more mirrors and sites are added, and the altitude raised, the benchmark case would be approached while revenues accrue and as electrical needs demand.

SOLARES

BENCHMARK CASE
(WORLD ENERGY SUPPLY CONFIGURATION)

SPACE COMPONENT		TERRESTRIAL COMPONENT (29° LAT)	
EACH MIRROR	**TOTAL MIRROR SYSTEM**	**TOTAL (5 SITES) SYSTEM**	**EACH SITE**
RADIUS: 500 m	AREA: 45,800 km^2	POWER: 720 GW_e	0.9 kW/m^2 (SOLARES)
DENSITY: 0.01 kg/m^2	MASS: 4.58×10^8 kg	CI = 675 B$	0.26 kW/m^2 (AMBIENT)
ALTITUDE: 4146 km	COST: $\$2 \times 10^6$/MIRROR		AREA: 1168 km^2
INCLINATION: 45°	CI = 117 B$		CON. EFF.: 11%
			42 Q RAD/YR
			144 GW_e

TOTAL CI: 792 B$

CI/P: 1100 $\$/kW_e$

O & M: 4 $mills/kWh_e$

RETURN RATE: 15%

LIFETIME: 30 y

BUSBAR ENERGY COST: 23.8 $mills/kWh_e$ (CURRENT BASELINE: 15-30 $mills/kWh_e$)

YEARLY GROSS REVENUE: 150 B$/YR

Space Manufacturing and Costs

Recently we have examined in some detail the elements of implementing a SOLARES system. The table shows our estimated costs of the various components of a single orbiting mirror, assuming 80,000 are installed over a 6-year period for the implementation of a complete world energy supply system. Item costs reflect total charges, except for R&D and transport, which are included in the lower table. Costs were derived by summing the component cost at launch site, orbital labor and construction. Component and materials costs were found by using the present price of aluminized Mylar ($0.40/$m^2$) for the mirror, 1985 predicted costs of graphite-epoxy ($25/kg) for the structure, a 1985 projection for the motor-generators, including housing, and $4,000/kW for the solar cells. Since instrumentation needs for pointing, command, telemetry, check-out, etc. are not known, a rather arbitrary best-guess assignment of $50,000/mirror was made for this cost. Since some 80,000 redundant copies are required, this estimate is likely high. For labor an orbital burden of $420/hr was used: over 40% due to personnel transport, based on a 4-month tour of 1,000 work hours and use of an advanced Shuttle personnel system as postulated for SPS; $100/hr for salary and benefits; $50/hr attributed to training and selection; and $90/hr for on-orbit support (principally work-crew habitats at a total cost of $5B for the 6 years). Estimates were made of the assembly time required for each item, either joined from modules, set in place or machine constructed in orbit. It was assumed that a "spider" would lay the mirror surface by unrolling the sheet, 4 m wide containing spoke stringers every 4 m, while forming a graphite-epoxy spiral and joining the sheet with stringers to it as the spiral winds. This machine would also connect the guys to the stringers at 2 m intervals and run them to the mast. Laying the mirror is by far the highest cost item because of the compex "spider" and the assignment of 3 men continuously to it. The torus is also manufactured in orbit (from prepreg tape). Other components are set-in place except for the mast which arrives in 25 m nested cones, on a support mandrel to distribute the launch g-loads.

The lower part of the table summarizes, by function, these costs and adds those affecting the overall mirror, namely transport and R&D. Because of the total mass required to be placed in orbit, it appears cost effective to develop a heavy lift launch vehicle (HLLV). HLLV transport costs are estimated to be below $20/kg. However, since SOLARES would not use the vehicles so fully (SPS costing is based on more than ten-times our total mass to orbit) and would need a higher altitude of about 800 km for mirror construction, a cargo transport cost of $44/kg has been used. This figure includes an "empty-space" and consumables allowance. Personnel transport costs are included in the labor category and are based on a second generation Shuttle carrying 75 work-force members at $13.5M per launch. R&D costs for developing the required space transportation system, the orbital facilities, ground plants and tooling for the flywheels, masts, and mirror blankets, instrumentation development and tests, and the various research and demonstrations necessary were estimated to be $14 billion.

SOLARES

ESTIMATED COSTS FOR SPACE REFLECTOR

(MARK I DESIGN - 1km DIA. - 4146km ORBIT)

COMPONENT REQUIREMENTS	MASS (kg)	INSTALLED COST (1978 k$)
REFLECTOR - 0.1 μm Al ON 2.5 μm POLYMER	3,212	791
STRUCTURE - HM GRAPHITE EPOXY		
MAST - 10 m BASE x 250 m HEIGHT, TAPERED	854	37.3
TORUS - 0.96 m DIA.	319	38.2
STRINGERS - 5 mm DIA. x 0.15 mm WALL	880	41.6
GUYS - 10 μm Al TRIPLE STRAND	250	62.5
CONTROL		
MOMENTUM WHEELS - HS GRAPHITE EPOXY	586	40.4
MOTOR-GENERATOR COUPLER	30	4.5
SOLAR CELLS and CONDITIONING (5.5 kW)	182	30.6
INSTRUMENTATION	50	79.2
GROWTH ALLOWANCE	1,500	350
TOTALS	7,863 (10.0 g/m^2)	1,475.4 (1.88 $\$/m^2$)

COSTING - BY FUNCTION	COST (1978 k$)
RAW MATERIALS, GROUND MANUFACTURING, LAUNCH SITE DELIVERY AND PACKAGING	640
ORBITAL LABOR: SALARY, BENEFITS, SUPPORT, HABITAT, PERSONNEL TRANSPORT	651
ORBITAL ASSEMBLY: EQUIPMENT, SUPPORT AND MAINTENANCE	183
TRANSPORT, EARTH-TO-ORBIT: MATERIALS AND SUPPLIES	346
R&D, PER MIRROR, PRO RATA	180
TOTAL COST OF ONE ORBITING MIRROR	$2M

Space Manufacturing and Costs, Continued

As indicated in the table, to establish the space system having some 80,000 mirrors in a period of 6 years will require: 384 "spiders" at $40M each, a constant orbital work force of 5184 (1232 man-hours/mirror), perhaps an order of magnitude greater ground force, a personnel vehicle launch every 42 hours and an HLLV every 33 hours using a total of 4×10^9 kg of hydrogen as fuel, 2×10^8 kg of polymer for mirrors and a like amount of graphite-epoxy composite, $3 \times 10^6 m^2$ of solar cells, and a total investment of $160B. These numbers are large but not relative to available resources or expected return. Plastics will constitute a 183×10^9 kg/yr industry by 1990 and the automotive industry will be using graphite-epoxy at 30 times our rate. The bottom line on natural resources is energy payback time. The total energy use (mining through turn-on) to produce the space system would be about 5×10^{12} BTU (1.5×10^{12} kWh). This is equivalent to only <u>10 weeks</u> of energy production at the five ground sites, assuming 15% conversion of the mirror and direct Sun insolation. Inclusion of the ground system adds from 4 to 15 weeks to this number, depending on the conversion system assumed.

SOLARES

MIRROR SYSTEM--BASELINE (WORLD ENERGY SUPPLY) CASE

NUMBER OF 1 km^2 REFLECTORS	80,000
IMPLEMENTATION TIME	6 YEARS, BEGINNING 1990
ORBITAL WORK FORCE, AVERAGE	5184
MAN-HOURS PER MIRROR	1232
KG INSTALLED/MAN HR	6
MIRROR LAYERS REQUIRED	384 SPIDERS @ $40M EACH
SPIDER RATE	41 m^2 & 100 GUYS PER MIN
LAUNCH RATE	
HLLV @ 400 MT	EVERY 33 HR
PERSONNEL @ 75	EVERY 42 HR
MATERIALS	
LIQUID OXYGEN	1×10^{10} KG (5% OF EST. NATIONAL USAGE)
GRAPHITE-EPOXY	2×10^{8} KG (3%)
POLYMERICS	2×10^{8} KG (1%)
ENERGY REQUIRED (MINING THROUGH TURN-ON)	4×10^{15} BTU
ENERGY PAYBACK TIME (AT 15% GROUND CONV. EFF.)	10 WEEKS

35-994 O - 79 - 14

COMPARISON OF SOLARES, NORMAL SOLAR FARMS AND SPS FOR WORLD ENERGY SUPPLY

It is interesting to make a comparison between alternative energy systems and SOLARES. To do so we must compare on some common basis; we chose here to ask what number of normal solar farms (operating on ambient sunlight) and SPS units (1 satellite plus two ground sites each delivering 5GWe) must be used to give equivalent electrical energy to that being produced by a SOLARES (mirrors plus 5 ground sites) system. Since SOLARES would make a significant contribution to world energy supply, we are thus essentially asking: If these three methods are used to meet the predicted year 2000 electrical energy needs of the world, what would be the capital investments, energy costs, etc.?

Two SOLARES mirror altitudes are considered: 4146 km and 6384 km; corresponding values are shown in pairs in the table, the former topmost and the latter lower. If both SOLARES ground sites and the Normal Solar Farms use the ERDA Goal (15% efficiency) solar cells, the two columns shown on the left result; if all use the SPS Goal photovoltaics (17% AMO, 20.4% AMI) the three columns on the right pertain.

Some pertinent conclusions can be drawn from the values shown. For the ERDA Goal case it is seen that a normal solar farm requires $4,620/kWe capital investment whereas SOLARES is more in line with current nuclear plants, viz. $1,000/kWe. The significant improvement on ultimate energy cost accruing from the added SOLARES insolation can be seen: 88.3 mills/kWh for the normal solar farm and ca. 22 mills/kWh for SOLARES. If we examine the systems all operating with SPS Goal photovoltaics, similar conclusions can be seen. Here SOLARES is ca. 14 mills/kWh with solar farms and SPS at ca. 44 mills/kWh. In fact, it is seen that the cost for SPS of 45.2 exceeds that for a solar farm using the same solar cells, thus making that space system development seem less attractive if the current baseline SPS costing estimates remain intact with further study. Notice also that the number of SPS units required to equal the output of SOLARES would be 99.5 - 233.5. At the baselined rate of implementation of SPS systems of one per year, this would indicate a 100 - 234 year buildup time for SPS. Other factors, such as total mass in space required (SPS is 20-40 times that of SOLARES) and land area required (SPS is about the same as for a normal solar farm and about 4 times that of SOLARES) are shown.

The conclusion to be reached is that SOLARES does offer a significant opportunity to meet world energy needs by ca. 2000 - 2010 and at costs comparative to current fossil and nuclear alternatives. The other systems considered here could only partially meet this demand and at higher energy costs.

COMPARISON OF SOLARES, NORMAL SOLAR FARMS AND SPS

FOR WORLD ENERGY SUPPLY

	SOLAR CELLS: ERDA '85 GOAL ($500/kW)		SOLAR CELLS: SPS GOAL ($193.5/kW)		
	SOLARES	NORM. SOLAR SYSTEM	SOLARES	NORM. SOLAR SYS.	SPS
AVERAGE POWER/SITE (10^9 W_e)	144 338	27.9	199 467	38.5	5
TOTAL POWER/SYSTEM[a] ($10^9 W_e$)	720 1690	27.9	995 2335	38.5	10
NUMBER OF UNITS TO EQUAL SOLARES OUTPUT	-- --	25.8 60.6	-- --	25.8 60.6	99.5[b] 233.5
CAPITAL INVESTMENT PER UNIT POWER ($\$/W_e$)[c]	1.10 0.976	4.62	0.602 0.492	2.22	2.29
TOTAL CAPITAL INVESTMENT (10^{12} \$)	0.792 1.65	3.33 7.80	0.599 1.15	2.20 5.18	2.28 5.35
BUSBAR ELECTRIC ENERGY COST (mills/kW_eh)[d]	23.8 21.6	88.3	14.9 12.9	43.9[e]	45.2[e]
TOTAL MASS IN SPACE (10^8kg)	4.58 5.52	0	4.58 5.52	0	97.0 228
LAND AREA REQUIRED (10^4 km^2)	0.70 1.59	3.02 7.09	0.70 1.59	3.02 7.09	2.70 6.34

[a] SYSTEM: 5 SOLARES SITES PLUS MIRRORS, 2 RECTENNAS PLUS SPS SATELLITE, OR 1 NORMAL SOLAR FARM GROUNDSITE

[b] AT RATE OF 1 SPS PER YEAR (BASELINE DESIGN) THIS MEANS 100 YEARS TO INSTALL TOTAL SYSTEM

[c] INCLUDES COST OF ENERGY STORAGE TO MEET DEMAND CURVE AND HEAT DISPERSAL FOR SOLARES & SOLAR FARM BUT NOT FOR SPS

[d] RATE OF RETURN: 0.15, LIFETIME: 30y, PLANT FACTOR: 0.95, OPERATIONS & MAINTENANCE: 4 mills/kW_eh

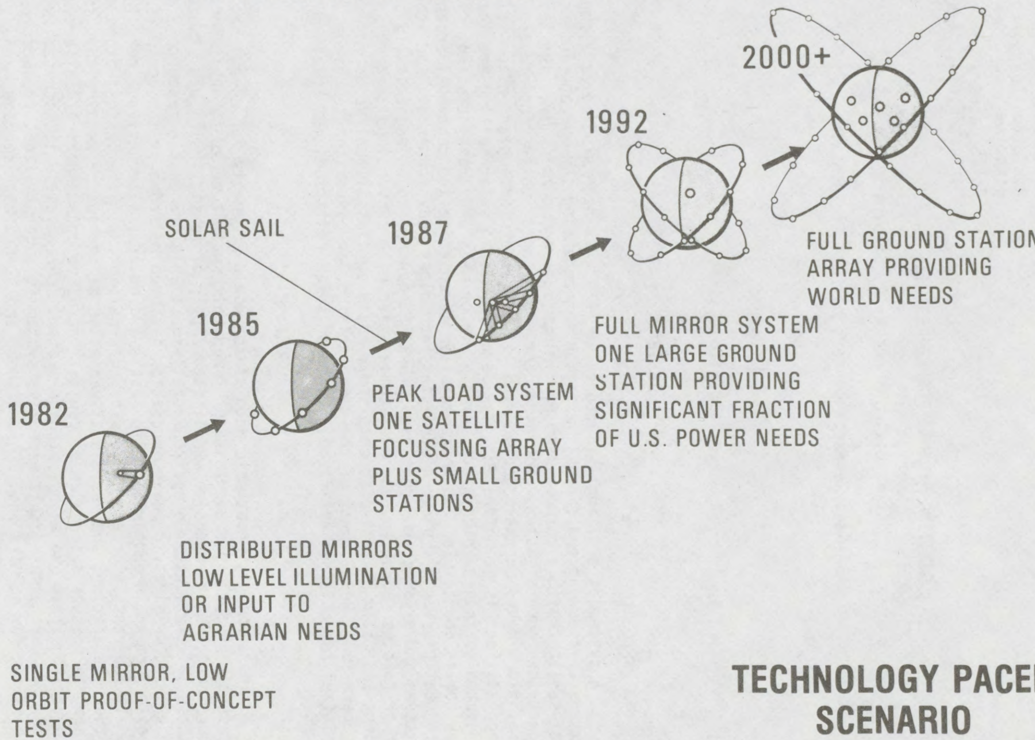
[e] NOTE THAT THE COST OF SPS - GENERATED ELECTRICAL ENERGY IS GREATER THAN THAT OF A NORMAL SOLAR FARM PROVIDED BOTH USE THE SAME SOLAR CELLS.

NOTE: PAIRED NUMBERS CORRESPOND TO MIRROR ALTITUDES OF 4146 AND 6384 km

Shuttle Test and Incremental Mirror System Implementation

An important aspect of SOLARES is the capability of incremental implementation. This allows, as shown in the figure, crucial and definitive proof-of-concept testing on one or more small mirrors, compatible with Shuttle launch, and in an early time frame of 1982 based upon our technology readiness (not budget cycle) estimates. Such tests will clearly lead to the ultimate mirror design, control, etc., and reduce the risks on capital investment and other areas associated with the space component of SOLARES. A single small scale (20-200 m radius) low areal density (10-20 gm/m^2) mirror placed in orbit above 800 km would allow meaningful and realistic tests of the pointing and maneuvering, solar sailing and other orbital characteristics, mirror figure, thermal effects and extended time reflectance characteristics. Furthermore, as has been more completely discussed in our initial assessment, as the mirror system is gradually built up, most likely over a fifteen year interval, intermediate usage ranging from low insolation applications (lighting, etc.) to higher intensity single ground converter site electrical generation can also evolve. Finally, as energy demands increase, the system can also increase with altitude raising and additional mirror addition to meet the foreseeable energy needs of the world.

SOLARES
INCREMENTAL IMPLEMENTATION APPROACH



TECHNOLOGY PACED SCENARIO

Presented at: 3rd NASA Conference on
Radiation Energy Conversion
NASA- Ames Research Center
26-28 January 1978
Moffett Field, CA 94035

ORBITING MIRRORS FOR TERRESTRIAL ENERGY SUPPLY

K. W. Billman* and W. P. Gilbreath*

NASA-Ames Research Center, Moffett Field, Calif.

and

S. W. Bowen†

Palo Alto, Calif.

ABSTRACT

A system of orbiting reflectors, SOLARES, has been studied as a possible means of reducing the diurnal variation and enhancing the average intensity of sunlight with a space system of minimum mass and complexity. The key impact that such a system, providing continuous and slightly concentrated insolation, makes on the economic viability of solar farming and other solar applications is demonstrated. New developments in solar sailing are incorporated to reduce space costs, namely mirror mass and transportation. The system is compatible with incremental implementation and continual expansion to meet the World's power needs. Key technology, environmental, and economic issues and payoffs are identified. SOLARES appears to be economically superior to other advanced, and even competitive with conventional, energy systems and could be scaled to completely abate our fossil fuel usage for power generation. Development of the terrestrial solar conversion technique, optimized for this new artificial source of solar radiation, yet remains.

INTRODUCTION

The seemingly insatiable need of the world community for energy has recently prompted the examination of many alternate sources to substitute for our increasingly expensive and limited supply of fossil fuel. Use of one of these alternatives, the environmentally desirable, renewable resource - solar energy - for electric power generation has been retarded by the economics of solar farming in comparison with fossil and nuclear alternatives (ref. 1). Small inherent solar energy density, diurnal intensity variation, cloud and other obscuration, and positional variation of the source require the "solar farm" to possess a large area, capital intensive optomechanical collection or conversion array and energy storage system, schematically illustrated in Fig. 1. Furthermore, this expensive system is underutilized, frequently operating for no more than 6 h/d without and 12 h/d with storage.

*Research Scientist.

†Consulting Aerospace Engineer.

These factors have conspired to keep the cost of solar-derived electrical energy at approximately five times that of fossil-derived for the past ninety years, even though fossil fuel costs have increased more than fiftyfold during this period.

This paper reports the highlights of an earlier assessment (ref. 2) and subsequent investigations by the authors into a space orbiting mirror system, SOLARES, designed to obviate many of the above problems by providing continuous and slightly concentrated reflected solar energy to selected terrestrial solar conversion sites. Such additional insolation, chosen arbitrarily as $I \approx 1\ kW/m^2$, is significantly higher than the best time-averaged value for the United States of $0.25\ kW/m^2$ and about equal to the peak, noontime intensity. Consequently, for a given solar farm output electrical power, an approximate reduction of $(1 + 0.25)/(0.25) = 5$ in area, and hence area-related costs (collectors, photovoltaic converters, land, maintenance, etc.) is obtained. Additionally costly energy storage (typically one-half of the solar farm capital investment) can be nearly eliminated. Finally, the system can be nearly continuously utilized. Thus, provided the cost of the space component of SOLARES is low enough, substantial reductions (ca. 5 to 10) from conventional solar farm capital investment and resultant electrical energy cost may be realized.

Indeed the initial assessment of this concept (ref. 2) did show that space costs could be low enough, and with the assumption of modest development of mass-produced, 15% efficient cadmium sulfide photovoltaic flat plate array ground conversion in the time frame of SOLARES implementation, busbar electrical energy costs of 10-20 mills/kWh resulted. As seen in Fig. 2, this not only was an improvement on the costs predicted for other advanced systems (ref. 3), but is competitive as well with conventional fossil and nuclear costs. Our more exact examination of the SOLARES concept during recent months has not changed this assessment, at least for reasonable orbital altitude. This report will discuss the technical feasibility and the possible environmental and economic impact of such a synergistic space-terrestrial energy production concept.

Space mirrors have been considered by many authors (refs. 3-7). Geostationary orbits have frequently been faulted (ref. 8) on the basis of scale: both the focused image size ($D = f\alpha = h\alpha$, where f is the effective mirror focal length, $\alpha = 9.3$ mrad is the subtense angle of the Sun, and h is the image distance, that is, the altitude of the mirror above the Earth) and the mirror area which, to provide an I in the ground spot, must exceed the image area to make up for atmospheric transmission losses and geometric spreading. Thus, the seemingly desirable arrangement of a geostationary mirror (h = 35,800 km) remaining fixed above a single site appears nonviable at this time since it produces insolation over an area in excess of 87,000 km^2 and requires a mirror area of about 200,000 km^2 to provide I! As will be seen later, the capital investment associated with such a system would be exceedingly large (greater than $\$4.5 \times 10^{12}$), and it would produce a concentration of energy, as well as an amount, far in excess of what can be used at this time. Unfortunately, the use of a multi-mirror focusing system at GEO to produce a smaller ground spot does not solve this dilema. One finds that even larger mirror areas are necessary, thereby increasing the capital investment in the space system. Smaller ground costs are attained; however, the power output is correspondingly reduced and hence, overall the economics are further acerbated.

To achieve a more practical spot size, reduce the total reflection area, and serve a number of world-wide ground stations, we have considered a system of lower orbit mirrors, schematically illustrated in Fig. 3, which collectively constitutes an Archimedian (focusing) array; individual free-flyer mirrors are continuously pointed to project their solar images on a common ground spot above which they are located at that time. Various orbits (polar, other inclined, and equatorial), altitudes and mirror spacings have been examined to determine in particular the requisite total mirror area necessary to provide continuous insolation I_0 and, in general, to ascertain the scaling laws for mirror area, ground spot size, number of ground sites serviceable, resultant power generated (with assumed conversion efficiency) and requisite capital costs and ultimate energy costs. As will be seen, the collective mirror areas necessary are large, but this is entirely consistent with a system which can sizably augment and possibly replace the present electrical generating capacity of the World. It is also consistent with the emerging technology of the large area, low mass density structures possible in the weightlessness of space. Finally, because of their high performance factor of kilowatts of electricity produced per kilogram of mass transported to orbit, and their low materials content and resultant cost, it will be seen that the space mirrors do indeed represent a reasonably small fraction of the total SOLARES capital investment.

It should be noted here that the space aspects of SOLARES, viz. mirrors, orbits, transportation, etc., have received our foremost attention in this study. Now that the feasibility and economic viability of this has been established, attention must be given to exploring the methods of ground conversion which are most optimal to this new source of solar irradiation. Continuity and concentration will undoubtedly add new dimensions and allow exciting new possibilities to this task, in addition to the economic advantages cited above. Hopefully, such possibilities will occur to those who are experts in solar farming, and other uses of solar energy.

REFLECTORS

The space mirror configuration required to reflect solar energy to the ground may take many forms, ranging from a single large figured mirror to many smaller mirrors which may or may not be physically linked. For many reasons, it appears that individually pointed, free-flyer, planar mirrors of area 1 - 10 km^2 are preferred. As was shown schematically in Fig. 3, a continuous array of such reflectors would orbit over the selected site, each mirror controlled in such a manner to continuously direct its reflected image of the sun onto the site. In general, each mirror will be in a "tumbling" mode, i.e., rotating about its diameter, as it orbits around the Earth. As will be seen, slight accelerations will suffice during the "over site" operational period (the time for the reflector to move from 30^o at one horizon to 30^o at the opposite horizon) to modify this free rotation angular velocity so that the reflected image of the Sun remains fixed on the site.

There are many factors which have led to this choice of a free-flyer focusing mirror array: easier mechanical fabrication of smaller, planar mirrors, lower unit area costs through volume production, easier deployment and packaging, simpler control characteristics and mirror figure maintenance, reduced areal density (since this is found to increase with mirror size), reduced insolation variation, and expanded orbit choices. Of course, certain disadvantages of the large number of mirrors also should be mentioned: restriction to less efficient, non-concentrating, flat plate terrestrial collector/converters (since beams arrive from many sources simultaneously); the need to avoid possible mirror collisions because of intersecting orbits; the need to track and control many objects; and possible added "glint" (spurious reflection) at other, non-conversion site global locations. These problems do not appear insurmountable.

Figure 4 illustrates one of the aforementioned advantages of using smaller mirrors: the reduction of intensity temporal fluctuation at the solar farm. The remaining fluctuation would be further reduced as the instantaneous over-site number is again increased, while maintaining constant cummulative area. Note the inclusion of ambient sunlight in these plots, providing the increase between hours 6 to 12.

Another example of the advantage of the smaller mirror approach is the reduction of the torques which must be applied to the reflector structure as it passes over the site (since the mirror orbits about the Earth's center and not the site). For a given orbital altitude h, the angular velocity variation $\dot{\delta}(t)$, and requisite acceleration $\ddot{\delta}(t)$ is prescribed (ref. 2); a typical case is shown in Fig. 5. From such curves, and the choice of a particular mirror configuration, i.e., moments of inertia I_x, I_y, and I_z, the requisite torques, mechanical power, etc. may be determined. Clearly these quantities therefore scale with $I_i \sim \sigma A R_i^2$ where σ is the average areal mass density, A is mirror area, and R_i the characteristic radial dimension along the i'th rotational axis. As will be seen later, structural integrity requires σ to be an increasing function of R_i (other authors have argued, incorrectly we believe, that it is a decreasing function) and hence I_i, and the torques and required mechanical power increase nonlinearly (ca. as $A^{2.5}$ to A^3) with mirror area. Thus there is a severe penalty for increasing mirror area; an increase from 1 km^2 to 15 km^2 area, say, would increase the torques by a factor of 870 to 3,340. More elegant mirror designs may reduce this; our point here is to show that present design, with $A \sim 1$ km^2, leads to reasonable $\sigma \sim 10$ gm/m^2 for which peak momentum wheel torque powers of only tens of kilowatts are required. These are easily obtainable from on-board solar cell arrays. Note also from Fig. 5 that the symmetry of $\ddot{\delta}$ about $\dot{\delta} = 0$ indicates that the average acceleration is zero, and the use of momentum transfer flywheels should suffice for control needs, including the necessary reorientation between ground sites if the latter are judiciously chosen.

Current Structural Reflector Design

At this time we are in the early stages of assessing the possibilities in the realm of large area, low density structures for space usage. However, to realistically assess the feasibility of SOLARES, both on technical and economic grounds, it has been necessary to design a mirror structure which, in principal, can work. Such a design is shown schematically in Fig. 6. The reflector is a polymeric film of 2.5 μm thickness with 0.1 μm aluminum evaporated onto each face; overall reflector areal density is 3.55×10^{-3} kg/m^2. The film is tensioned onto a supportive structure, consisting of an outer torus, radial spokes and azimuthal stringers. Such tensioning is necessary to maintain the reflector planarity, or "figure" despite the perturbing radiation pressure, gravitational gradient, and angular acceleration forces acting on it. The rim torus must have sufficient buckling strength to provide this tension. The central mast and guy wire system is required to prevent out-of-plane buckling. The principle demand placed upon the mast structure is to withstand buckling under the requisite torques which must be used for mirror pointing and tracking. The current design postulates centrally located momentum wheels to provide these torques; near term examination will be made of rim-located ablative thrusters which may reduce the mirror masses derived below. We have assumed the mast and torus to be thin shells of aluminum matrix carbon fiber composites (ρ_C = 2.2 gm/cm^3 density and Young's modulus of E = 2.7×10^{11} nt/m^2). Substantial reduction in mast mass will accrue from the use of a stiffened open-weave composite structure, as shown in the figure insert, and other improvements such as tapering the mast, as suggested by Hedgepeth (ref. 9), however, such improvements have not been included in this report. We are thus presenting results for a reflector structure which, by careful mechanical design, will indeed function for the SOLARES needs but which is a "Mark I" device upon which further improvements are possible.

It will be impossible to detail here the mathematical model developed for Mark I which determines the overall average areal density σ as a function of service altitude, h, the radius, a, of the reflector, and other parameters such as densities of materials comprising the subelements and the allowable stresses. Suffice it to say that the first consideration is the evaluation of the requisite tension, as a function of altitude, for the polymeric film in order to maintain a flatness or figure which will allow a distorted, increased ground spot area of no more than 5% above that which would be obtained with a perfectly flat mirror. It is found that the film stress required never exceeds 2% of the yield stress. The torus cross sectional radius and thickness to give this stress is derived from the in-plane buckling of the torus ring together with the thin wall local buckling formulas (ref. 10). The mast wall thickness is then determined essentially from the moments required for pointing. An iterative numerical analysis results in the Mark I structure required for various altitudes.

As shown in Fig. 7, for a given reflector radius, the (overly robust) structure demands very large average areal densities σ for low orbit operation, decreasing to much lower values for altitudes where the mechanical perturbations are smaller. As also seen, for a given altitude, the mass density increases with mirror area, as contended earlier. In general then, the desire to reduce the number of mirrors in orbit, for a given ground site insolation and hence necessary collective reflector area, must be paid for by a corresponding increase in total mirror mass in orbit (cost) as one increases the individual mirror area.

For illustrative numerical purposes throughout this report, it will be useful to discuss a "benchmark case". We choose this to correspond to a reflector altitude h = 4146 km, corresponding to an orbital period P_o = 3 hrs, and a reflector radius a = 500 m. Figure 7 then shows σ = 10 gm/m^2.

Solar Sailing

As was discussed in the initial SOLARES assessment (ref. 2), the low areal density of the reflectors not only minimizes the payload mass which must be transported to orbit, per unit radiant energy provided to the worldwide network of conversion sites and hence per the subsequent electrical busbar energy developed, but it also serves to reduce subsequent space costs and allow additional flexibility. For these densities it is found that mirrors deployed, or constructed in orbit from modular units, have solar radiation forces approximately ten times that of drag for altitudes above 800 km. Thus, the mirror can be solar sailed from this low Earth orbit (LEO) to the desired operation orbit without the need of the development of an orbital transfer vehicle and the subsequent fuel costs. Furthermore, flexibility in modifying orbits is allowed, either to bring a mirror to a lower repair and maintenance facility or to raise the orbit, as will be discussed later, to increase the power output of SOLARES to keep pace with world energy demand. Again, this option is particularly consistent with the smaller mirror scheme since the rather long orbital transfer time (ca. 34 days to sail from 800 km to 2000 km) is tolerable when compared with the much longer time (perhaps 15 years) needed to assemble the complete array. It is recognized, of course, that the radiation pressure will modify the operational orbits with time; however, the possibility of dedicating part of each orbit, when not over serviceable ground sites, to orbital correction exists. Alternately, the allowed accumulation of orbital error can be corrected by routinely removing a small fraction of the mirrors from ground insolation service and dedicating their entire orbits to solar sailing back into the desired orbit.

ORBIT CONSIDERATIONS

A variety of orbit options are available for placement of the reflectors. The choice depends on a number of factors, including investment available, ground site location, ground conversion technique, insolation levels required, need for continuous insolation, energy output desired and the degree of international cooperation. Additionally, mirror design features, such as acceptable torque rates, thermal control, material lifetime, ballistic coefficient, station keeping sophistication, configuration and maintenance requirements will place further limits on the final orbit choice.

Historically, our earlier studies (ref. 1) placed much emphasis upon the examination of SOLARES scaling laws for various orbital inclinations ($i = 0^\circ$, equatorial; $i = 90^\circ$, polar; and $i \approx 45^\circ$, moderately inclined), altitudes (especially $1{,}000 \leq h \leq 4{,}000$ km and the geostationary case for $i = 0^\circ$, h = 35,800 km), and retrograde and sun synchronous cases. The considerations were especially helpful (1) to point out special features which may be useful to mirror use during the period of buildup of a full mirror array, (2) to minimizing the number of large mirrors necessary for servicing a given ground site, and (3) to estimate the upper limit of ground sites serviceable around the world.

However, with the introduction of the useful concept of the focusing array, a roughly uniform distribution of smaller mirrors, many of these earlier considerations are of lesser importance. They serve mostly to provide general guidance and extremums against which the current computer calculations can be checked. For a detailed discussion of these orbit considerations, the reader is referred to (ref. 2) and (ref. 11).

Typical of the more general orbit examined presently is that shown in Fig. 8 which illustrates the 24 hr ground trace of a single reflector with $i = 45^{o}$ and $h = 4146$ km ($P_o = 3$ hr). Here is also shown a typical useful viewing circle (UVC), i.e., the intersection of a right circular cone of 60^{o} relative to the zenith of a ground site with a sphere of radius $R_e + h$. A mirror track within the UVC indicates the period during which the mirror supplies useful ground insolation; as can be seen, for this particular orbit and ground site, three very useful, and a fourth less so, passes per day are made for the particular orbit shown. Additional mirrors, placed into similar orbits, but with orbital planes displaced in longitude, interleave the trace shown to essentially make an instantaneous "glittering" array over the site as discussed earlier. It should be noted that other, non-intersecting viewing circles can be placed world-wide to simultaneously collect radiation from the mirrors over these locations. The optimized set of such sites has yet to be determined.

INSOLATION PROFILES

Of equal importance to the development of an analytic model of the Mark I mirror for the accurate and quantitative assessment of SOLARES, has been the development of the model to determine the solar insolation as a function of time for a terrestrial site at given longitude and latitude and a mirror of given orbital inclination, altitude, and area. The position of the sun relative to the mirror for the particular sideral time is assessed and used to account for eclipsing, the determination of the mirror normal which must bisect the angle 2δ defined by the solar incidence to the mirror and the current ground site location, the resulting effective mirror area ($A \cos \delta$), the atmospheric attenuation (as discussed below), and the geometric size of the reflected image which is elliptical for all cases where the mirror is not at the zenith. A sum is made over all such inputs from the mirrors within the UVC.

The initial choice of the mirror spacing and individual mirror size, and hence the total collective mirror area A_m (km^2) needed in the UVC for a desired, time averaged site center insolation I_o (kW/m^2), with an ambient (normal) solar insolation of I_{Av} (kW/m^2) for the site, can be estimated from an empirically derived formula

$$I_o = I_{Av} + 2165\ A_m/h^{1.894} \qquad (1)$$

where the orbital altitude h is expressed in km and a nominal I_{Av} (good solar site) value for the U.S. is 0.255 kW/m^2. This scaling law was derived, unlike the aforementioned analytical model, with the simplifying assumptions of unity mirror reflectivity, uneclipsed mirrors, zenith mirror passes, and coplanar mirror, site, and sun. It does correctly account for atmospheric absorption, however, using the transmission expression (ref. 12)

$$T = 0.1283 + 0.7548 \exp(-0.3866 / \sin\theta) \qquad (2)$$

where θ is the source (mirror) elevation angle above the horizon. All angular and distance factors are also correctly included. As can be appreciated, Eq. (1) sets a lower limit for A_m. The detailed analytic model, of necessity more cumbersome to use, determines the total area over site and the total mirror area in orbit by direct caculation for a particular altitude h. From such calculations, the altitude scaling implied by Eq. (1) together with an analytic calculation of the ratio of the fraction of mirrors within the UVC allows an accurate estimation of the total collective mirror area A_T which must be distributed worldwide, as shown in Fig. 9, to provide continuous, 1 kW/m^2 average radiant energy to the recipient ground sites. (Special mirror usage, for example extension of daylight hours or intermittent insolation for a given site would, in general, require less than A_T since mirror "bunching" would be possible.) Also shown is the σ for a mirror of radius a = 500 m. The product $\sigma A_T = M$, is the total mass of the space orbiting mirror system. Interestingly, it has a minimum near our benchmark case of h = 4146 km. Here $A_T = 63{,}000$ km^2, $\sigma = 10$ gm/m^2, and $M = 6.35 \times 10^8$ kg. The individual mirror area of $\pi(0.5)^2 km^2 = 0.785$ km^2, would dictate the total number of mirrors in orbit to be 80,000.

This number of "space objects" would appear, at first glance, exceedingly unrealistic. However, certain points should be made. First, no physical constraints, such as the availability of orbital space or the ability to track and control such a number, have surfaced which would preclude this number. Second, the number can be reduced by the expedient of increasing the individual mirror size (A_T must remain fixed however for a given insolation), but at the added expense associated with increased σ (see Fig. 7). Since, as will be seen, the current predicted busbar energy costs are low compared with current alternatives, this appears reasonable. However, it is premature to speculate how far this may be carried until more sophisticated mirror designs are developed. Finally, a proper perspective on this mirror area, or indeed the total area required by SOLARES should be maintained relative to the task at hand. As will be seen, this system would supply an amount of electrical energy in excess of that currently used worldwide. It can be viewed therefore as an equivalent to the extensive worldwide system of hydro, nuclear and fossil plants estimated to be of value in excess of 10^{12} dollars. As such we should indeed be surprised if SOLARES were smaller than calculated!

Illustrative Profiles

To illustrate the results typically obtained from the analytic model of SOLARES, Fig. 10 shows the temporal radiant intensity on a site located at 29°N latitude, 118°W longitude for our benchmark orbital case. The 24 hr period shown is for 1 July; it is seen that a rather continuous insolation is attained with the inclusion of ambient sunlight. Figure 11, for 7 December, shows the effect of winter mirror eclipsing around local midnight. For this site some buffering conversion system would be required if continuous electrical output were desired.

The site chosen, Guadalupe Island, located west of Baja, California, is interesting in that Gemini photographs have shown that the gentle upwelling of warm air from the island, produced by solar insolation, serves to generally keep the area above the island free of clouds even though the surrounding ocean is covered. Thus, a controlled release of sensible heat to the ambient from the site may allow the use of many sites, particularly near water, which would seemingly be unusable because of normal cloud obscuration.

Figure 12 illustrates the calculated spatial intensity profile; a circle of diameter $h\alpha$ = 38.6 km (24 mi.) is seen to contain a large fraction of the energy. Figure 13 shows this daily accumulated energy as a function of radial distance from the insolation "footprint" center; approximately 70% is within $h\alpha$. The central region would receive approximately 39 Q = 4.1×10^{19} Joules/yr for I_0 = 1 kW/m^2 and I_{Av} = 0.2 kW/m^2. If the entire radiant input were converted to electrical energy with a conversion efficiency of 15%, this single site would produce an average power P_e = 196 GWe which is to be compared with the current U. S. usage of ca. 250 GWe. Five such sites, located around the world, appear possible for this orbital benchmark case; the total power would exceed current world usage, which is estimated to be 10^{12} We.

GROUND CONVERSION

As mentioned earlier, the determination of the optimal solar conversion techniques for SOLARES has not yet been made. Since the apparent cost, to be discussed later under economics, of the presently assumed conversion method is one-half of the entire system cost, it is clear that such optimization is of utmost importance.

Certain properties of SOLARES must be kept in mind when considering conversion techniques. Foremost, of course, is insolation continuity which will obviate the need for energy storage to a large degree and, of equal significance, reduce the collection array necessary to provide the same output power. The ramifications here can be significant. Thus, although the busbar energy costs predicted for a photovoltaic solar farm, using the "1985 ERDA Goal" \$500/peak kW cells, would be ca. 84 mills/kWh, the same costing procedure (ref. 13) when applied to near term mass produced CdS cells, and incorporating SOLARES insolation would predict ca. 13 mills/kWh. Similarly, the shallow solar pond energy conversion system (ref. 14) is predicted to give, in the near term (5 yr), 56 mills/kWh without, and ca. 13 mills/kWh with SOLARES. Similar cost reductions should obtain for systems associated with space heating, industrial process heat, agricultural solar uses such as pumping of water and grain drying, and desalination of water. The single effect still, producing distilled water at significantly reduced rates, could have a profound effect on Third-World economics.

A second SOLARES possibility is solar concentration. In the studies reported here, we have chosen a nominal reflected insolation value of 1 kW/m^2. By adding more mirrors this could be increased, however. Aside from environmental constraints (to be discussed) the economic advantages of operating solar farms at insolation values of more than one solar constant have yet to be explored. Of concern here, of course, are the microweather changes which may result if waste heat is indiscriminately, locally released to the atmosphere. Certainly winds would result, and although in moderation they could serve useful functions such as providing windmill-derived pumping for fluid circulation in the solar farm or helping disperse clouds, careful modelling will be necessary to assess the efficacy of higher insolation values provided by SOLARES.

A third SOLARES consideration is the eclipsing of the mirrors, which is most significant for very low orbits. Although this is somewhat reduced by having a large number of mirrors at various angles above the site at any given time, some insolation eclipse loss will result if the smaller spot size orbits are chosen. Because of this, it may be desirable to initiate SOLARES with systems which do contain short term buffering or storage, such as solar ponds or chemical fuel production, such as hydrogen or ammonia.

At higher orbits, this eclipsing problem is greatly reduced; however, the spot size ($h\alpha$) is larger. If this insolation is completely used for direct conversion to electrical power, the input to the grid could be very large when compared with current facilities. Thus, the use of highly redundant electric generating and transmission architecture would appear necessary to avoid widespread outages in case of partial system failure or downtime. Surrounding this core photovoltaic, or possible Rankine cycle generating plant, would likely be solar stills which would use the reject heat to desalinate water to serve as feedstock for hydrogen, and possibly ammonia production. Such storable fuels could be produced during low electrical demand periods, allowing for the first time the use of a solar farm as a true baseline system. Further heat dispersal, hot water pumped by the windmills provided by the controlled, omnidirectional winds designed into the system, would be to a surrounding high yield food crop and bio-feedstock farm. Finally, in the outer reaches of the insolation provided by SOLARES, would be a moderate climate industrial and urban community, making full use of this lower level solar radiation as well as the reject heat from electrical generation. Of course, such a "solar total farm" is an old concept (ref. 1). However, it will likely assume new forms and certainly new economics with the incorporation of SOLARES.

Another characteristic of SOLARES which must be considered is the fraction of time which the mirrors spend over the oceans and non-industrial nations. For the latter, it would appear that the possible reduction in desalination cost, as well as the production of fixed nitrogen, such as ammonia, for fertilizer, and the pumping of water would be especially significant. Again, much remains to be done in evolving these new techniques. For the ocean sites, either islands or artificial platforms, the production of these commodities and subsequent shipment by super-tanker needs investigation. Possible enhancement of ocean thermal energy conversion (ref. 15) may also accrue with SOLARES if reasonable elevation of surface water temperatures can improve the Rankine cycle efficiency.

In summary, the new opportunities which would be afforded by the orbiting mirror system, will likely allow exciting new concepts in solar conversion techniques. Much work now remains to be done in this area.

ECONOMICS

Although precise costing of SOLARES is clearly impossible without an in-depth study and the analysis of certain technological issues, preliminary estimates can be made which are useful to testing the viability of the concept and identifying the cost drivers. System cost is comprised of space (materials, construction, and transportation) and ground (collection, conversion and conditioning) capital investments, R&D and operations and maintenance elements. In the discussion that follows, it is assumed that the system is operational in the 1990 time frame and can thus employ the expected normal growth in technology over the next ten years to enhance the effectiveness of the system.

Presently there are large uncertainties in the manufacturing costs of the mirrors and especially how these costs will scale with the particular unit mirror area chosen. Some components will depend upon area, such as the polymeric reflector substrate (aluminized 2.5 μm mylar presently costs $0.40/m^2$), others may depend upon mass, and yet others, such as on-board computers, will probably be fixed cost items. Pending further analysis, we have chosen a mirror cost (reflector, support structure, controls and construction) to be $250/kg. For comparison, typical large scale aircraft, with complexity probably exceeding that of the reflectors, and with a much smaller volume production of several hundred units, cost $125/kg - $175/kg. This cost of $250/kg, together with σ predicted for the Mark I mirror, as was shown in Fig. 7, determines the "space material cost" for various operational altitudes. Transportation is another capital item for space. While transport costs with the current Shuttle will be about $1000/kg to reach deployment altitude, it is anticipated that a second generation vehicle would lower this to $300/kg. In fact, since transport costs with a heavy lift launch vehicle (HLLV) could achieve $20/kg in the time frame of importance to us (ref. 3), it is estimated that, with more moderate development, a vehicle tailored for the present mission should provide transport at $166/kg. The sum of these space costs per kg of reflector in orbit can be coupled with total mirror mass M as was shown in Fig. 9.

The second major element of SOLARES costing is that of the ground conversion system. Conventional solar energy systems require $1500-$2000 of capital investment per output kWe. However, as argued earlier, and discussed in detail in (ref. 2), a nearly four-fold reduction is expected with SOLARES. Using a costing analysis similar to DeMeo (ref. 13) which properly accounts for area related and installed power related costs, together with predictive costs for mass produced, large area CdS photovoltaic arrays (ref. 13) and the (reasonable) assumption of attainment of 15% conversion efficiency by 1985, the solar farm capital investment, CI, can be evaluated from

$$CI = (\$30/m^2)\, A_G + (\$70/kWe)\, P \qquad (3)$$

where A_G is the installed ground site area and P the system power output. The total capital investment is thus found from the number of usable sites for a given orbital inclination and altitude, the effective usable conversion area ($\sim h\alpha$) per site, and the power output as determined from insolation profiles as shown in Fig. 13, averaged for the year, including a plant duty factor of 1, here and the assumed solar cell efficiency of 0.15.

The sum of the space and ground conversion capital investments per installed kWe are shown in Fig. 14 as a function of orbit altitude. It is clearly seen that for reasonable orbit altitudes, significant reduction over normal solar farms is attained, and in fact for the benchmark case CI/P = $506/kWe, which is competitive with current fossil and nuclear plants. Indeed the space costs of SOLARES have not led to excessive total system costs!

Design, development, test and evaluation costs are estimated, for both the space and ground phases, to be about $16 billion, roughly equally divided between the transportation system, a maintenance and construction facility in space, and the ground system. These costs, when amortized over the expected system power output for 30 years, contribute less than 1 mill/kWh.

Using the standard algorithm for relating the CI to its contribution to busbar energy cost (ref. 2), with assumed rate of return of 15% and system lifetime of 30 yr, this energy cost is evaluated. To this must be added operations and maintenance; a value of 4 mills/kWh appears reasonably consistent with standard solar farm estimates and that made for the space solar power system (ref. 3).

The resultant variation of busbar energy cost with altitude is shown in Fig. 15; again this is competitive with current alternatives (15-25 mills/kWhe). For the baseline case, the energy cost is 13 mills/kWhe).

The Benchmark Case

It is useful to collect the various values which appeared throughout the text for the benchmark case; this is seen in Table I. A few comments are in order. This configuration is for a full-operation, world electrical energy supply (ca. 10^{12} We) system. As will be discussed later, initial system startup would be on a smaller scale, using lower orbital altitude, and thus less mirror area, and probably a single conversion site. This would lead to substantially lower initial capital investment while yet providing some revenues. (A single site providing 20 GWe average power should return ca. $3.5B/yr.) As more mirrors and sites are added, and the altitude raised, the benchmark case would be approached while revenues accrue and as electrical needs demand.

ENVIRONMENTAL AND SOCIAL IMPACT

As with any technological system of the magnitude of SOLARES, capable of generating a large fraction of the world's energy needs, a critical assessment of its environmental and social impact must be made. We have begun this task and report here only on the identification of some crucial areas, as listed in Fig. 16; others will undoubtedly be discovered.

Clearly one positive impact of SOLARES will be to allow conservation of non-renewable fossil fuels which are currently used for electric power generation. In addition, if the system is large enough, such power may also be used for other applications, such as transportation, for which fossil fuels are now the only economical option. Additional conservation would occur if

35-994 O - 79 - 15

the reject heat of the solar farm were used for such purposes as water desalination, industrial process heat, crop drying, space heating, etc. . Significantly, in addition to fossil fuel conservation, SOLARES would also remove the chemical pollution due to the mining, transporting, and burning of these fuels. Similar problems exist with nuclear alternatives.

The positive social impact of SOLARES will depend heavily upon its ultimate range of applicability (multiple use) and degree of implementation. If economically viable, the agrarian uses will provide important essential social benefits (food and water) to the developing nations while other mirrors simultaneously supply electricity to the industrial countries. Substantial investments in resources: manpower, land, energy, materials, and money will be necessary for a system of SOLARES' magnitude.

A system such as the baseline case which would be capable of supplying ca. 10^{12} We or four times the current U. S. electric power usage, would require a $500B capital investment. For fifteen year implementation, the annual investment of $33B would be large. However, it does not appear excessively large when one considers the current estimates of $25B - $30B yearly necessary to expand our conventional power system to meet demand in the U. S. alone.

It should be appreciated that the investment by the U. S. in such a system would ultimately allow our nation to regain its position of an energy exporter to the World rather than ever increasing dependency on foreign energy import.

Possible negative environmental impacts have been seen in Fig. 16: careful assessment of their importance has not yet been possible. The release of waste heat from the radiant energy to electricity conversion process to the atmosphere must be minimized to avoid high velocity cool air flow into the surroundings. The design of a total energy usage conversion system, as discussed earlier, will hopefully do this. Light glint (global) and scattering (near conversion sites) may be especially serious problems for astronomers. Photochemical effects produced by the added sunlight of SOLARES in the atmosphere and other "spheres" do not appear negative at this time. Land usage also does not appear extreme. In fact, because of its properties, SOLARES demands approximately five times less land per unit of electrical energy produced than a conventional solar farm or the SPS (microwave system). It compares favorably with conventional power plants ($\sim$25 km^2/GW) because its waste heat removal needs are similar. Finally, there will be possible pollutant (noise and chemical) concerns with the launch system necessary to place the mirrors in space. On the positive side, however, the development of this superior launch system may open new possibilities for space usage such as easier establishment of space astronomical facilities.

CONCLUSIONS

In this report we have briefly outlined the concept of the orbiting mirror system and examined the important technical, environmental, and economic questions and payoffs. Clearly the commitment of the nation, or the World community, to such a means toward ultimate energy self-reliance would be a major undertaking. As such, we should comment on two aspects of the system which bear upon (1) its general world acceptance and (2) its ability to be tested on a small scale prior to full implementation.

The first is illustrated by Fig. 17, which illustrates some of the many uses to which SOLARES could be put. Most importantly, these could be simultaneous applications wherein those mirrors over industrial nations could be producing electrical power while those over agrarian nations could be providing energy for such needs as desalination and pumping of water, etc., again with the economics attendant to continuous and concentrated insolation. Indeed, some such uses may prove economically unattractive when further analysis is made. But it does indicate a flexibility of applicability possessed by no other advanced system and one of more general attractiveness to the World community than the exclusive production of electrical power.

The second important aspect of SOLARES is the capability of incremental implementation. This allows, as shown in Fig. 18, crucial and definitive proof-of-concept testing on one or more small mirrors, compatible with Shuttle launch, and in an early time frame of 1982 based upon our technology readiness (not budget cycle) estimates. Such tests will clearly lead to the ultimate mirror design, control, etc., and reduce the risks on capital investment and other areas associated with the space component of SOLARES. Furthermore, as has been more completely discussed in our initial assessment (ref. 2), as the mirror system is gradually built up, most likely over a fifteen year interval, intermediate usage ranging from low insolation applications (lighting, etc.) to higher intensity single ground converter site electrical generation can also evolve. Finally, as energy demands increase, the system can also increase with altitude raising and additional mirror addition to meet the foreseeable energy needs of the world.

In conclusion, SOLARES appears to offer significant improvement to the possible large-scale generation of electricity from the environmentally desirable and renewable resource, solar energy. Technology requirements appear achievable in the near term and costs, spread over a fifteen year implementation period, appear reasonable especially when compared with conventional necessary system expansion costs and those of the imported fuel to service these plants. The system affords the possibility of small-scale testing with a Shuttle launched single mirror, and of incremental buildup, by increasing altitude and adding mirrors, to keep pace with increasing world energy needs. Its positive environmental impact - reducing our expenditures of nonrenewable fossil fuels and the inherent pollution attendant to their mining, transportation, and burning - seems to outweigh possible negative effects. Multiple, simultaneous alternate uses appear desirable and possible. Extensive, in-depth engineering design and optimization must now proceed to confirm the economic viability of the concept. Of especial importance is the evolution of solar conversion techniques most suitable to this new source of continuous solar radiation.

REFERENCES

[1]Meinel, A. B. and Meinel, M. P., *Applied Solar Energy*, 1st. ed., Addison-Wesley Publishing Co., Reading, Massachusetts, 1976.

[2]Billman, K. W., Gilbreath, W. P., and Bowen, S. W., "Introductory Assessment of Orbiting Reflectors for Terrestrial Power Generation," NASA TM X-73,230, April 1977, NASA-Ames Research Center, Moffett Field, California.

[3]Piland, R. O. et al., "Initial Technical, Environmental and Economic Evaluation of Space Solar Power Concepts," NASA JSC-11568, Vols. 1 and 2, Aug. 1976, NASA-Johnson Space Center, Houston, Texas.

[4]Oberth, H., *Wege zur Raumschiffahrt*, Oldenburg Verlag, Berlin, 1929 (*Ways to Spaceflight*, NASA Technical Translation, NASA TT F-662, Clearinghouse for Federal Scientific & Technical Information, Springfield, Virginia).

[5]Buckingham, A. G. and Watson, H. M., "Basic Concepts of Orbiting Reflectors," *J. Spacecraft*, Vol. 5, July 1968, pp. 851-854.

[6]Hyde, R. A., "Design and Behavior of Ribless Solar Reflectors," UCRL-52191, Dec. 1976, Lawrence Livermore Laboratory, Livermore, California.

[7]Ehricke, K. A., "Cost Reductions in Energy Supply Through Space Operations," Paper IAF-A76-24, 27th International Astronautical Congress, Oct. 1976, Anaheim, California.

[8]Glaser, P. E., "Perspectives on Satellite Solar Power," *J. Energy*, Vol. 1, Apr. 1977, pp. 75-84.

[9]Private correspondence with John Hedgepeth, ASTRO Research Corp., Santa Barbara, California.

[10]Seckler, E. E., *Elasticity in Engineering*, 1st. ed., Wiley & Sons, New York, New York, 1952.

[11]Billman, K. W., Gilbreath, W. P., and Bowen, S. W., "Satellite Mirror Systems for Providing Terrestrial Power: System Concept," Paper No. AAS-77-240, Twenty-Third Meeting of American Astronautical Society, "The Industrialization of Space," Oct. 1977, San Francisco, California.

[12]Hottel, H. C., "A Simple Model for Estimating the Transmittance of Direct Solar Radiation Through Clear Atmospheres," *Solar Energy*, Vol. 18, March/April 1976, pp. 129-134.

[13]DeMeo, E. A., "Assessment of Cadmium Sulfide Photovoltaic Arrays for Large Scale Electric Utility Applications," EPRI ER-168, Feb. 1976, Electric Power Research Institute, Palo Alto, California.

[14]Dickinson, W. C., Clark, A. F., Day, J. A. and Wouters, L. F., "The Shallow Solar Pond Energy Conversion System," *Solar Energy*, Vol. 18, Jan./Feb. 1976, pp. 3-10.

[15]McGowan, J. G., "Ocean Thermal Energy Conversion - A Significant Solar Resource," *Solar Energy*, Vol. 18, March/April 1976, pp. 81-92.

Table I The benchmark case

SPACE COMPONENT		TERRESTRIAL COMPONENT (29^o LAT)	
EACH MIRROR	TOTAL MIRROR SYSTEM	TOTAL (5 SITES) SYSTEM	EACH SITE
RADIUS: 500 m	AREA: 63,000 km^2	POWER: 980 GW_e	1 kW/m^2(SOLARES)
DENSITY: 0.01 kg/m^2	MASS: 6.35×10^8 kg	CI=232 B$	0.2 kW/m^2(AMBIENT)
ALTITUDE: 4146 km	COST: 416 $/kg		AREA: 1087 km^2
INCLINATION: 45^o	CI=264 B$		CON. EFF.: 15%
			39 Q RAD/YR
			196 GW_e

TOTAL CI: 496 B$

CI/P: 506 $\$/kW_e$

O & M: 4 $mills/kWh_e$

RETURN RATE: 15%

LIFETIME: 30 y

ENERGY COST: 12.8 $mills/kWh_e$

(CURRENT BASELINE: 15 - 25 $mills/kWh_e$)

FIGURE CAPTIONS

Fig. 1 Impact of SOLARES on the economics of solar energy production.

Fig. 2 Electrical energy busbar costs (1976 dollars).

Fig. 3 Schematic of SOLARES focusing mirror array.

Fig. 4 Reduction in intensity variation at the ground site by replacing a single large mirror of area A in the viewing cone with six smaller mirrors of the same cumulative area.

Fig. 5 Typical angular velocity ($\dot{\delta}$), acceleration ($\ddot{\delta}$), and product ($\dot{\delta}\ddot{\delta}$) for orbiting mirror as a function of angle of mirror (Θ) above the ground site horizon or, equivalently, the time (t). These curves are for a h=2500 km orbit.

Fig. 6 Schematic of Mark I planar mirror.

Fig. 7 Mirror average surface density variation with orbit altitude and mirror radius.

Fig. 8 Ground track for a typical, single mirror for a 24 hr. period. Mirror altitude is 4146 km and inclination is 45^o. The UVC for a site at 29^{o}N latitude and 118^{o}W longitude is shown.

Fig. 9 Altitude variation of mirror areal density and total mirror system area and mass required to give 1 kW_r/m^2.

Fig. 10 Central spot radiant intensity for July 1 on the benchmark site.

Fig. 11 Central spot radiant intensity for December 7.

Fig. 12 Typical plot of the spatial distribution of energy accumulated on ground site.

Fig. 13 Normalized radial energy distribution on ground site.

Fig. 14 Total capital investment for SOLARES system (space plus terrestrial) as a function of orbital altitude.

Fig. 15 Busbar energy cost as a function of mirror altitude.

Fig. 16 Environmental impact of SOLARES.

Fig. 17 Simultaneous, multiple use of SOLARES.

Fig. 18 Incremental implementation approach for SOLARES.

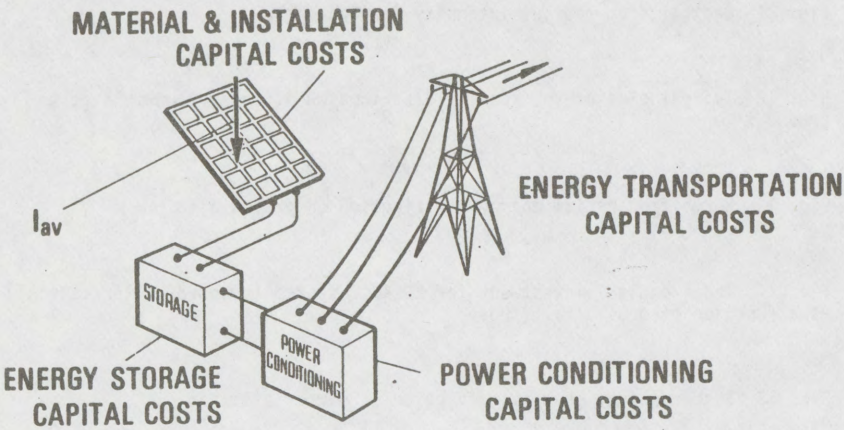

MATERIAL & INSTALLATION
CAPITAL COSTS
I_{av}
STORAGE
POWER CONDITIONING
ENERGY TRANSPORTATION
CAPITAL COSTS
ENERGY STORAGE
CAPITAL COSTS
POWER CONDITIONING
CAPITAL COSTS

Fig. 1

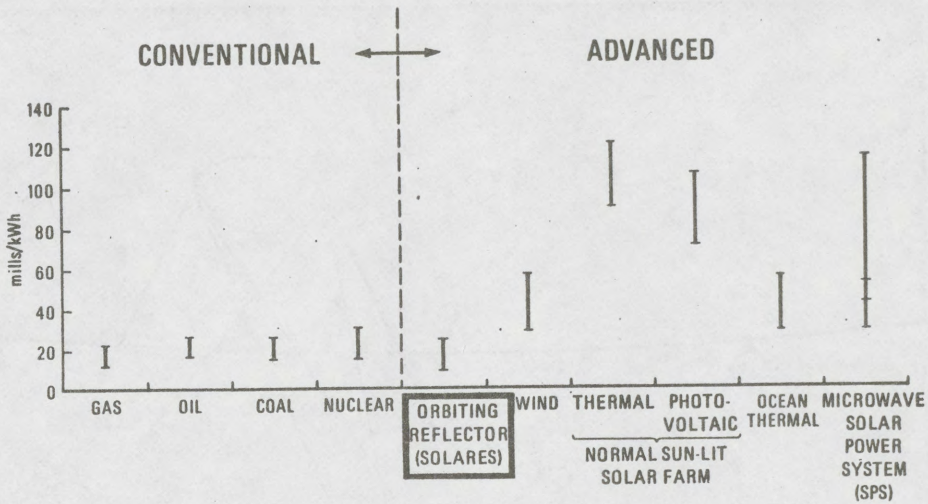

CONVENTIONAL
ADVANCED
mills/kWh
140
120
100
80
60
40
20
0
GAS
OIL
COAL
NUCLEAR
ORBITING REFLECTOR (SOLARES)
WIND
THERMAL
PHOTO-VOLTAIC
NORMAL SUN-LIT SOLAR FARM
OCEAN THERMAL
MICROWAVE SOLAR POWER SYSTEM (SPS)

Fig. 2

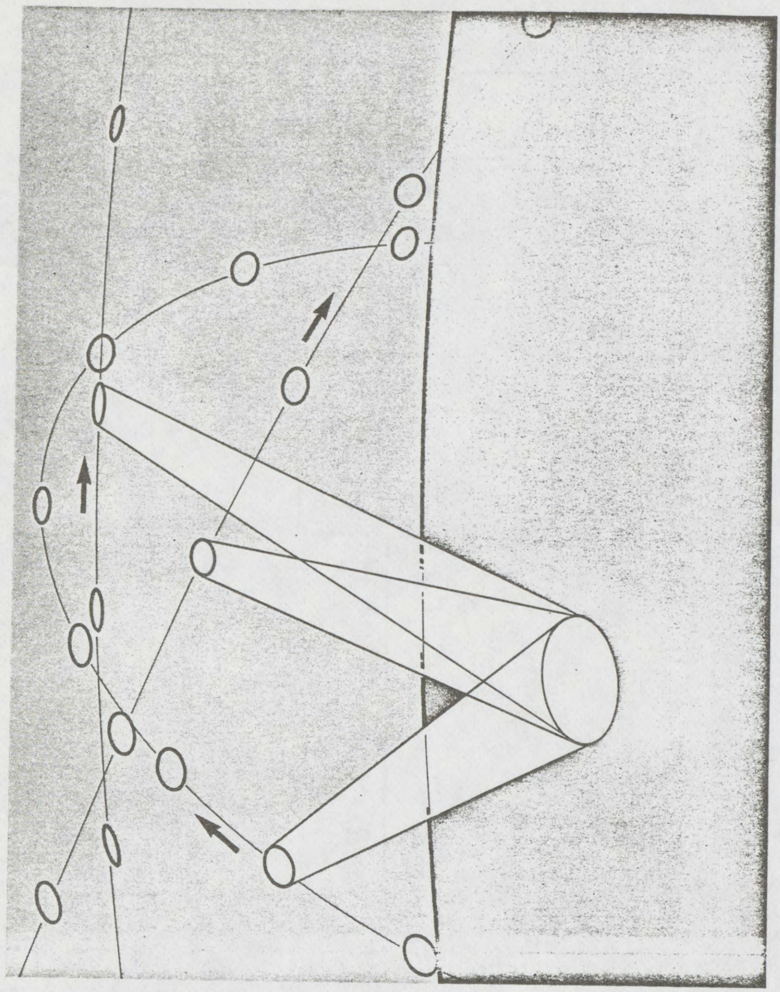


Fig. 3

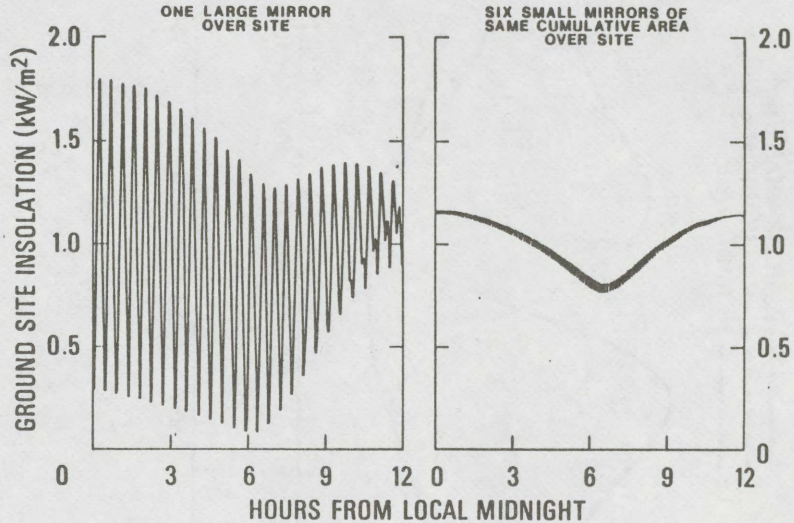

ONE LARGE MIRROR
OVER SITE
SIX SMALL MIRRORS OF
SAME CUMULATIVE AREA
OVER SITE
GROUND SITE INSOLATION (kW/m²)
2.0
1.5
1.0
0.5
0
0
3
6
9
12
HOURS FROM LOCAL MIDNIGHT

Fig. 4

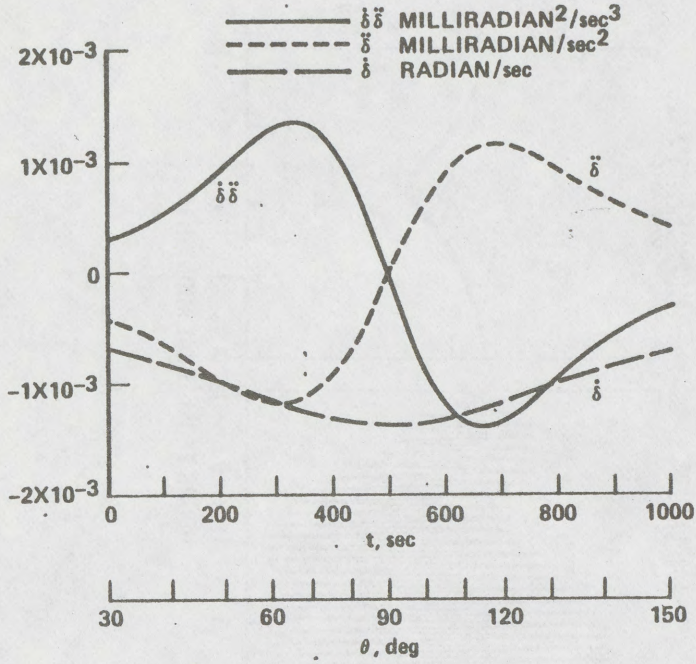

$\dot{\delta}\ddot{\delta}$ MILLIRADIAN^2/sec^3
$\ddot{\delta}$ MILLIRADIAN/sec^2
$\dot{\delta}$ RADIAN/sec
2X10^{-3}
1X10^{-3}
0
−1X10^{-3}
−2X10^{-3}
$\dot{\delta}\ddot{\delta}$
$\ddot{\delta}$
$\dot{\delta}$
0
200
400
600
800
1000
t, sec
30
60
90
120
150
θ, deg

Fig. 5

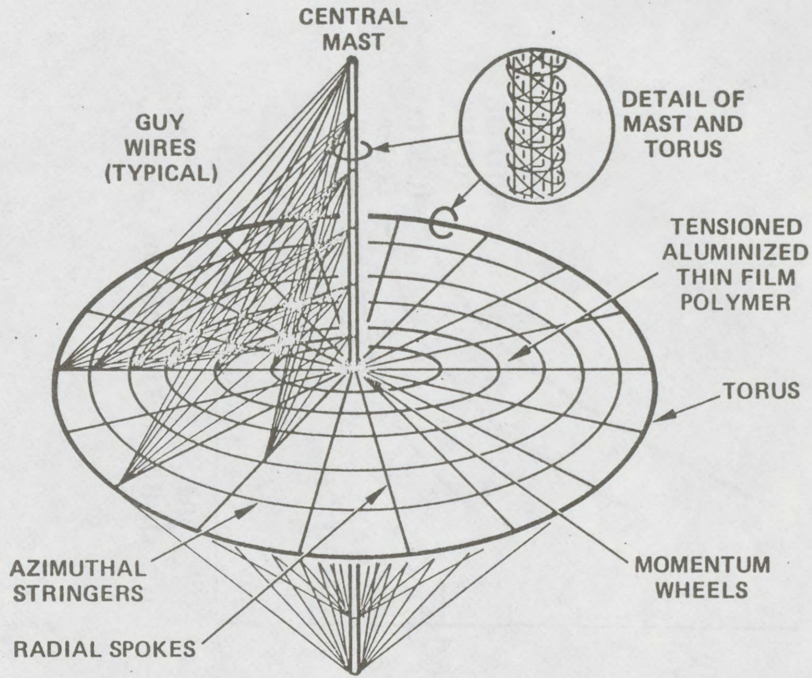

CENTRAL
MAST
GUY
WIRES
(TYPICAL)
DETAIL OF
MAST AND
TORUS
TENSIONED
ALUMINIZED
THIN FILM
POLYMER
TORUS
AZIMUTHAL
STRINGERS
RADIAL SPOKES
MOMENTUM
WHEELS

Fig. 6

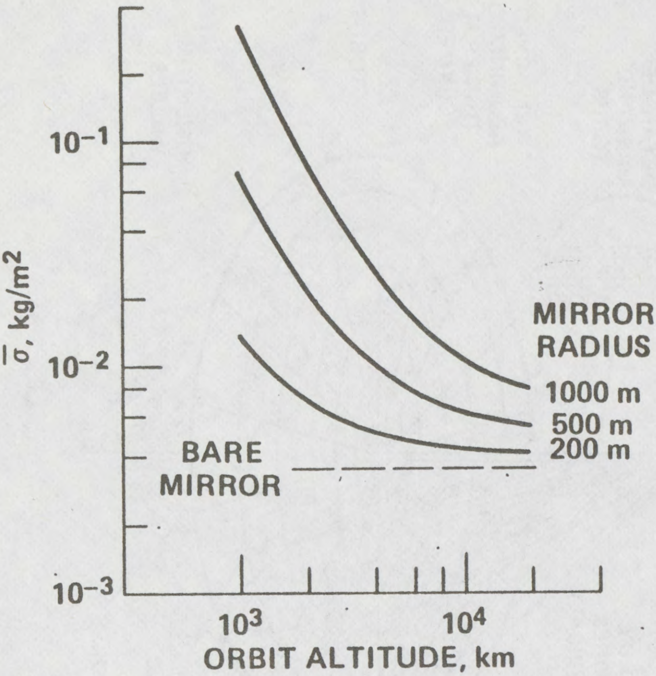

10^{-1}
10^{-2}
10^{-3}
$\bar{\sigma}$, kg/m^2
MIRROR RADIUS
1000 m
500 m
200 m
BARE MIRROR
10^3
10^4
ORBIT ALTITUDE, km

Fig. 7

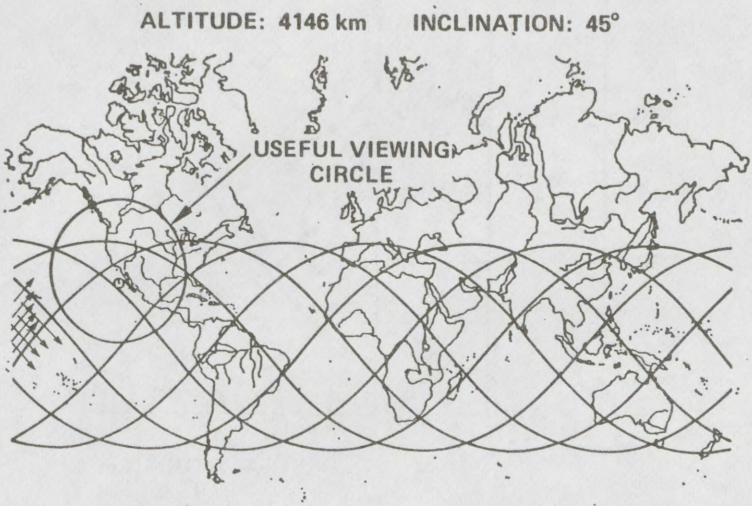


Fig. 8

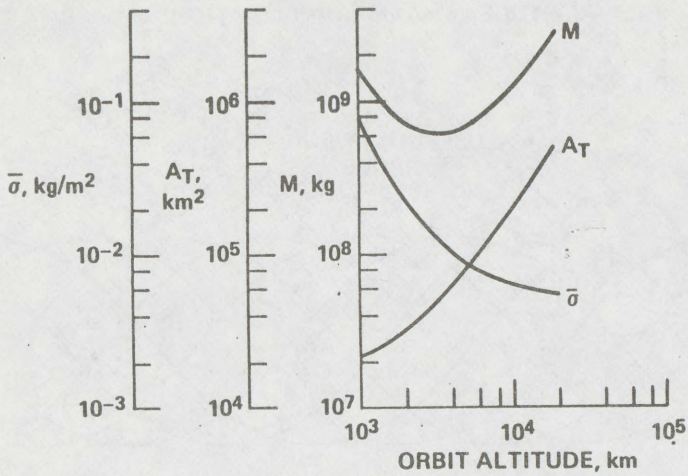

$\overline{\sigma}$, kg/m^2
10^{-1}
10^{-2}
10^{-3}
A_T, km^2
10^6
10^5
10^4
M, kg
10^9
10^8
10^7
M
A_T
$\overline{\sigma}$
10^3
10^4
10^5
ORBIT ALTITUDE, km

Fig. 9

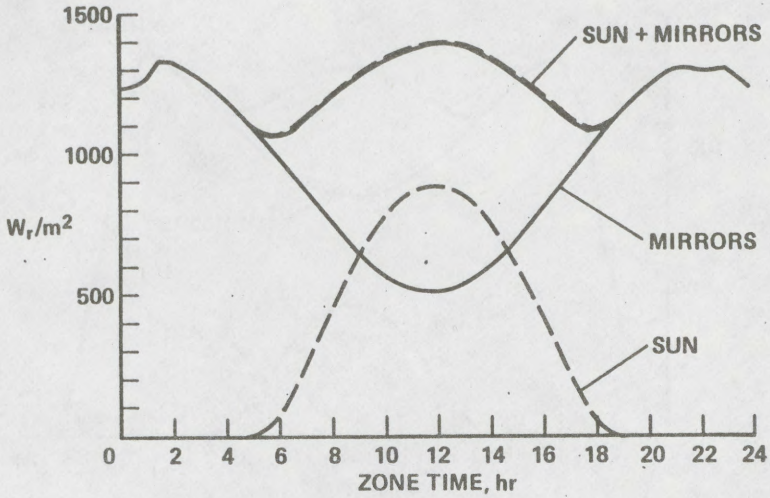
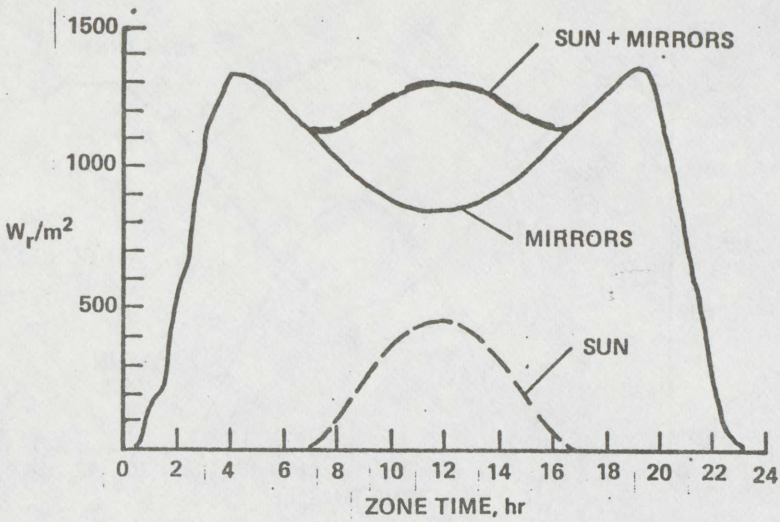


Fig. 10

35-994 O - 79 - 16



1500
1000
500
W_r/m^2
SUN + MIRRORS
MIRRORS
SUN
0
2
4
6
8
10
12
14
16
18
20
22
24
ZONE TIME, hr

Fig. 11

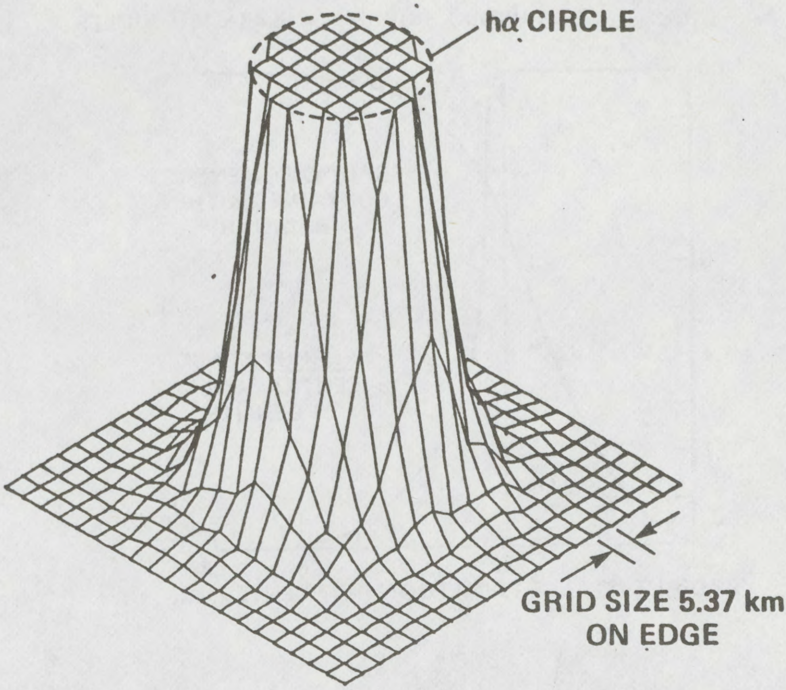


Fig. 12

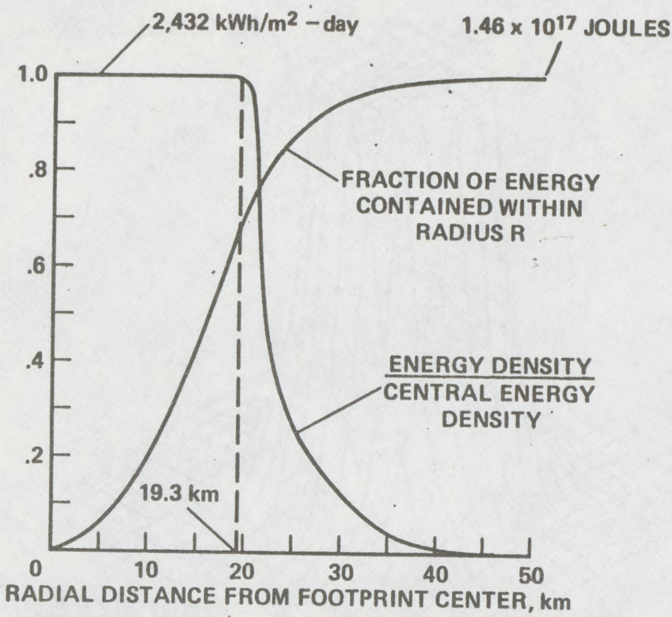

2,432 kWh/m² – day
1.46 x 10¹⁷ JOULES
1.0
.8
.6
.4
.2
0
10
20
30
40
50
FRACTION OF ENERGY CONTAINED WITHIN RADIUS R
ENERGY DENSITY / CENTRAL ENERGY DENSITY
19.3 km
RADIAL DISTANCE FROM FOOTPRINT CENTER, km

Fig. 13

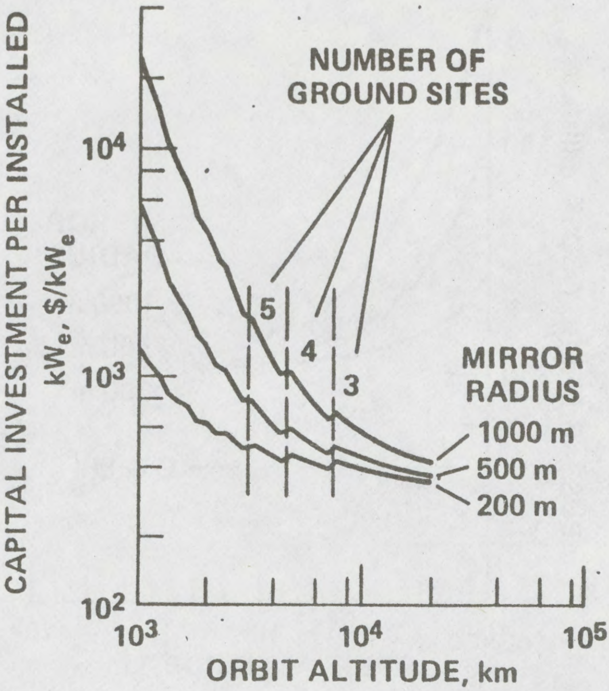
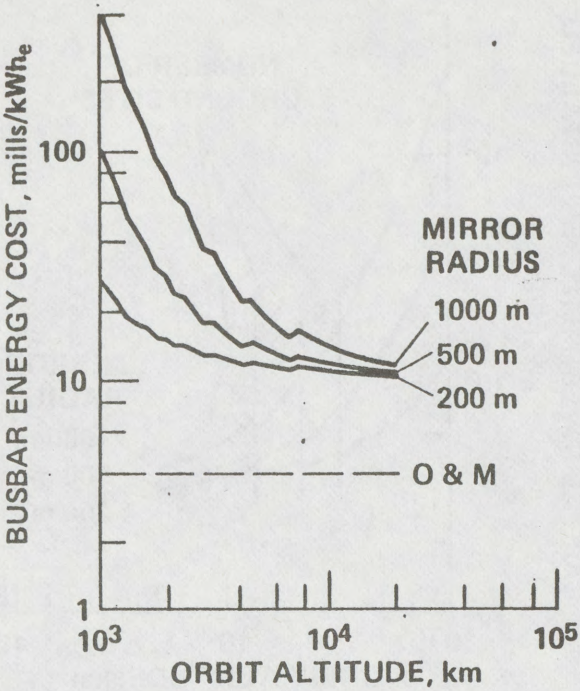

NUMBER OF GROUND SITES
5
4
3
MIRROR RADIUS
1000 m
500 m
200 m
CAPITAL INVESTMENT PER INSTALLED kW$_e$, \$/kW$_e$
10^4
10^3
10^2
10^3
10^4
10^5
ORBIT ALTITUDE, km

Fig. 14



BUSBAR ENERGY COST, mills/kWh$_e$
100
10
1
MIRROR RADIUS
1000 m
500 m
200 m
O & M
10^3
10^4
10^5
ORBIT ALTITUDE, km

Fig. 15

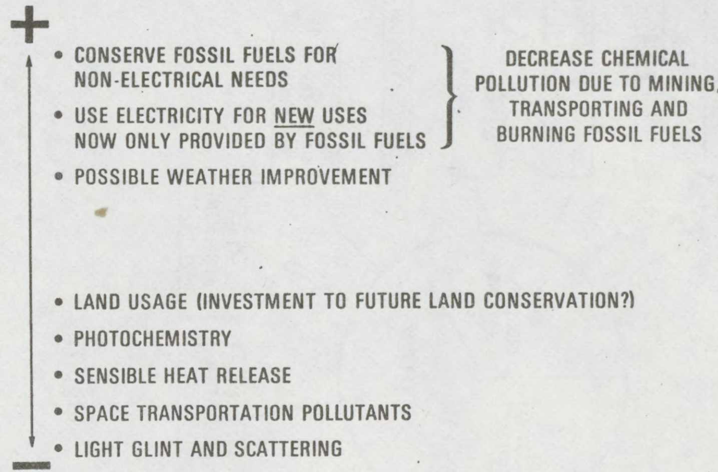

+
• CONSERVE FOSSIL FUELS FOR NON-ELECTRICAL NEEDS
• USE ELECTRICITY FOR NEW USES NOW ONLY PROVIDED BY FOSSIL FUELS
DECREASE CHEMICAL POLLUTION DUE TO MINING, TRANSPORTING AND BURNING FOSSIL FUELS
• POSSIBLE WEATHER IMPROVEMENT
• LAND USAGE (INVESTMENT TO FUTURE LAND CONSERVATION?)
• PHOTOCHEMISTRY
• SENSIBLE HEAT RELEASE
• SPACE TRANSPORTATION POLLUTANTS
• LIGHT GLINT AND SCATTERING
—

Fig. 16

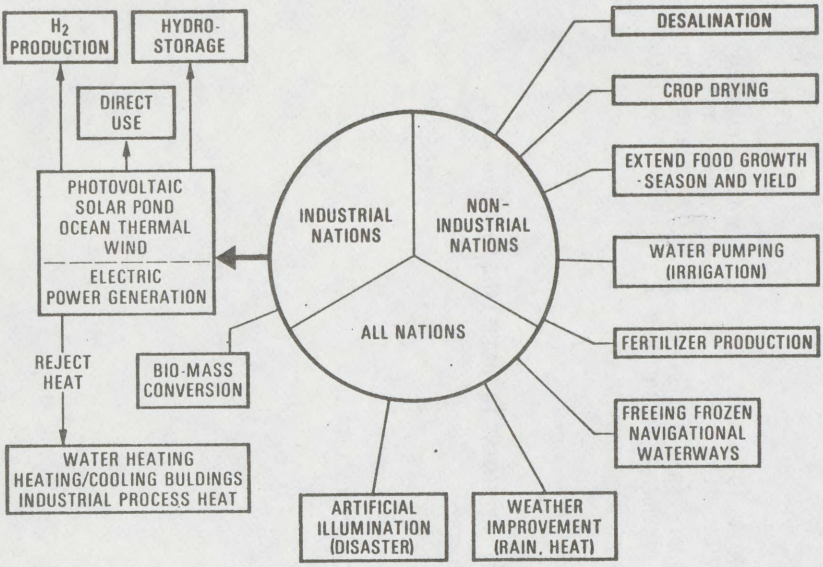

H2
PRODUCTION
HYDRO-
STORAGE
DIRECT
USE
PHOTOVOLTAIC
SOLAR POND
OCEAN THERMAL
WIND
ELECTRIC
POWER GENERATION
REJECT
HEAT
WATER HEATING
HEATING/COOLING BULDINGS
INDUSTRIAL PROCESS HEAT
BIO-MASS
CONVERSION
INDUSTRIAL
NATIONS
NON-
INDUSTRIAL
NATIONS
ALL NATIONS
DESALINATION
CROP DRYING
EXTEND FOOD GROWTH
SEASON AND YIELD
WATER PUMPING
(IRRIGATION)
FERTILIZER PRODUCTION
FREEING FROZEN
NAVIGATIONAL
WATERWAYS
ARTIFICIAL
ILLUMINATION
(DISASTER)
WEATHER
IMPROVEMENT
(RAIN, HEAT)

Fig. 17

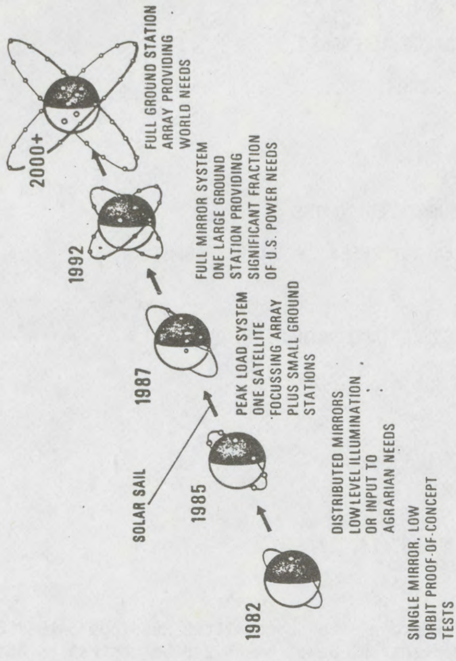

1982
SINGLE MIRROR, LOW ORBIT PROOF-OF-CONCEPT TESTS
1985
DISTRIBUTED MIRRORS LOW LEVEL ILLUMINATION OR INPUT TO AGRARIAN NEEDS
SOLAR SAIL
1987
PEAK LOAD SYSTEM ONE SATELLITE FOCUSSING ARRAY PLUS SMALL GROUND STATIONS
1992
FULL MIRROR SYSTEM ONE LARGE GROUND STATION PROVIDING SIGNIFICANT FRACTION OF U.S. POWER NEEDS
2000+
FULL GROUND STATION ARRAY PROVIDING WORLD NEEDS

Fig. 18

STATEMENT OF

GREGG R. FAWKES

ECON, INC.

SUBMITTED TO THE

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

OF THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES

U.S. SENATE

AUGUST 14, 1978

Statement to be entered in the record of the Subcommittee Hearings on S2860, cited as "Solar Power Satellite Research, Development and Demonstration Act of 1978"

As the Solar Power Satellite (SPS) concept represents one of the more promising long-range energy alternatives, I am pleased to have this opportunity to present some of the conclusions which we at ECON, Inc. have reached after studying various aspects of the economic feasibility of SPS systems during the last four years. We have been under contract both to NASA centers and to aerospace companies to conduct analyses of the potential economic feasibility of SPS, comparative cost analyses of different configurations, as well as studying other issues such as the international political implications of SPS systems.

As a result of these studies, we believe that:

- evidence to date indicates a potential economic viability of the SPS approach of such a magnitude that it supports a program of research*,

- the objective of this research at this point should be to provide information for future decision-making (in particular, hardware development and testing should be directed at "buying" information to direct the program; the value of the information gained from each test should exceed its cost, with those tests being conducted first which offer the greatest reduction in uncertainty about the technical and economic viability of the concept),

- the vigorous pursuit of alternative energy technologies (both SPS and others) provides present benefits by reducing the optimal OPEC prices for oil now and until such alternatives become available** and further by providing an economic disincentive for another embargo.

---

* "Space-Based Solar Power Conversion and Delivery Systems Study, Second Interim Report, Vol. III, Economic Analysis of Space-Based Solar Power Systems," ECON, Inc., Princeton, NJ, Report No. 76-145-2, June 30, 1976.

** "The Effect of Energy R&D on Optimal OPEC Petroleum Prices", ECON, Inc., Internal Working Paper, July 1978.

ECON

I wish to review three basic issues concerning the formulation of, and justification for energy development programs and discuss SPS in relation to these issues: 1) the uncertainty of long-range alternatives, 2) United States balance of payments, and 3) energy and technology export. In discussing these issues I will provide support for the previously stated conclusions.

The Issue of Uncertainty in the Consideration of Long-Range Alternatives. To the best of my knowledge, never before has a project of the economic and technological scale of the full SPS program (if it were implemented) been considered twenty to thirty years prior to commercial implementation, which is the time frame currently being discussed for SPS. Clearly, if we could know the future, a decision could be made now as to which energy technologies would be implemented at each point in time, indefinitely. Instead we are presented with a number of alternative technologies in various states of development with respect to technical and economic feasibility, with different dates of likely implementation, offering different forms of energy end-products.

We continue to utilize fossile fuels because, in spite of the recent substantial increases in fossil fuel prices, they remain cheap--for the moment--relative to the available alternatives, especially when the cost of converting the energy infrastructure upon which our economy is based is considered. However, it is clear for a number of reasons that the consumption of fossil fuels cannot continue beyond a limited time horizon. It is instructive to consider the time frame in which decisions will have to be made conerning the introduction of new technologies (presumably based on "inexhaustible" energy sources) to replace fossil fuel technologies.

For the present (that is, in the short term between today and the mid-1980's), it is desirable to reduce the balance of payments problem created by significant levels of oil imports, to reduce the external costs (such as pollution) associated with fossil fuel energy technologies, to prolong the period of utilization of existing energy supplies through conservation, and, importantly, to buy information about potential long-range energy alternatives.

It is crucial to note that even during this short-term period, an approach of "keeping all of one's options open" with respect to future energy technologies is not economically efficient. A fairly cursory analysis would reveal that the cost of pursuing all of the available candidate energy systems would soon represent an intolerable burden upon the economy. It is necessary to pursue the most promising candidates only to the extent that (and only so long as) improving information (through design and testing) about the technical and economic characteristics of the system justifies it.

ECON, Inc. analyses of the SPS program as well as the fusion energy research program have detailed an approach by which a research and development program is constructed as a series of tests which represent decision points in the program either to proceed with the program as designed, based on the results of the test, or to modify the program or to terminate it. This decision analysis approach allows the calculation of the expected economic value (and the uncertainty associated with that estimate) of any program at any point in time as a function of the information (or "state of knowledge") available at that point, and, of course, a comparison with equivalent analyses of competing programs is possible at each point along the way.

On the basis of this form of analysis under varying assumptions about the price of power from competing energy systems in the long-range time frame, the SPS concept has been found to have a sufficiently high potential viability that a research program is merited on the order of that proposed in the bill under consideration (S 2860) for the next fiscal year.

In the mid-term period (from the mid-1980's to the year 2000), in addition to furthering conservation efforts, it will probably be necessary to implement improved fossil fuel technologies (such as coal liquefaction or gassification) on more or less stopgap basis. Furthermore, it is during this time period that energy systems for the long-term will be developed and selected and the necessary infrastructures created, based on such decisions as centralized vs. decentralized electrical energy generation.

In the long-run (beyond the year 2000), the "solutions" which have been developed will be implemented as appropriate. It is useful to keep this time frame for decision-making in mind to focus attention on the task at hand which is that of buying information for decisions which will be made as appropriate in the future. It is not necessary (nor is it possible) now to design in complete detail an SPS system to be employed twenty to thirty years from now. Indeed, it is extremely unlikely that any system designed now would ever fly. However, sufficient information already exists to begin a constructive program of design, testing and evaluation to reduce uncertainty about the SPS system.

United States Balance of Payments. The existence of long-term alternatives creates present expectations which feed back into present decision-making. In the case of OPEC oil pricing, when an alternative becomes available it will limit or reduce the price that OPEC can charge for its oil. If OPEC planners act in an economically rational manner (that is, act to maximize the net present value of their reserves), then a credible energy research and development program which serves to shorten the period of time until alternatives to oil exist will bring about a reduction in the price of oil-in order to sell a larger quantity while the value is still relatively high. Hence, a well-designed research program directed at future alternatives can supply a downward pressure at the present on the price of oil.

Now, of course, this does not provide a quarantee against future oil price increases (above the rate of inflation)--particularly, politically-motivated price increases--or even another embargo; however, a vigorous energy research and development program provides a calculable, and substantial, economic disincentive against a (real) price rise or an embargo by OPEC.

Energy and Technology Export. As the United States considers a long-range energy research program, it should bear in mind that (after agriculture) advanced technology products such as military hardware, aircraft, nuclear technology, and high technology electronics have been responsibile perennially for the majority of our export revenues. In fact, it can be argued that only by continuing to make technological advancements can the United States maintain a balanced economic position with respect to other industrialized nations which have, for one reason or another, lower production costs. The SPS concept is perhaps unique among long-range energy alternatives in offering the U.S. the potential of becoming an energy exporter, thus reversing the current situation. It is unlikely that any other nation could enter as rapidly as the United States into the implementation of SPS systems, should they prove economically desirable; hence, the United States might be without competition for a substantial period of time. This cannot be said of any of the other long-term energy alternatives currently being considered, for indeed there would be intense competition among advanced industrial countries as well as developing countries to gain market shares of whatever energy technologies become commercially competive. This consideration of SPS's potential ability to help maintain the United States' technological advantage and even move the United States in the long-term into the position of being an energy exporter is one which should be weighed as the shape of the United States energy research policy is developed.

Statement of George B. Merrick
President - Space Systems Group
Rockwell International Corporation
August 1978

Mr. Chairman, I welcome this opportunity to express the views of Rockwell International Corporation in support of S. 2549, the Solar Power Satellite Research, Development, and Demonstration Program bill. We believe that this bill will provide the timely technical thrust necessary to support the SPS concept, which has the potential for satisfying a substantial part of the world's electrical energy needs.

In the Space Industrialization hearings held on September 29, 1977, by Congressman Don Fuqua's Space Science and Applications Subcommittee, Rockwell International outlined an approach to gain the full potential of practical space applications based on the availability of the Space Shuttle. This approach envisioned the achievement of sufficient technical, economic, and other relevant information on alternative, major, clean, renewable energy sources by 1990 to make a national decision on whether to commit to full-scale production and operations of a space solar power system. Additional views were expressed by Rockwell in Congressman Teague's Future Space Programs hearing on January 24, 1978. This paper builds upon the results of these hearings. It reviews briefly the issues associated with SPS and then proposes a plan for its cost-effective technical verification.

I would like to comment at the outset that the space solar power studies and technology developments that Rockwell International Corporation and other organizations have performed thus far lead me to the conclusion that the basic thrust of the current DOE-sponsored program should be expanded and the pace of research increased significantly. On the other hand, I believe that a national commitment to full-scale development at this time is premature.

35-994 O - 79 - 17

SUMMARY OF THE ROCKWELL POSITION

The Rockwell position on Solar Power Satellite development may be summarized in three key points:

- ✓ First, we believe that desirable technology advancement related to solar power development and utilization is best accomplished by focusing on programs with specific objectives and definable technical requirements rather than proceeding sporadically on disconnected technology developments. In this respect, the currently postulated SPS concept should be the key system "driver" leading to focused technical progress and experimental results.
- ✓ Second, solar power satellite research and development provides a program goal-oriented challenge that will bring about significant technology advances, which will also offer benefits to other proposed terrestrial and space system developments of value to the nation.
- ✓ Third, as a result of the preceding logic, we are led to the strong conclusion that the most effective and productive commitment that can be made now is to proceed with a well-conceived and properly funded SPS *technology verification* program that can explore and resolve the key developmental issues involved in the solar power system concept.

KEY ISSUES

I believe it is essential at this point in SPS system concept definition to mount a determined experimental attack upon identified critical technical and environmental issues that could impact timely development of the solar power system. These key issues can be grouped in three major categories:

1. Effects of the SPS system on earth's environment and life forms.
2. Effects of the natural environment on SPS system development and operation.
3. State-of-the-art advancement in critical component development.

The SPS system can affect the environment through interaction of the microwave beam with the ionosphere, microwave system radio frequency interference, microwave radiation on life forms and the ecology, and launch vehicle emissions into upper atmosphere.

The natural environment can affect the health of space construction personnel through radiation, high-voltage power conversion and power amplification equipment performance through the effects of space plasma, and materials lifetime through interaction with the space environment.

A key issue involves technical items associated with the development of advanced state-of-the-art SPS components, such as solar cell blankets, microwave conversion devices and antennae, high-voltage switchgear, and power converters, plus the full spectrum of construction techniques required to support large-scale space structure fabrication.

The microwave power transmission system is clearly the most critical subsystem from the standpoint of basic technical feasibility. State-of-the-art advances are required in dc-to-RF and RF-to-dc conversion, phase control, RFI suppression, and thermal control. Klystrons with power levels up to 70,000 watts and power distribution systems with capacities up to 40,000 volts must be developed to operate for 30 years in the geosynchronous environment. Intensive early development efforts are required for these power amplification and distribution components. The achievement of low-cost, high-volume pilot-plant production of solar cells, blankets, and flight-rated solar arrays also mandates an early R&D effort in view of the four to five year lead times involved.

Each of these environmental and technical issues I have outlined requires early concentrated experimental research efforts to quantify the probable effects and provide a logical technical basis for deriving mitigation techniques and accomplishing successful component design and development. The exploratory research plan under consideration by the Department of Energy (DOE) for initial FY 1980 funding is a necessary first step in this direction; however, it does not go far enough. Proposed ground testing is limited to microwave phenomena only, with emphasis on environmental effects. The research plan limits key component development to low-power, non-prototype levels only and puts off the definition and initiation of critical early ground and space-related technology verification development and testing.

A more comprehensive research and development program effort with an FY 1979 start, as proposed in Senator Melcher's Solar Power Satellite Research, Development, and Demonstration Program bill, is in our judgment, best suited to the task of resolving the key SPS technical issues that I have outlined here.

RECOMMENDED SPS VERIFICATION PROGRAM

Our approach to an SPS research and development plan covering a ten-year period from 1980 to 1990 is shown on the planning scenario overview (Chart 1). The first five years (1980 to 1985) include the exploratory research effort contemplated by DOE, as well as an intensive component and subsystem development effort for microwave power transmission, power conversion and distribution, and definition of large structure construction techniques. The DOE exploratory research plan segment is contained within the dashed lines and provides the "seed bed" for prototype microwave power transmission component and subsystem development.

Microwave Environmental Accessment

The current SPS design concepts have limited the maximum microwave beam intensity to less than 23 mW/cm^2 at the center of the beam and 1 mW/cm^2 outside the rectenna fence line. The maximum limit is less than a fourth of the incident solar energy at the earth's surface. The minimum is a tenth of the current United States microwave standard. Despite these low levels of energy, it is necessary to conduct tests to assess potential long-term effects of continuous microwave radiation on man and the total terrestrial ecological system.

Microwave testing also will determine beam interactions with the ionosphere that could induce interference with terrestrial airborne and spaceborne communications. These tests can be conducted with use of facilities located at Arecibo or Plattsville. The maximum beam intensity level previously mentioned is expected to be sufficiently low to avoid significant interactions.

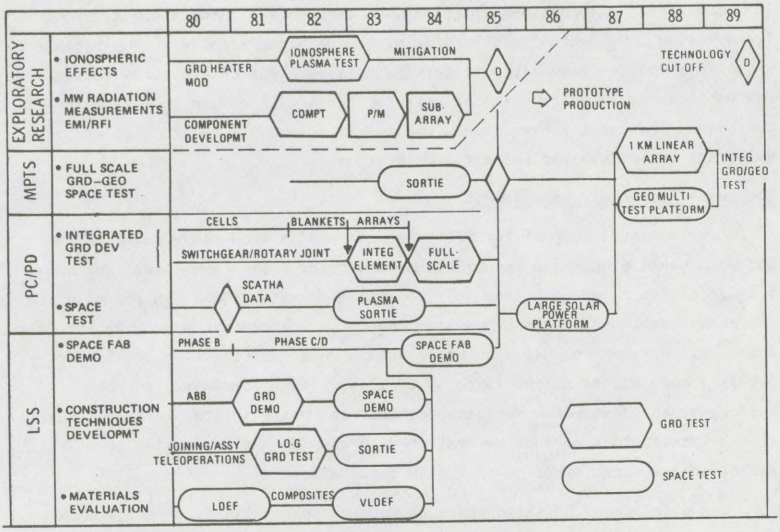


Chart 1. Proposed Rockwell Approach

ABB	automated beam builder
COMPT	component
D	decision
EMI	electromagnetic interference
GEO	geosynchronous earth orbit
GRD	ground
LDEF	long duration exposure facility
LO-G	low gravity
LSS	large space structure
MPTS	microwave power transmission system
MW	microwave
PC/PD	power conversion/power distribution
PM	power module
RFI	radio frequency interference
SCATHA	satellite to evaluate spacecraft charging phenomena
VLDEF	very long duration exposure facility

Incidental and spurious emissions, at frequencies outside the SPS power transmission band, which fall outside of the rectenna area, also may produce undesirable radio frequency interference on some electronic systems throughout the hemisphere. Results of these emission tests will result in mitigation techniques that will either reduce the levels at the SPS or identify effective filtering techniques for the affected systems.

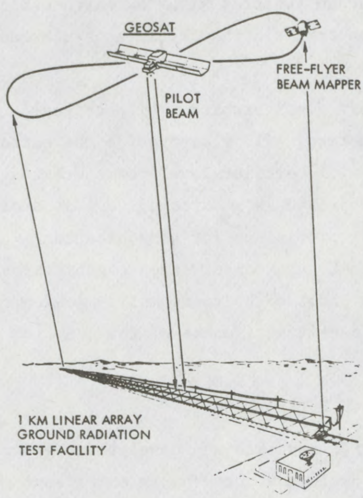
Component Technology Advancement

Developmental support for SPS power conversion technology consists of DOE solar cell production research and NASA solar array development and high-voltage/plasma research. Inasmuch as gallium arsenide (GaAs) solar cells are currently baselined in the SPS system concept, a concentrated program for GaAs solar cell development needs to be pursued. Power distribution development requires more effort in the 20 to 40 kV high-voltage components such as switchgear and dc-to-dc converters, as well as rotary joints. High-voltage/plasma interactions need to be evaluated by use of Shuttle sorties to establish low earth orbit power system thresholds.

The development of large space structures technology is essentially a NASA-supported effort at present, with emphasis on generic development with broad application. SPS requirements reflect the ultimate mission application and should be reflected back into basic technology development to enhance commonality and applicability to those large SPS test articles projected for the second half of the decade.

Ground and Space Testing

Commitment to large-scale SPS development ground and space test activity is anticipated about 1985 on the basis of exploratory research and key component development results and progress. At that time, the emphasis will shift confidently to large structures orbital testing in both low earth and geosynchronous orbits. Low earth orbit tests will involve demonstrations of microwave power transmission at power levels in the range of 500 kW to 2 MW. The test article would then be boosted by electric propulsion to geosynchronous altitude for space-to-ground and ground-to-space tests. A major emphasis will be on maximizing ground hardware. An example of how this would be accomplished is shown on Chart 2. In order to demonstrate antenna beam pointing and phase control performance accuracies, a phase-array antenna element up to 1 km in length must be tested. Testing this array in a geosynchronous orbit-to-ground mode would result in excessive costs. A viable cost-effective alternative is to build the transmitting array on the ground and transmit the beam to a small beam-mapping satellite at geosynchronous orbit, functioning in effect as an inverted microwave test range.



OBJECTIVES

- TEST PERFORMANCE OF RETROELECTRONICS USING FINAL APERTURE
- DETERMINE MANUFACTURING TOLERANCES FOR RETROELECTRONICS
- DETERMINE ATMOSPHERE EFFECTS
- TEST EFFECT OF TRANSIENTS
- POWER DENSITY PROFILE MEASUREMENTS

GRTF CHARACTERISTICS

- GROUND ANTENNA INSTALLATION
  - ✓1 KM EAST-WEST LINE SOURCE SIZE
  - ✓ONE PWR MODULE WIDE - RADIATES 50 KW
  - ✓LOCATION - S.E. USA
  - ✓PROTO MODULAR MPTS ELEMENTS/PHASE CONTROL
- GEOSAT
  - ✓INTEGRATED GEOSYNC ORBITAL TEST SYSTEM
  - ✓GEOSAT ELEMENTS
    - PROTO 500 W PILOT BEAM
    - BEAM MAPPER SUB-SATELLITE
    - MODULAR GaAs SOLAR ARRAYS - 100 KW
    - SCALED POWER CONVERSION - POWER DISTRIBUTION SUBSYSTEMS
    - EOTV PROPULSION SYSTEM FOR ORBITAL TRANSFER & RETURN
    - MPTS COMPONENT TEST SUBSYSTEM

Chart 2. Inverted Microwave Transmission Test

Pilot-Plant Demonstration

The technology verification phase of SPS research and development can be completed by 1990 to support a confident commitment at that time to proceed with the pilot-plant demonstration phase.

The pilot-plant demonstration phase reflects, in general, a modular "precursor" demonstration philosophy as the most cost-effective approach to a large-scale, commercial-type, pilot-plant, end-to-end performance demonstration. Use of Shuttle-derived low-cost launch vehicles with low earth orbit assembly and dedicated electric propulsion orbital transfer to geosynchronous is baselined.

The pilot-plant demonstration platform configuration, while driven principally by SPS prototype design parameters, will also provide the nation, before the year 2000, with a long-life, multi-megawatt-level power station in geosynchronous orbit, which could be categorized as a *National Geostationary Space Facility* with capability and modular provisions for communication/ navigation antenna farms and extended manned earth observation capabilities on a self-sustaining basis. The benefits provided by these multi-mission services would considerably improve the cost-effectiveness of the SPS pilot-plant concept.

IMPACTS OF COMMITMENT LEVELS ON PROGRAM SCHEDULE AND COST

In attempting to derive a realistic SPS research and development program with appropriate decision milestones, we evaluated three basic commitment levels.

The first level is that represented by the DOE exploratory research plan, which is limited to microwave effects analysis and does not include component technology advancement, space-related technology, or Shuttle experimentation.

The second level is an expanded comprehensive technology verification program, beginning in FY 1979 with an intensive component development effort and culminating in the late 1980's with major low-cost proof-of-feasibility space testing. This testing will provide verification results that will support a confident commitment by 1990 to pilot-plant demonstration activity.

The third level would encompass all phases (research, verification, and pilot-plant demonstration) in one large-scale continuous developmental effort leading to full-scale SPS demonstration by the year 2000.

With respect to cost and schedule implications of these commitment levels:

✓ A program limited to the proposed DOE exploratory research plan would cost about $100 million over a five-year span, but would slip both technology verification and pilot-plant demonstration phases by about five years.

✓ A commitment to a comprehensive ten-year technology verification program of interactive ground and space testing, with cumulative funding of about $3 billion, would support a well-planned SPS development scenario and assure a pilot-plant demonstration before the year 2000. Cumulative funding for the first five years would be on the order of several hundred million dollars. The large-scale orbital testing programmed for the second five years would require an investment of a few billion dollars; however, this commitment would not have to be made until 1985 and would hinge on successful prior development activity and results of microwave environmental testing.

✓ A decision <u>now</u> for a full pilot-plant demonstration commitment would accelerate the schedule if an early start on a space construction base also were made. However, an early definition of a large space construction base gambles on the precise knowledge of what the pilot-plant configuration and construction technique would be. This level of commitment would involve tens of billions of dollars from 1990 through 2000.

As a result of our evaluation of commitment alternatives, Rockwell International recommends that a comprehensive SPS *technology verification program* of balanced ground- and space-related technology advancement be the basis for an SPS research and development commitment at this time. Limiting the program to microwave effects analysis impacts the schedule too severely and diminishes program thrust. Committing now to a major pilot-plant demonstration phase that would not occur until the year 2000 is neither necessary nor desirable.

APPLICABILITY OF SPS VERIFICATION PHASE OUTPUT TO OTHER SYSTEMS AND PROGRAMS

The technical benefits of the proposed SPS *technology verification program* will have effects reaching far beyond SPS applications. The microwave environmental tests will provide the understanding currently lacking in microwave interactions with life forms, ecology, and other systems. This will result in improved microwave standards and techniques for mitigating the interactions. High-efficiency and low-cost solar cell blanket manufacturing techniques also will have application to terrestrial solar photovoltaic systems. Potential solid-state microwave dc-to-RF converter breakthroughs may result in high-efficiency, high-power transistors for radar, microwave oven, and radio transmitter and receiver applications. Overall benefits to the space program will include large structures technology and low-cost power sources for space operations.

In conclusion, Mr. Chairman, the Solar Power Satellite Research, Development, and Demonstration Program bill now under consideration by your subcommittee is a realistic approach for supporting the technology development that will bring about significant benefits. The need for a clean, inexhaustible cost-competitive energy source is one of the most critical problems facing the United States today and will be for many years ahead. Solar power satellites have the potential of providing a long-term solution to this problem. Their promise is sufficiently great for this nation to plot a bolder course and invest the relatively modest funding required to demonstrate that the concept is practical and the payoff is real.

BIOGRAPHY OF GEORGE B. MERRICK, PRESIDENT, SPACE SYSTEMS GROUP

George Merrick is president of Rockwell International's Space Systems Group. He is responsible for three business segments: Shuttle Orbiter Division, Satellite Systems Division, and Space Transportation System Integration and Operations Division.

Joining the Space Division in 1966, Mr. Merrick served as director, Apollo System Engineering, and chief Apollo program engineer, and subsequently as vice president for the cislunar and lunar scientific missions, the Skylab spacecraft, and the Apollo-Soyuz Test Project, representing a total of thirteen million miles in space, including over 20,000 in-space man-hours. In 1974 he was appointed vice president and program manager of the Space Shuttle Orbiter Project.

As president, Merrick directs the Space Systems Group's efforts in the design, development, and operations of major space program systems. At the Space Systems Group numerous contractual studies and independent research and development programs are contributing to aerospace technology and to the nation's increasing inventory of space benefits. His technical management and executive leadership have been of major significance in the nation's space program achievements.

Since joining Rockwell in 1949, Merrick has held key engineering posts on projects which included the X-15, America's experimental spacecraft which was the first winged vehicle to carry pilots into space altitudes; the F-100 supersonic fighter, the first aircraft to maintain a velocity faster than the speed of sound at level flight; and the XB-70, a triplesonic speed delta winged experimental bomber. On the company's aircraft programs, Merrick was responsible for analysis and evaluation of stability augmentation and automatic flight control systems. He later became chief of Operations and Systems Analysis for advanced military weapon systems. He was also a program manager for the company's advanced manned strategic aircraft projects which led to the development of the B-1 bomber. Additionally, he served as assistant to the corporate director of Systems Engineering.

Merrick is a recipient of the NASA Public Service Award, one of the space agency's highest honors for a person outside government, and two Certificates of Appreciation for Apollo program contributions. He was born in St. Paul, Minnesota, and was graduated from the University of Minnesota with a B.S. degree in aeronautical engineering.

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.,
Washington, D.C., September 1, 1978.

Senator HENRY M. JACKSON,
Washington, D.C.

DEAR SENATOR JACKSON: The Energy Committee of The Institute of Electrical and Electronics Engineers (IEEE) is committed to a study of the proposed Satellite Solar Power System (SSPS). Although our study is not complete it appears to us to be premature to enter a "Solar Power Satellite Research, Development, and Demonstration Program" as contemplated in Senate Bill 2860.

Many fundamental questions in the areas of technical feasibility, economic viability, and environmental and social acceptability of the SSPS concept need to be addressed before the United States commits major resources to the SSPS. A program plan, jointly prepared by DOE and NASA, designed to obtain the initial information needed to make recommendations on developing the SSPS, is in place in DOE, NASA, and the Institute of Telecommunications Sciences. This effort, which will be complete in 1980, will provide the basis for a rational plan to move forward with the SSPS.

The IEEE Energy Committee therefore recommends against Senate Bill 2860, and urges the Senate Subcommittee on Energy Research and Development to find against the bill.

The IEEE Energy Committee is continuing its consideration of the Satellite Solar Power System. We will be pleased to make the results of our study available to the Congress and the Department of Energy as soon as they are complete.

Sincerely,

HILTON U. BROWN, III,
Chairman, IEEE Energy Committee.

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.,
Washington, D.C.

THE IEEE AND ENERGY

The Institute of Electrical and Electronics Engineers, founded in 1884, is the world's largest technical, professional, engineering society. One hundred and fifty thousand of our mebers reside in the United States. The purposes of the Institute, as defined in its Constitution, are scientific, educational, and professional. Within the IEEE structure are a number of professional units involving specific disciplines in electrical and electronic engineering such as Power, Nuclear and Computer Sciences, Magnetics, Antennas, and Industrial Applications, among others. These IEEE societies have in their ranks the foremost experts in the disciplines they represent.

As part of its continuing effort to provide technological advice in many of these disciplines, a special committee was formed in 1975, charged with solely looking into matters involving energy. The members of the IEEE Energy committee are experts in their fields and represent the Institute's broad spectrum of scientific and engineering talent.

The Committee has taken positions in such matters as Fussion, Solar Energy, and Energy Conservation, and is continuously reviewing the current status of U.S. programs involving energy with the objective of providing their comment whenever appropriate. The positions of the committee are available to the Congress or any other public body.

R/E DEV. INC.,
Billings, Mont., August 2, 1978.

Hon. JOHN D. MELCHER,
U.S. Senator, Subcommittee on Energy Research and Development,
U.S. Senate, Washington, D.C.

DEAR SIRS: This is prepared and submitted on behalf of Montana's small community of versatile and surprisingly capable scientists and engineers. It relates to Hon. John D. Melcher's Solar Satellite Bill S–2860.

It is not the purpose of this letter to, at this early stage, pass opinions as to feasibility of the proposed Solar Satellite other than to suggest that it appears not unfeasible. Rather, if an attempt can be made, steps recommended here can materially maximize chances of final success.

Even tho at times Montana parties have trouble with partially mundane things like welds on major space-related weaponry applications, its not impossible that knowledge may have emigrated to Montana as to how to make such exotic weaponry stand up and do very surprising tricks. Further, its not difficult to extrapolate a bit so as to render advantageous scientific and R & D methodology from these sources of very considerable value to a Solar Satellite program.

The primary point made here is that a small, carefully selected group in Montana can provide effective, direct over-all guidance and management during the several phases of the proposed Solar satellite study program particularly starting with the early formative steps. Value of such overall guidance should be considerable to all parties concerned.

Writers proposal, specifically, is that the Montana group, via this firm, R/E Dev Inc, be accorded under contract overall system responsibility for the Solar Satellite study program, starting at the very beginning. It would desirably be set up to continue on into manufacturing and deployment when and as justified by study results, upon decisions to proceed. A viable example exists in the system guidance provided, starting about 1949, in the successful Navy Bu Ord missile program (Terrier, Talos, Triton etc) by the Applied Physics Laboratory of Johns Hopkins University.

Items related to this thesis are as listed below. (also see appended summary)

a. Montana likely would build but very little of the hardware and thus has no such axes to grind. Accordingly, full objectivity of such a management effort, based on almost fully neutral ground, is greatly enhanced.

b. Montana's present energy potential is considerable and its utilization is being hotly debated on many sides, including quite numerous and vocal response from the 'con' parties. Also there is obvious a great need, illustrated by tenacious activity of the 'pro' parties. Accordingly there is singular motivation here to constructively assist in practical utilization of major renewable energy sources.

c. Being considerably more conscious of the grass roots areas from which the dollars in final analysis must grow and being unused to ten figure fundings, Montana parties can be expected to scrutinize costs carefully indeed. This course can be of inestimable value since excessive costs can founder programs and have foundered important major programs in very recent years. The recent advent of certain initiatives in the tax field have triply accentuated importance of reduced over-all expenditure; civilian participation in rigorous cost analysis and reduction should enhance public acceptance.

d. Demonstrated capability for such systems management is readily available in Montana.

e. The independent nature of the proposed system coverage should keep all parties involved "honest" to maximum extent. This is an important point.

Materials provided previously are utilized to substantiate the statements above and are discussed more fully in the summary enclosed.

Further material desired will be gladly provided and questions raised will be fully considered.

Very truly yours,

MELVIN P. ESPY, P. E., *President.*

Attachment.

SUMMARY OF DATA RELATIVE TO SOLAR SATELLITE STUDY PROGRAM—REFERENCES (DATE USED FOR IDENTIFICATION)

May 24, 1978, ltr, R/V Dev Inc to (Montana Delegation)

May 25, 1978 ltr, R/E Dev Inc to (Montana Delegation)

June 22, 1978 ltr, R/E Dev Inc to U.S. Dept of Energy, attn Dale Erickson, Dep. Regional Rep., Denver Colo.

June 20, 1977 Leaflet "The Engineering Generalist: His Function and Functioning in Really Difficult Trouble Shooting" by R/E Dev Inc.

December 3, 1973 Leaflet "System Engineering and Development Engineering Can Provide Vital Help in the Energy Crises." By R/E Dev Inc

July 14, 1977 Proposal "Developing a Practical Method to Achieve a Major Reduction of the Sonic Boom: An Aggressive and Highly Creative Program in Experimental Engineering" by R/E Dev Inc.

February 1978 "Space: Industry's New Frontier", in Nations Business

All references except those of July 14, 1977 and February 1978 are largely appropos to this proposal and related methodology and it is suggested that they be perused. Following are certain highlights.

"Properly handled, there is an excellent chance that Solar Satellites could be practical. Improperly handled, the concept could go the way of the B1 bomber at Rockwell International and the Supersonic Transport (SST) program at Boeing, both of which (are considered to have) priced and over-complicated themselves out of the market" (Ref 5/24/78). In the last two, very considerable sums of money were expended and presumably wasted.

Lets refer to the system team which the writer proposes as the Montana Team. It would number not more than say, four to six full time technical persons, one or two non-technical parties, several part time technical parties. Members would be drawn, most likely, from the Montana Universities, private engineering firms and particularly the MERDI group at Montana Tech.

While a useful fund of applicable technical information is available here, the primary function of the proposed Montana Team would be in the area of advanced methodology on concept development and refinement, and later on the several stages of Research and Development. During the concept stages, broad based system engineering (backed by development engineering) would be employed to gradually configure the most likely combination(s) of system blocks or links. This would draw in and utilize all useful technical inputs and proposals from the numerous well qualified specialists with particular interests and knowledge in the field. Where system blocks can be fairly well visualized by all concerned parties these would receive only limited further detailed attention from the Montana Team. A portion of the team instead would direct close attention, in development engineering fashion, to the questionable and quite difficult blocks of the emerging system, looking for individual breakthroughs that would permit simplifying the overall system while maintaining, or improving over-all system function.

Expressed otherwise, it would be a continual technical tailoring of the system blocks and overall system, paying very close attention to the tough points, aiming toward a final system configuration having the optimum mix of performance, simplicity, dependability and cost.

The term 'broad based system engineering' is used to imply and include starting from the 'people involved' base and taking into account all 'people affected' factors along the way and at the feed-out or conclusion. (Writer was among the very first to emphasize the important people factor, starting in 1957. Failure to take this into account has been the reason why many engineering programs have run into trouble in environmental and related matters.)

Then, when a system has been configured, whether it is an early or more fully developed concept, it is defined by the requirements for each block or link along with overall requirements and performance capability. These include the 'people factors' as just noted.

Top rated development capability is a prerequisite to reaching the very best in overall system concepts. See particularly the comments on this point at top of page 3 of the 12/3/73 reference.

Writer can state honestly, though immodestly, that he has had a somewhat unique background in successfully guiding operations as just described with relatively small resources. This is a portion of his basis for stating that a Montana Team can provide valuable system guidance easily and quite effectively. There is a marked difference between trying massively and failing as compared to working methodically and efficiently, at maximum creative level, to achieve a satisfactory result.

Note that, contrary to practice and belief of most technical people, none of the Montana Team would be super-specialist in particular portions of, for instance, high altitude solar or space operations but would be selected for particular and mature technical management capabilities, coupled with good all-around technical knowledge in the general work area. Composite capability of the team would cover ability to

a. Draw in and utilize technical inputs from numerous highly informed sources.

b. With assistance from those specialist sources, select the most desirable components and approaches, tailoring the composite into a system configuration with the optimum desirable overall capabilities and characteristics.

A bit of information regarding the writer vis a vis leading Aerospace firms may be in order. Writer has indeed a healthy respect for these firms, most particularly for the one firm that is far and away the practical leader in commercial, defense and (in large part) aero-space fields. Regarding that particular firm, writer went there in 1957 as the first qualified system engineer in the Pacific Northwest and, in his small way, made some useful contributions to that companies fairly rapid and marked transition to a system oriented firm.

System engineering is defined somewhat differently by almost every engineer in the field. It has been the writer's pleasure to become uniquely experienced in the concept development phase of system engineering, in circumstances that ruled out (to the writer's relief) the meaningless verbose portion of it and permitted major individual creative activity. However activity in that field has covered the systems course, up to and including field deployment of major systems.

In the above and other fields, writer has been in the forsight of aero pioneering since the early years of WWII (1941, 1942). The initial opportunity then was in personally developing high performance, high capacity closed loop servo systems. (didn't even have a proper name for the beasts then) These worked routinely at hydraulic pressures of 10,000 P.S.I., even up to 30,000 P.S.I., and performance in some respects remains unmatched even today. A number of other pioneering, or first-time-ever, items are noted in the 7/14/77 reference.

One essential ability resulting from the above background is that of readily identifying the most effective way of approaching very difficult problems or assignments. While the 7/14/77 references identifies what should be the most promising approach to one really difficult phenomenon (Sonic Boom), an entirely different approach would be selected for a creative, pioneering program like the proposed Solar Satellite.

Writer will be pleased to lead a Montana team in playing a useful part in the Solar Satellite study program.

In conclusion, writer wishes to make this statement:

Cost essentially becomes the major factor in establishing feasibility, assuming that an acceptable conceptual model will have minimized possible hazards to the public, of any nature.

Participation by a Montana team as described here should maximize accuracy of study results and chances of final success at acceptable costs.

R/E Dev., Inc.,
Billings, Mont., August 14, 1978.

Hon. John D. Melcher,
U.S. Senator, Subcommittee on Energy Research and Development,
U.S. Senate, Washington, D.C.

Dear Sirs: This writer wishes to provide a considerably greater assurance of success or feasibility, of the proposed Solar Satellite program, than expressed in his referenced letter of 8/2/78 to the subcommittee.

In summary, it is his feeling that whatever feasibility is judged otherwise to exist can be reinforced by a ratio of at least three to one or five to one.

The above is arrived at in view of methods and facility described in the 8/2/78 letter, including its attachments, and references, principally through:

a. Enhanced ability to arrive at the simplest and most fool proof of comprehensive concepts.

b. Illustrated assurance that ways can be found around or over very difficult technical or deployment road blocks encountered.

c. The above have an indeed significant effect in reducing cost and keeping it within prescribed limits.

d. Thus, costs, being reduced and known, become the prime criteria for final decision.

The Montana Team proposed would, in accomplishing the above improvements, objectively facilitate inputs and contributions from all qualified sources. This can be and would be handled relatively simply and by proven down-to-earth methods that can be readily understood and appreciated by those involved. Wherever complex management methodology is forced into play, it would be resolved to an understandable level.

The above should add significantly to assurance of final success.

Very truly yours,

Melvin P. Espy, P. E., *President.*

○