FINANCING ALTERNATIVES FOR SPACE INDUSTRIALIZATION*

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Abstract

Large scale space industrialization projects challenge conventional methods of financing commercial undertakings. As part of the Department of Energy's Satellite Power System Concept Evaluation Program, we examined the problems of financing both the lengthy and expensive R&D phase and the capital-intensive commercial implementation phase of an SPS program. Ten alternative schemes, ranging from purely public to purely private, were developed. One of these, a purely private enterprise approach, is already underway. Some of the alternatives presented here may be readily adapted to other space industrialization projects and to large-scale terrestrial projects as well.

Introduction

The concept of harvesting renewable solar energy in space for transmission to Earth for terrestrial use has attracted increasing interest and attention in recent years. A number of design alternatives have been considered, including transmission of energy by microwave beam, by laser beam, or by reflection of raw sunlight; geosynchronous equatorial orbit, sun-synchronous orbits, or highly elliptical polar orbits; actively stabilized configurations or gravity-gradient stabilized configurations; photovoltaic conversion, thermionic conversion, or thermal cycle conversion; construction from terrestrial materials in low Earth orbit, construction from terrestrial materials in geosynchronous orbit, or construction from non-terrestrial materials in high Earth orbits, using either the Moon or Earth-crossing asteroids as the primary material source; and countless others.

Although these design variations imply large variations in Satellite Power System (SPS) program costs, it nonetheless appears to be the case that the initial investment costs for an SPS program based on any of the options mentioned above may total several tens of billions of dollars over a time of up to 17 years prior to the return of commercially significant quantities of power. The SPS concepts may prove to be economically superior to such alternatives as massive coal exploitation or widespread deployment of nuclear fission power reactors, but financing and managing a single integrated program of this scale poses problems of a kind which have never before been faced by the utilities industry.

The possible benefits of an SPS program, however, both domestically and internationally, justify detailed and imaginative investigation of the issues involved in financing and managing such a large-scale program. We have identified ten possible methods of financing an SPS program, ranging from pure government agency to private corporations. Most of these methods appear to have viable roles to play, at least in some phase of an SPS program, and most of them could be adopted to space industrialization projects other than SPS or to large-scale terrestrial projects.

While the costs and duration of an SPS program are highly uncertain in light of the large number of engineering alternative available, we have used the cost estimates and timetable developed by NASA Marshall Space Flight Center for the SPS Reference Design for illustration purposes. Detailed economic analyses of cost/benefit ratios, present value, discounted value, etc., would serve little purpose in evaluating the various financing schemes considered, except for noting two salient points:

1. The SPS program naturally consists of two phases: a lengthy R&D phase in which as much as $45 billion must be expended to assure the economic and technical viability and credibility of the SPS program; and an implementation phase, in which SPS's are constructed for use by commercial utilities or other large energy consumers.

2. Capital cost per kilowatt of busbar capacity for the Reference Design is sufficiently high (more than $2500 per kilowatt) to make the Reference Design marginally competitive, at best, with

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nuclear power in the 1990's, so that approaches in which innovative designs could be developed and fostered should receive high consideration.

During the Sixteenth Century, when the New World and the Far East were first being exploited by the major European powers, Spain, England, and the Netherlands invested up to about 1% of their respective GNP's in colonization projects. For England and the Netherlands, which had far less centralization of power than did Spain, this was only possible because of a new social invention for financing large and expensive undertakings. That new social invention was the joint stock company.

As we stand on the threshold of extending our economic system into another new world, we too may need a new social invention to facilitate large-scale projects approaching 1% of our GNP over an extended period. In our study of possible financing methods for an SPS program we thus considered several social inventions as well as adaptations of tried-and-true arrangements.

Assumptions

Our consideration of possible schemes for financing and managing an SPS program necessarily began with certain assumptions about economic and political factors. These assumptions were as follows:

1. Most of the actual work involved in the SPS program will be carried out by pre-existing contractors and subcontractors. During the Apollo program, for example, more than 90% of the funding passed through NASA to industrial and academic contractors who actually performed most of the R&D, prototype construction and testing, and production or construction of hardware and equipment for ground facilities and for space missions.

Similarly, we assumed, the SPS organization will not enter the mining and refining business to produce aluminum and steel; it will not enter the manufacturing business to fabricate nuts and bolts and sheet stock; it will not enter the construction engineering business to build launch facilities or to prepare rectenna.foundations. While an SPS organization may perform some in-house R&D, most of that activity as well will be contracted out to industry and academia. The principal functions of an SPS organization at each stage will be to provide overall technical guidance, program management and control, and financing for the project as a whole.

2. We assume that the SPS program will be implemented only if the capital costs and/or the lifecycle costs of a power satellite are comparable to (or lower than) those of nuclear powerplants or of electrical generating plants burning fossil fuels (particularly coal). Should the SPS prove to be demonstrably cleaner from the viewpoint of environmental effects than the alternatives, or should an SPS program provide significant improvements in the U.S. balance of payments (through decreased requirements for petroleum imports), a modest premium in capital costs or lifecycle costs would perhaps be acceptable.

3. Assuming that capital costs and/or lifecycle costs for power satellites are competitive with alternative powerplants, we further assume that utility companies would be capable of financing the acquisition of power satellites in much the same manner as at present--by borrowing funds against future revenues from the sale of electric power.

(Some energy critics have suggested that the U.S. economy will not be able to support the capital requirements projected for electrical capacity growth during the next two or three decades. Whether or not this is true is irrelevant here--if the electric utilities can finance powerplants of any kind, they will be able to finance power satellites as well, provided Assumption 2 holds. If the utilities cannot afford conventional powerplants during this time period, SPS will have to become far less expensive than the Reference Design if an SPS program is to exist at all.)

4. Although major shifts in public attitudes are to be expected over periods as long as fifty years, we have assumed that the "American system" will continue to be based primarily on private enterprise with varying degrees of governmental regulation. Public suspicion of very large corporations or of very large government agencies, we have also assumed, will continue, perhaps even increasing in strength. It is to be noted, however, that size in the public view is a relative matter: large size is apparently less suspicious in the presence of vigorous competition (or, at least, the appearance of competition).

5. All cost and revenue figures quoted here are in constant 1977-1978 dollars, without allowance for inflation. Thus interest rates and discount rates should be adjusted upward by the reader's estimate of inflation rates to obtain the equivalent rates in current dollars. (During most of this century, mortgage interest rates for private homes have approximated the expected long-term inflation rate plus 3%.)

6. Cost estimates for the Reference Design are based on approximate relations developed from comparison of the more detailed Baseline Designs of NASA's Marshall Space Flight Center and NASA's Johnson Space Center. Neither of these designs is a mature, fully-optimized system. Thus the cost estimates for the Reference SPS Design were considered exemplary only, and to the extent allowed by the level of effort available for this study, we considered some of the implications of significant reductions in these estimates. (Should costs prove to be substantially higher than the Reference Design, it seems most unlikely to us, in view of Assumptions 2 and 3 above, that such an SPS program would ever be implemented. Thus only cost reductions were of interest here.)

7. From the documentation available to us on the Reference Design, it was not entirely clear what was and what was not included in the R&D efforts. Accordingly, we have assumed that the costs quoted are for a completely self-contained SPS program which develops all space transportation systems and orbital facilities beyond the Space Shuttle system, as well as the technology required for the power satellite itself, with no contributions from other space programs (such as advanced

nuclear powerplant proposed for Southern California would have cost about $1700 per kilowatt as of the late 1970's.)

As presented in the Reference Design, the commercialization phase is fairly slow in pace, bringing only 10 GW of additional capacity on line each year. The rate of construction, however, could be three or four times higher, but the start-up costs for a larger fleet of launch and orbital transport vehicles and for more extensive orbital assembly and living facilities would be somewhat higher.

The very size of the project poses difficulties in financing and managing the program. Important issues of controlling a large array of people and contracting companies arise at once. Finding large sums of investment capital could be a problem, resulting in abnormally high interest costs. The risks to society inherent in such large concentrations of power--financial, social, and political--are not trivial.

In many respects, the question of how to manage such a program is secondary to the question of how to finance it. The principal differences in management between the various possible schemes we have considered appear to concern the interfaces the SPS organization will have to deal with the implementation of the program. This problem, however, is merely a subset of the larger problem which every large-scale project must deal with if it is as large and as long as the SPS program is likely to be. That larger problem is to maintain close contact with the total human environment in which the project must operate. Should an SPS program be governmentally funded, it may have to deal with certain additional constraints applicable to virtually all government agencies in the United States, including the liabilities of the Civil Service system and the vicissitudes of Congressional and Executive support or opposition.

The total R&D costs for the first 15 years of the SPS program total $42.87 billion. Suppose that R&D expenditures of the n-th year were to be paid for from an endorsement fund deposited at interest at the beginning of the first year. How large an endorsement would be required if the funds earned 6% real interest annually (after inflation) compounded continually? The "present value" of the R&D program, defined in this way, is $24.28 billion.

If, on the other hand, the R&D expenditures were covered by annual borrowings (again at 6% real interest rate annually), the total indebtedness--the "compounded value"--of the SPS program just before revenues begin from the first completed power satellite would be some $68.29 billion. The high ratio of the compounded costs to the direct costs is the inevitable result of the prolonged nature of the R&D phase. The high interest costs make the R&D phase very difficult--if not impossible--for private industry to finance.

The total magnitude of the investment in the R&D phase also appears intimidating, primarily because it is concentrated in a single venture. Even large private enterprise projects (such as the Alaska pipeline--total cost of about $7 billion) are far smaller, and certainly much shorter in duration, permitting recovery of investment within 5 to 8 years (typically).

We have assumed that the difference between the costs quoted for the "First Unit" and the costs quoted for the "Average Unit" in the SPS Reference Design are entirely attributable to construction start-up costs, including factories for the manufacture of SPS components, procurement of the fleet of launch vehicles and the fleet of orbital transport vehicles, preparation of launch and recovery facilities, and deployment of facilities in orbit for worker habitats and assembly equipment. These start-up costs total $20.2 billion over a four year period just before revenues from sales of power satellites or from sales of electricity begin to come in. The ratio of the compounded value to the direct costs for start-up phase is low, within a range acceptable to normal financing methods for private industry.

The construction start-up costs could be amortized (including 6¢ real interest per annum) by annual charges of $4.06 billion for 7 years; $3.08 billion for ten years; or $1.98 billion for twenty years, these charges to be included in the costs of SPS construction. It was unclear to us whether the "transportation" and "assembly" costs quoted in the Reference Design included amortization of this equipment or not; if not, the cost per unit would be somewhat higher than quoted during the first few years until the construction equipment and fleet are paid off, with a subsequent reduction in SPS cost.

The costs of building a 10-GW increment after the entire system is in place and operating at a capacity of one 10-GW unit per year total $24.14 billion in direct costs, assumed to be evenly distributed over a four-year period. The compounded value of these costs at the end of the fourth year totals $27.53 billion for each 10-GW unit. Operations and maintenance costs are assumed to average $0.328 billion per year over the conservatively assumed 30-year life of each SPS, with annual revenues of $3.504 billion from sales of electric power (assuming 100% load factor and 40 mils per kilowatt-hour, or any other equivalent combination).

Assuming 6% real interest per annum to be the cost of money to a utility company, acquisition of a power satellite costing $24.14 billion per 10 GW could be paid off in approximately 10½ years out of the net revenues indicated, $3.176 billion per year after operations and maintenance costs. Such a time scale is longer than typical industrial investments, but is not unreasonable for utility companies. (Should power satellites in the early commercialization phase have to assume the burden of amortizing the construction equipment at a fast pace, i.e., $4.06 billion per year additional, the payoff period for the first seven sets of 10 GW SPS installations would be about 13½ years.)

(If the Reference Design costs include amortization of the construction equipment and fleet, the payoff period for a utility company buying a power satellite would be just 7 years if the capital costs could be reduced from $24.14 billion to $17.73 billion, a price just a few percent higher large-antenna communications and navigation systems, free-flying Spacelab, free-flying Shuttle power module, etc.). This assumption, it should be observed, places additional burdens on the viability of the SPS; should SPS prove viable despite these handicaps, it will in the real course of events be still more successful when integrated with such other activities.

8. The Reference Design assumes that two power satellites will be completed each year, each having a capacity of 5 GW. To simplify some of the financial analysis, it has occassionally been convenient to compute interest payments, revenues, and capitalization in annual increments. Thus for convenience we have frequently lumped two such 5 GW power satellites together as a single 10 GW system produced at the rate of one per year; the errors introduced by not including six months of interest on the costs of half of such a 10 GW system are insignificant for our present purposes.

Prior Literature

The bulk of the literature on the financing and management of a Satellite Power System program tends to be very general and qualitative, outlining general issues which must be addressed by any specific scheme. A substantial body of literature addresses such economic questions as cost/benefit ratios and discounted program costs, but these have little direct bearing on the problem at hand.

Three specific proposals have been advanced in the literature, however, outlining possible methods for financing and managing an SPS or an SPS/space colonization program, and these are examined here. The concept of using existing agencies (especially NASA and DOE) has also been suggested, but with little serious advocacy. A number of other historical precedents have occasionally been suggested in general terms as possible models for an SPS program. Some of these alternatives would be more likely to succeed under certain economic reforms (especially with respect to tax laws), some of which have been advocated for reasons entirely independent of an SPS program. In these cases, the SPS program itself could provide an important incentive for implementation of these reforms.

Some of the literature dealing with the general issues any specific SPS program must face is implicitly ideological, arguing that such a large and economically vital project as a large-scale energy system must (or must not) be entrusted to government rather than to private enterprise. Our own bias is in favor of private enterprise approaches for reasons we will discuss below.

The costs of an SPS program and of an individual power satellite are vitally important in the decision of whether or not to proceed with an SPS program. The literature on alternate design options is vast; the best studied alternatives are the MSFC and JSC Baseline Designs from which the Reference Design was derived. To the best of our knowledge, no other alternatives have been examined in nearly as much detail. Thus it is difficult to know how far the capital cost per kilowatt of installed capacity might be reduced below the cost of the Reference Design.

As an example of the potential alternative designs may have for reduction of costs, it appears on the basis of the 1977 NASA Ames Summer Study on Space Manufacturing from Nonterrestrial Materials that the cost of a 10 GW SPS could be $3.1 billion (exclusive of ground station costs) versus approximately $18 billion for the Reference Design. The ground station costs quoted in the Reference Design amount to an additional $6.37 billion; presumably this cost is independent of whether or not the space segment of the system uses terrestrial or nonterrestrial materials. This entire question of cost per unit, in our opinion, requires a great deal more study, considering the wide variety of design alternatives available and the impact of the cost per unit on financial scenarios.

The sheer size of solar power satellites as presently envisioned (5 to 10 GW each) poses significant problems for utility company system integration and financing. It should be noted, however, that the sizing of these designs is based on early system optimizations which traded off several engineering factors without consideration of the economic costs of integrating such large powerplants into networks consisting of much smaller units. The original trades included transmitter antenna size and mass, collector and converter system size and mass, space transportation costs, and average land costs. These factors were constrained by the assumption that the microwave flux density through the ionosphere would be limited by plasma instabilities to 23 mW/cm^2 or less. Furthermore, it was assumed that only geosynchronous orbit would be used, with a transmission frequency in the range of 2 to 5 GHz.

Many of the costs assumed in these trades have changed during the last few years. It appears that significantly higher flux densities may be acceptable in the ionosphere; new technologies for the production of microwaves at far higher frequencies with high efficiency have been developed, allowing one to entertain the possibility of significant reductions in transmitter and receiver array areas; other orbits have become more attractive (at least politically); and the possibilities for construction of power satellites using nonterrestrial materials have become far more credible. New trades including some of these considerations as well as updated costs for factors included in the earlier trades should be done; if these trades suggest that 1 or 2 GW sizes are feasible (or even optimal), the overall viability of an SPS program would be considerably enhanced, especially if front-end costs for the program scaled downward as well.

Capital Requirements For An SPS Program

The magnitude of the difficulties of financing and managing an SPS program are indicated by the cost estimates for the Reference Deisgn (1). The R&D phase (which includes verification and design, development, test, and evaluation) is long and expensive. Procurement of parts, launch into space, and assembly in orbit of each 10 GW increment of capacity, on the other hand, is expected to require only four years, with orbital assembly requiring only the last year of that period. The capital cost of about $2500 per kilowatt is likely to be comparable to nuclear powerplants of equivalent capacity in the 1990's. (The Sundesert per unit of capacity than the abandoned Sundesert nuclear powerplant.)

From the foregoing discussion, it should now be clear what is unique about the SPS program from a financing point of view: the magnitude and duration of the R&D phase are much greater than anything the energy industry has hitherto attempted. Financing the acquisition of a power satellite is feasible for utility companies by conventional methods, provided capital and lifecycle costs per kilowatt of generating capacity are competitive with alternatives. Financing of the construction start-up costs is likewise possible by private industries willing to enter a new business. But the R&D effort seems singularly difficult; no private investor would be willing to put up money for fifteen years or more before collecting dividends or some other tangible economic rewards. The basic issue in financing an SPS program is the question of "filling up the hole," paying off the enormous negative cash flow incurred by the R&D effort. Most of the existing literature on SPS assumes that only federal financing out of general tax revenues is capable of supplying the necessary funds. As we shall see, however, several alternatives can be devised, including one purely private enterprise approach presently in the early stage of actual implementation.

OWNERSHIP AND CONTROL

The financing and the management of an enterprise represent, in effect, the two questions of *ownership* and of *control*. Whoever provides the capital for an enterprise is *de jure* the owner; depending on a number of institutional and legal considerations, however, the owners of the enterprise may have control over the day-to-day business decisions of the enterprise which range from absolute (as in sole proprietorship) to virtually non-existent (as in the case of an individual who owns a single share of a large multinational corporation).

The ultimate source of capital for purposes of this discussion can be taken to be the individual. Figure 1 shows a variety of paths by which capital can flow from a individual to such a large-scale undertaking as an SPS program. The paths marked 1 and 3 in the figure are subject to the individual's control; the individual can allocate portions of his disposable income among various of these alternatives in accordance with his perception of the relative risks, returns, and desirabilities of these investment or savings opportunities. Only path 3 represents a direct investment in the SPS program, presumably by way of the stock market. Paths 1 represent indirect investments: the individual selects a decision-maker (such as the board of directors of a corporation, the investment managers of mutual fund, or the directors of a bank or savings and loan institution) and entrusts his funds to their care.

While the individual has a great deal of control over paths 1 and 3, he has very little control over path 4 since the government sets the tax rates. The taxpayer's control is solely through electing officials and by lobbying, both of which take effect very slowly.

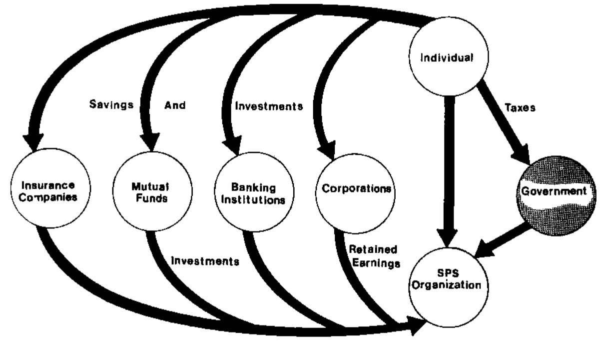

Fig. 1 Possible flows of capital funds.

A potential SPS enterprise, then, must look to paths 2, 3, or 5 or its sources of capital. Individuals and corporations are relatively free to determine whether or not to invest in an SPS enterprise on the basis of their own investment needs and guidelines, which seldom include cost/benefit analysis. More frequently, these decisions are based on subjective perceptions of risk, effective yield of the investment, potential for appreciation of value, or glamor of the investment. The government, on the other hand, must base its decision to invest on political considerations, including public support for a possible program, vociferous opposition for whatever reason, lobbying interests, regional tradeoffs, and economic analysis which may include cost/benefit considerations. Yield on investment and potential for appreciation seldom enter into consideration.

Capital sources can thus be categorized into three basic channels: individual investments by the purchase of shares; corporate investments by insurance companies, mutual funds, banking institutions, or other business corporations; or government funding.

The managers of an enterprise are subject to varying degrees of governmental control in their day-to-day decisions. Ultimately, the government has complete control of all enterprises in its jurisdiction since it defines the laws of the land, especially the tax laws, which can greatly affect the attractiveness of an investment. In practice, however, the government delegates varying amounts of control or freedom to different types of entities. It is convenient for these purposes to group possible SPS organizations into three basic types, in order of decreasing governmental control: government agencies; government-sanctioned monopolies; and private, competitive corporations.

Existing international enterprises of various sorts (other than multinational, private corporations) are based on treaty arrangements, bilateral or multinational accords and protocols, or subdivisions or subagencies of larger international entities such as the United Nations of the Organization for Economic Cooperation and Development. During the present century, one other type of entity was granted international legal recognition, namely, the free city of Danzig, but its existence was terminated by World War II. At least one proposal (2) has been made for the establishment of a space colonization/Solar Power Satellite enterprise under similar status which could be granted by the United Nations but the endorsement of the idea by dozens of nations would be required.

Control of an internationally implemented SPS program would be most likely to involve either a government agency (such as the European Space Agency - 10 nations) or a government-sanctioned quasi-monopoly (such as INTELSAT - 102 nations.)

Management Principles

From the viewpoint of management theory and practice, the SPS program poses difficulties on two fronts: first, the length of the program (especially in R&D phase); and second, the scale of the undertaking in terms of annual cash flow and numbers of highly trained personnel working on a single project. But these are matters of degree rather than of kind, it seems to us, and a number of successful examples can be studied in recent history. These include the Apollo program, the Marshall Plan, and day-to-day management of organizations as large as General Motors or Exxon.

Regardless of the scale or duration of a project, performance of any task sufficiently complex to require the participation of more than a handful of people involves four key processes of management:

1. delegation of authority;
2. delegation of responsibility;
3. control; and
4. rewards and penalties.

For large-scale enterprises, especially those taking more than a few years until fruitful completion, several additional factors appear to be necessary for success; these have been discussed thoroughly in Reference (3) by James E. Webb:

1. organizational flexibility;
2. close interaction with the environment of the enterprise;
3. exceptional personnel;
4. fostering and using innovative ideas; and
5. avoidance of managerio-sclerosis.

These general principles will apply to any of the candidate SPS organization forms discussed below. Depending on the details of the financing of the SPS program, however, some differences may be necessary in the ways in which the SPS organizations interface with suppliers, customers, investors, regulatory organizations, and other government agencies, both in the U.S. and abroad.

Organizational Forms For An SPS Program

Any proposed scheme for actual implementation of an SPS program must come to grips with the fact that a substantial investment of money and time must be made in R&D (research and development: technology and system verification, and engineering design, development, testing, and evaluation) before the first commercial power satellite is built. The NASA Reference Design (in the Marshall Space Flight Center version) assumes a fifteen-year R&D program, including the development of advanced transportation systems and of orbital assembly and habitation facilities, as well as the development of SPS technology, with the final two years of DDT&E overlapping construction of the first unit.

While it may be possible to reduce the time scale from 13 years before initial construction to perhaps 8 or 10 years, and to reduce the costs by a factor of perhaps two, the front-end burden would still be a major impediment to conventional business investment approaches. As a general rule of thumb, industry cannot invest in capital equipment which will not pay for itself within five to eight years; for utility companies, a new generating plant can take up to ten or twelve years to pay for itself, but the return on investment for the bondholders and stockholders is correspondingly lower for utility companies than for manufacturing companies, for example.

Once the technology for deployment of a commercial SPS has been developed, however, actual construction could be financed more or less conventionally, since revenues would commence as little as four years later, within the time frame feasible for private enterprise.

For these reasons, the qualitative differences between the R&D phase and the commercial implementation phase are enormous. Organizational designs for an SPS program must recognize these differences and come to grips with them. Failure to recognize these differences has lead many to assume (often tacitly) that only government ownership of the SPS enterprise is feasible. This need not be the case, however, if the SPS program is organized differently in the two successive phases.

Accordingly, we have considered possible organizational forms for an SPS program in two major categories: (1) those organizational forms which could undertake the entire SPS program, from verification through DDT&E into commercial implementation; and (2) those organizational forms which could undertake only the commercialization phase of the program, after technical and economic risks had been demonstrated to be acceptable by some other organization. A total of ten organizational models were considered in this study; their positions in the ownership/control matrix are shown in Figures 2, 3-A, and 3-B.

Possible organizational forms for carrying out the entire SPS program, from R&D through commercialization, are shown in Figure 2. These candidate forms are as follows:

1. Existing government agencies (DOE, NASA, etc.)
2. New government agency, here designated the "Space Utilization Authority" as proposed by Philomena G. Grodzka (4) as an analog to the Tennessee Valley Authority.
3. Taxpayer stock corporation, herein designated "U.S. Powersat Service." This concept was first proposed by George E. Fredericks and Richard D. Stutzke (5) as a government chartered monopoly, although

it could be established as one of several competitive corporations.

4. Trust fund supported by energy taxes, here designated as "Federal Spacepower Trust Fund," an analog to the Federal Highway Trust Fund which created the Interstate Highway System with funds derived from gasoline taxes paid by all highway users in the United States.
5. Federal agency supported by floating long-term bonds backed by the Treasury, here designated "Federal National Space Projects Association" (nicknamed "Fannie Spray"), in close analogy to the Federal National Mortgage Association ("Fannie Mae").
6. The staging company concept, already incorporated in Delaware as of August 3, 1978, under the name International Satellite Industries, Inc., by attorney Christian O. Basler of New York who first proposed this concept. (6,7)

Several combinations of ownership and control are marked "X" in Figure 2 to indicate that they are unlikely to be feasible combinations. Individual investment capital alone is almost certain to be insufficient to finance the entire duration of an SPS program, regardless of the degree of government control exercised over the project. Similarly, purely corporate investments in such a very long term project are virtually impossible except perhaps in very token amounts if they can be treated as philanthropic tax deductions. The schemes shown in this diagram will be described in greater detail below.

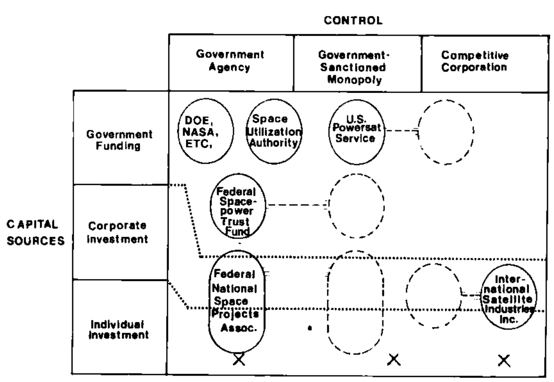

Fig. 2 Possible organizational forms for full duration of SPS program.

If we now consider the commercial implementation phase only, assuming that government agencies such as DOE and NASA have already provided the R&D necessary over a period of perhaps 7 to 15 years, four possibilities arise. Funding and control are shown in Figures 3-A and 3-B for these four:

7. A government-chartered monopoly, here designated "Solar Satellite Corporation" in analogy to the Communications Satellite Corporation, with ownership divided between the general public and the utilities industry.
8. The consortium model, in which one or more consortia of aerospace companies, high technology companies, engineering companies, and management companies undertake to construct SPS's using the technology base developed by ODE, NASA, and others during the R&D phases. (The consortium members--as in the case of the Concords and of the General Dynamics F-16 fighter built for NATO--may span a number of countries.)
9. The corporate socialism model, analogous to the method of financing the Union Pacific Railroad and the development of jet air transport more recently.
10. The universal capitalism model, proposed by Louis O. Kelso as an economic reform permitting wider participation in the ownership of stocks, leading to a "Second Income" (dividends) for most workers. (8) (See Figure 3-B.)

Any of the methods based on non-governmental agencies, of course, would be improved in their effectiveness and profitability by certain types of tax legislation. Whether such public subsidies would be desirable in any given case cannot be discussed here.

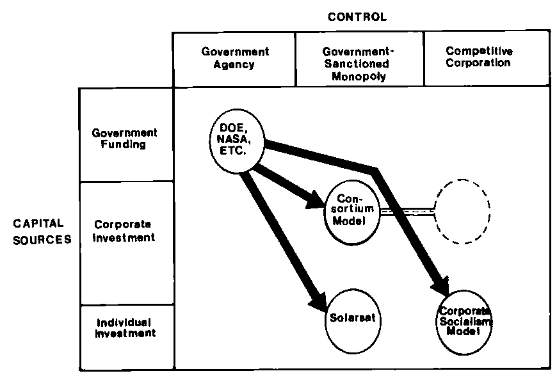

Fig. 3A Possible organizational forms for implementation phase of SPS program.

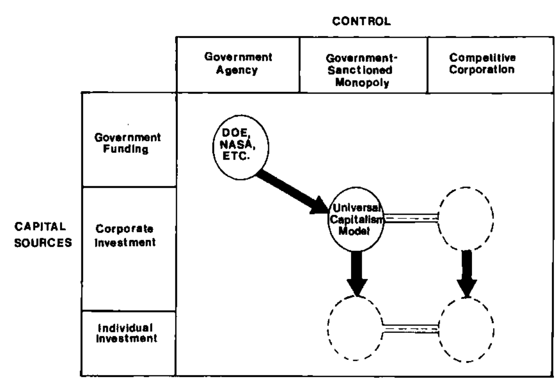

Fig. 3B Possible organizational forms for implementation phase of SPS program.

In the following sections, we will discuss only the six organizational forms for financing the R&D phase or the entire program. If the R&D phase were to be carried out by existing agencies such as DOE and NASA and implemented by one of the organizational forms shown in Figure 3, implementation would be 15 to 20 years away, and of little interest to the present audience. (9)

Detailed Descriptions of Alternatives

1. Existing government agencies. In principal, an SPS program could be implemented by existing agencies including Department of Energy and NASA. The Reference Design cost estimates assume about $40 to $45 billion over the first fifteen years for verification and for DDT&E, with a peak expenditure of about $7 to $8 billion in one year. Such a level of effort is somewhat below the peak expenditure levels during the Apollo program (with due allowance for inflation since then). The R&D phase of the program it would seem, could be managed and financed in this manner, assuming sufficient political support for the program.

A significant potential benefit to using this approach during the R&D phase is the possibility of synergisms with other space programs, including large space construction, large solar power systems, and advanced orbital transfer propulsion capability required for advanced communications and navigation systems in the late 1980's--early 1990's timeframe. (10) A liability of this approach is resistance from the space science community to the use of the Space Shuttle for space industrialization programs.

Actual implementation of the SPS program through these channels, however, would be much more difficult. The Reference Design cost estimates suggest costs rising rapidly from about $12.9 billion during the first year to $29.2 billion in the fourth year, dropping to $24.5 billion in the fifth year, rising gradually over 30 years to a peak of $32.7 billion before tapering off to about $9.8 billion annually for maintenance and repair thereafter. Neglecting interest costs, the power satellites would have to be sold outright for more than $2500 per kilowatt of busbar capacity if implementation were not to be a burdensome tax liability.

Significant liabilities to such an approach include the civil service status of existing government agency employees; opposition to tax support of large, expensive, and unproven technologies; the placing of government agencies in direct competition with private industries providing comparable services (viz., construction of generating equipment for the utilities); charges of governmental usurpation of a major sector of the economy; uncertainty of long-term stability of management and purpose; inefficiency and inflexibility; slow responsiveness to external changes in society and technology; restriction of international participation due to direct involvement of the U.S. government; lack of participation by corporations and individuals domestically.

2. New government agency--"Space Utilization Authority." Grodzka (4) has pointed out some parallels between economic conditions prevailing during the 1970's and some of those in the Depression during the 1930's. One of the most successful programs of the New Deal was the creation of the Tennessee Valley Authority which deliberately set out to transform the economy of perhaps the most depressed area of the nation at that time. As a result of those efforts, the region served by TVA has the highest proportion of jobs in manufacturing of any region in the nation. The original program cost about a quarter of a billion dollars then. Grodzka argues that using tax dollars for the creation of new technologies and new industries of high leverage (as the space industry has proven itself to be) can stimulate the economy far more effectively than equal amounts spent in welfare programs, especially since an SPS program would create a large number of new jobs for unskilled and semi-skilled workers (particularly in the manufacture and assembly of rectenna components and in rectenna construction).

Placing an SPS program within a newly formed agency would certainly solve many of the internal political problems such a program would face within existing agencies. Management practices could be tailored to the long-term goals of the project far more effectively than would be possible within NASA or DOE where the wide range of goals and research foci would dilute managerial attention to SPS. But most of the liabilities listed above for existing agencies would still remain. The diffuse and indirect nature of the benefits to the taxpayers is a major obstacle for SUA as well as for DOE/NASA as a potential SPS organization.

Depending on the degree of independence afforded SUA by its charter, it could behave either like a government agency or like a government-sanctioned monopoly. Its lack of direct accountability to the public, however, is a major difficulty; TVA has itself experienced some difficulties in recent years because of local opposition to specific dam projects and nuclear powerplant construction projects, in which the residents of the affected areas felt their viewpoints were not sufficiently considered.

Over the decades, the increasing size of SUA would pose significant problems of concentration of power. For SUA to break up into several smaller units, each of them remaining a government agency, would provide little improvement. Should SUA wish to sell off a division to one or more private corporations, it would be difficult to ascertain the correct valuation. Alternatively, if an entire division were to be transferred to the private sector by issuing shares and selling the division off through the stock market, a tremendous liquidity problem would ensue, since the total capitalization of SUA could eventually exceed that of the largest corporations today. It would be difficult to imagine the government opening up the SPS market at that time to competition from new private companies because of the government's vested interest in SUA.

3. The taxpayer stock corporation--"U.S. Powersat Service." Fredericks and Stutzke initially proposed this concept (5). The flows of funding and authority are shown in Figure 4. One fundamental objection to the two schemes discussed above is the coercive nature of funding a controversial project by general taxation: the decision to invest tens of billions of dollars would have been

made by the Executive and the Congress. In order to permit a more direct voice in the operation of an SPS organization supported by public taxation and to reduce the sting of being forced to financially support a project to which many taxpayers may be opposed, Fredericks and Stutzke proposed the creation of a taxpayer stock corporation.

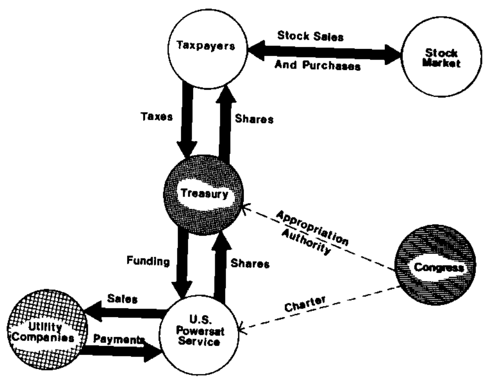

Fig. 4 U.S. Powersat Service

The basic idea is to create a quasi-public corporation by act of Congress to implement the SPS program. Funding would be provided by a specific appropriation each year, but every taxpayer would receive some number of shares to stock in the corporation each year in proportion to the fraction of his or her taxes which had been appropriated to the corporation in that year. Taxes directed into the program early in the life of the project would, in effect, purchase more shares per dollar than would tax dollars allocated to the project near fruition on the basis of a formula price for the stock of the corporation. Such a formula price could be computed on the basis of the discounted value of the anticipated future earnings per share.

Since shares in the U.S. Powersat Service could be freely traded on the stock market, taxpayers opposed to the project could "redeem" at least some fraction of their taxes spent on the project by selling the shares issued to them by the Treasury after filing of their income tax returns. Similarly, pensioners whose investment time scales were too short to anticipate significant earnings from their shares could obtain short-term benefits from current taxes. For those taxpayers who support the SPS program would have the opportunity to purchase more shares in anticipation of later rewards.

While USPS would be subject to significant control by Congress during the R&D and early commercialization phases, the shareholders would elect the Board of Directors from a very early stage. As the system matures during the commercialization phase, and no further appropriations from Congress are necessary, the Directors would be answerable only to the shareholders, just as in conventional private corporations, creating significant pressures on the management of the SPS program to maintain profitability and accountability. A further advantage would be foreign financial participation from the very start, as well as the diffusion of capital ownership among the general population, which would have beneficial effects throughout society and the economy. (See the discussions of the universal capitalism model in References 8 and 11 for considerations of some of these benefits.)

Whether or not the taxpayer stock corporation is adopted specifically for the SPS program, it is a new social invention of some merit in its own right which could be considered for other long-term projects as well which are expected to provide long-term economic benefits. (Candidates might include large-scale hydraulic projects, Ocean Thermal Electric Conversion power systems, or smaller scale space industrialization options.)

Because of the novelty of this idea, it is somewhat difficult to evaluate how successful it would be in terms of the criteria discussed in the previous section. If public confidence in the success of the entire program were low, the actual stock market value of the shares issued would be very low; the only current benefit to taxpayers who did not wish to keep their shares would be to claim a capital loss upon selling off their shares, seriously hampering the political acceptability of the concept.

4. <u>Trust fund supported by energy taxes--"Federal Spacepower Trust Fund."</u> During the last three decades, the federal government has provided most of the funding necessary for a domestic project comparable in magnitude to an SPS program, viz., the Interstate Highway System. This was motivated by the desire of Congress to improve the efficiency and versatility of the transportation infrastructure; by the military for possible use in a mobile ICBM system; by the automobile and petroleum industries as a means of expanding their markets; and by the middle-class dream of owning their own individual home with a garden.

The method of financing chosen was to impose a modest tax of a few cents per gallon on motor vehicle fuels across the nation. Private individuals and trucking companies have contributed the majority of the funding; state governments have contributed some stated percentage of the costs of each project and have assumed the burden of maintaining the system. The beneficiaries have been considered to be the motorists who have contributed most of the funding, in the form of better highways, greater convenience, and increased options in choosing where to live and where to work. Total expenditures to date have exceeded $75 billion (or about $180 billion in 1978 dollars).

An SPS program could be supported analogously. A modest tax on each unit of energy consumed (particularly electrical energy) could be channeled into a federal trust fund to finance the R&D phase and the construction start-up costs. The long-term benefits to energy consumers who paid the taxes into the trust fund would be reduced energy costs for the SPS relative to other energy alternatives not implemented by the federal government. Flows for this scheme are shown in Figure 5.

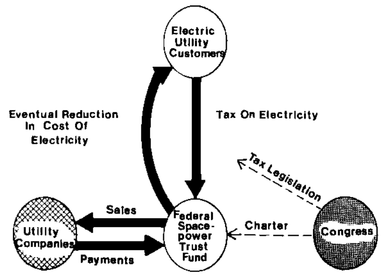

Fig. 5 Federal spacepower trust fund.

Utility rates are regulted at the present time by each of the states. In most cases, utility companies are prohibited from charging more than token expenditures for R&D on future energy technologies to current rates. Federal legislation overriding these state policies and practices would be required, possibly triggering a "states rights" battle.

Total U.S. electrical production in 1974 was 1.865×10^{12} kwhr. Assuming a tax of 2 mills/kwhr on electricity delivered to consumers, more than $4 billion per year could be collected during the 1980's by this means. Comparing this figure to the present value for the R&D program of $24.28 billion, it is clear that the necessary funds could be accumulated (at interest) in a period of less than six years before starting the R&D program; if the tax were at a lower rate or if it began concurrently with the R&D program, the tax would have to continue for as long as ten years. At present rates for electricity, this tax would effect the cost to consumers by less than 5%.

Some of the advantages of this approach include the fact that it places the burden of cost and risk on those who use the most energy and thus push the demand for new generating capacity the most. Disadvantages include all those mentioned earlier for government agencies.

5. Long-term government bonds--"Federal National Space Projects Association." Long-term bonds would provide an alternative with greater freedom of choice for investors than funding by either general tax revenues or energy user taxes. The Federal National Mortgage Association ("Fannie Mae") is a government-chartered corporation which provides mortgage funds for homeowners through long-term bonds traded on the bond market. The Bonds are issued at a price significantly lower than their maturity value; the difference between these two prices corresponds to an interest rate over the life of the bond which reflects the investment community's sense at the time of issue of the medium-to-long-term interest rates. The bonds themselves are subsequently traded during their life at a market price which declines when interest rates go up to provide an effective yield equivalent to competitive interest rates. As maturity approaches, the market value approaches the maturity value to maintain the competitive position of the effective interest rate.

Fannie Mae is self-supporting; bonds are redeemed at maturity from the principal and interest payments of mortgage borrowers. The government assumes some risk in case of defaults by a significant fraction of the borrowers. Speculative investors absorb the gains (or losses) due to changing interest rates during the life of the bonds.

The flows of authority and of funding for a Federal National Space Projects Association ("Fannie Spray") are shown in Figure 6. Fannie Spray would be self-supporting if the SPS project came to fruition; otherwise, the Treasury would eventually have to absorb the costs of redeeming the bonds issued to finance the R&D phase. To the extent that inflation exceeded the effective yield of the Space Bonds, the ultimate cost of an abandoned SPS program to the taxpayers would be lessened in comparison with financing from current taxes. On the other hand, Fannie Spray could repay some of the costs of the R&D program by vigorous marketing of patent licensing rights acquired during the R&D phase. (This would also apply to NASA, SUA, or USPS were sufficient emphasis given to this kind of marketing.)

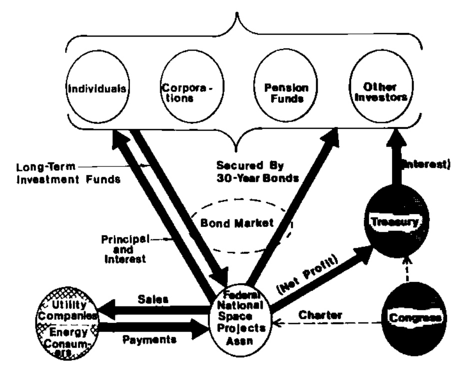

Fig. 6 Federal National Space Projects Association ("Fannie Spray")

Adequate funding of the SPS R&D phase could probably be assured if the effective yield on the Space Bonds were sufficiently high at date of issue to compete with other investments in the bond market. Assuming a 6% per annum real interest rate (before inflation)--a very severe penalty for the SPS program--the total value of bonds plus interest outstanding at the end of the R&D phase would be $68.29 billion. Assuming the bonds were issued for 20-year maturity (with the option for Fannie Spray to redeem bonds prior to maturity date), this total indebtedness could be paid for by charging "licensing fees" of $5.954 billion each year during the first twenty years of the commercialization phase. In the Reference Design timetable, this would imply a cost to the utility companies of $33.482 billion for 10 GW of generating capacity. Assuming the same 6% real interest rate per year, the net revenues would amortize this total cost over about 17 years, a time scale which seems to stretch credulity even in the utility industry.

Either Fannie Spray would have to significantly reduce the cost per kilowatt for SPS below the Reference Design, or the Space Bonds would have to be stretched to thirty years allowing a lower licensing fee, or the rate of construction and sales of power satellites would have to be increased above 10 GW per year. (Any of these approaches would improve the performance of any financing scheme discussed here.)

Compared to the taxpayer stock corporation, Fannie Spray would be less accountable to the taxpayers. Psychologically speaking, Space Bonds would compete directly with other needs for capital funding in a way that taxes do not. On the other hand, since bond financing would not appear as a line-item in the federal budget, it would be far easier to obtain public support for this method of financing than for direct appropriations to an SPS program.

Unless the charter of Fannie Spray were organized along lines similar to private enterprise corporations (as is the case--to a certain extent --with Fannie Mae), it would be hampered by the management liabilities of government agencies in general.

6. The staging company approach--International Satellite Industries, Inc. Thus far, the only proposal of which we are aware for private funding of an SPS program all the way through from R&D to commercial implementation is the staging company concept of Basler. (8,9) The staging company concept recognizes the essential qualitative differences between the R&D and the implementation phases of an SPS program. The principal challenge to private financing is the length of the R&D phase during which large expenditures are required without any hope of revenues. Once an SPS program has been demonstrated to have low economic and technological risks, i.e., once the utility industry can be assured that an SPS ordered at a certain time can be delivered with reasonable certainty on or before some specified date at a cost known within narrow uncertainty limits, implementation can proceed at a rapid pace with normal financing methods.

How can the R&D phase be funded privately if no revenues can be expected for ten or fifteen years? The idea of the staging company is based in part on the economic value of new technology itself. Instead of relying on dividend income during the R&D phase, investors who are willing to be somewhat speculative could expect capital appreciation of their shares in a staging company: the accumulation of technological advances and of patent rights would make possible future profits whose anticipation would push up the value of the staging company's shares.

International Satellite Industries, Inc., has already been incorporated (August 3, 1978, in the State of Delaware), as a partially closed-end non-diversified management investment company, and a preliminary prospective has been published, pending final registration with the Securities Exchange Commission. (In effect, ISI is a kind of mutual fund.) A conventional mutual fund would distribute most of its dividend earnings and capital gains distributions from its investments to its shareholders. ISI would instead spend substantially all of its income on R&D contracts directed toward power satellites. To stretch the funds available from its portfolio income, ISI intends to contract for R&D primarily with companies willing to share the costs of R&D as joint venturers. Patent rights directly related to SPS would be controlled by ISI; other patent rights could be reserved to the joint venturers or shared with ISI. The joing venturers would receive options to purchase ISI stock after its conversion from an investment company into an operating company.

As originally envisioned by Basler, the staging company would invest primarily in aerospace companies and other high-technology companies likely to profit from space industrialization. Through the R&D process, ISI would gain significant insight into the prospective profitability of such companies. ISI would then be able to make its investment decisions with a high degree of confidence. The market's appreciation of ISI's confidence in the future profitability of such companies would exert strong upward pressure on the value of shares in which ISI had invested, increasing the value of the staging company's portfolio and thus the value of ISI shares, enabling ISI to sell more stock and thus finance more R&D. (Figure 7-A shows the flows for the staging company phase.)

(This mechanism is not described in ISI's preliminary prospectus draft; it is not very likely to play an important role in ISI's investment decisions during the first year or two, but should become increasingly significant.)

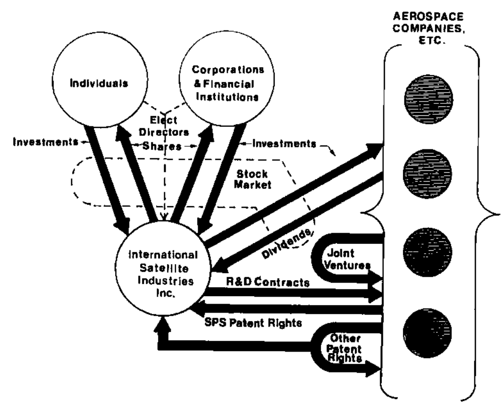

Fig. 7A INTERNATIONAL SATELLITE INDUSTRIES, INC. Staging company phase.

Once the prospect for successful commercial implementation of an SPS program was assured to the satisfaction of ISI's stockholders, the company would convert into an operating company and commence space operations using more conventional financing methods including advance sales of power satellites to utility companies. In the operating company phase, the relevant flows would be as shown in Figure 7-B.