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Historical Evidence of Importance to the Industrialization of Flat-Plate Silicon Photovoltaic Systems:

Executive Summary

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16. Abstract

The study analyzes the Low-Cost Silicon Solar Array Project plans for the industrialization of new production technologies expected to be forthcoming as a result of the project's technology development efforts. In particular, LSSA's mandate to insure an annual production capability of 500 MW peak for the photovoltaic supply industry by 1986 is critically examined. The examination focuses on one of the concerns behind this goal -- timely development of industrial capacity to supply anticipated demand. Some of the conclusions include: (1) Construction of small-scale pilot plants should be undertaken only for purposes of technology development; (2) large-scale demonstrations should be undertaken only when the technology is "well in hand"; (3) commercial-scale production should be left to the private sector; (4) the 500-MW annual output goal should be shifted to Program Headquarters. A voluminous Rand Corporation study, Analysis of Federally Funded Demonstration Projects, is drawn upon extensively for supporting evidence.

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Historical Evidence of Importance to the Industrialization of Flat-Plate Silicon Photovoltaic Systems:

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PREFACE

This study was prepared by the Low Cost Silicon Solar Array Project staff on two somewhat disjoint subjects: the diffusion of new industrial production technologies and the determinants of success of previous federally funded demonstration projects. The research was limited to secondary sources. In essence, a literature search on these two subjects was the primary aim of the study.

That search led, however, to some fairly strong conclusions out of which specific recommendations for the future plans and conduct of the LSSA Project have been derived. It must be emphasized that these recommendations are made *only* on the basis of the evidence considered. That is, no attempt has been made here to incorporate the myriad other factors which bear significantly on the Project (e.g., funding levels or political imperatives). Thus, these recommendations are *not* intended as a comprehensive set of project management recommendations to the Photovoltaic Program or the Department of Energy. They are to be viewed as an *input* into such a comprehensive set.

EXECUTIVE SUMMARY

This document summarizes the results of a study which analyzes the Low Cost Silicon Solar Array Project (LSSA) plans with respect to the industrialization (as opposed to commercialization) of new production technologies expected to be forthcoming as a result of the project's technology development efforts. In particular, LSSA's mandate to insure an annual production capability of 500 MW peak for the photovoltaic supply industry by 1986 is critically examined. The examination focuses on one of the concerns behind this goal--timely development of industrial capacity to supply anticipated demand. Conclusions from the analysis are utilized in a discussion of LSSA's industrialization plans, particularly the plans for pilot, demonstration, and commercial scale production plants. Specific recommendations for the implementation of an industrialization task and the disposition of the project quantity goal are derived.[1]

For the purposes of the National Photovoltaic Program (and this document), industrialization has been explicitly defined as the process by which new technology is adopted by the photovoltaic supply industry. Commercialization, on the other hand, refers to the process by which an effective demand for photovoltaics is realized, given product price. Thus, commercialization deals with user acceptance and industrialization with supplier acceptance. This document is concerned only with supply-side issues, in accordance with the LSSA Project plan.[2] Problems associated with the demand for photovoltaics are not considered. In particular it is assumed that "adequate" demand for photovoltaic arrays exists. This demand may arise from purely private sources, or from some combination of private, governmental, and government-subsidized purchases. With this assumption, it is possible to discover if purely supply-side constraints may give rise to barriers that impede the successful introduction or diffusion of photovoltaics.

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[1] See the Preface for a discussion of the intent behind these recommendations.

[2] See Commercialization and Industrialization of Photovoltaics: Draft Plan, Photovoltaic Program Planning Group, July 1977.

The activities of the Photovoltaic Conversion Program of DOE's Division of Solar Technology are planned "to develop and to promote the use of photovoltaic systems to such an extent that the *private sector* will produce and utilize cost-competitive photovoltaic systems"[1] (italics added). This broad statement of purpose has been translated into specific objectives for both the Photovoltaic Program and the LSSA Project. In particular, the specific JPL project goal for 1985-86 is "to reduce today's (1975) solar array prices of $20,000 to $25,000 per kilowatt (peak) in annual quantities of 100 kilowatts to less than $500 per kilowatt (peak) in annual quantities of 500,000 kilowatts."[1]

Given the emphasis on cost-competitiveness and private sector involvement and production with which the program began, the importance attached to price reduction seems entirely appropriate. LSSA's resources are primarily devoted to reducing the cost of photovoltaic arrays. It is clear that photovoltaics will never make a significant contribution to the nation's energy supply unless and until it becomes competitive in the price dimension with other sources of electricity.

From the beginning, however, both the program and project have been concerned that a demonstration of the technical ability to produce solar arrays at a "cost-effective" price will not be sufficient to bring about their speedy introduction, acceptance, and diffusion into the energy production sector. Thus, the cost reduction goal has been supplemented with other goals specifically aimed at promoting user and supplier acceptance.[2]

"The objectives of the ERDA [DOE] Program are

> ...to stimulate the creation of a viable industrial and commercial capability to produce and distribute these systems for widespread use in commercial, residential, and governmental applications."

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[1] First Annual Report, LSSA Project, ERDA/JPL-1012-76/5, p. 1-1.

[2] Ibid, p. 1-1.

"JPL's role in the ERDA plan:

> ...to encourage expansion of industrial capability to produce solar arrays. To support methods of user acceptance."

Thus, the 500 MW peak/year capacity goal of the LSSA project is at least partially the result of such concerns over supply-side acceptance of new production technology and the speed with which new production technology can be brought on line.

There are, however, at least two possible interpretations of, or motivations for, the 500 MW peak/year output goal in addition to the promotion of supplier acceptance. First, attainment of the capacity goal has come to be viewed as an aid in the successful realization of the project price goal. That is, because of the factors lying behind the so-called "learning curve," assuring a large annual output will in and of itself promote the attainment of a smaller per unit cost.

More fundamentally, the 500 MW peak/year goal can be interpreted as an ultimate standard against which the entire photovoltaic program may be judged. Since 500 MW is approximately 1 percent of the total annual additions to the electrical generation capacity in the United States, this may be viewed as the threshold level above which the photovoltaic program will be considered a success. The implications for the LSSA project of either alternative interpretation of the output goal are elaborated below.

Thus, this document analyzes the industrialization goal of the LSSA project. The conclusions of that analysis are used to develop recommendations with respect to pilot, demonstration, and commercial scale production plants, as well as the disposition of the current LSSA annual output goal.

Following from this evidence, four major recommendations for the LSSA project are set forth in the final chapter:

(1) Construction of small scale pilot plants is recommended if and when it is believed they would contribute significantly to technology development.

(2) Large-scale demonstrations of photovoltaic production technology should only be undertaken when, from the operating experience gained in pilot facilities, it is determined that the technology is "well in hand." (See below for an elaboration of the definition, purpose, and characteristics of well-planned federal demonstrations.)

(3) Commercial scale production of photovoltaic arrays should be left to the private sector. (However, significant quantities of arrays will likely be forthcoming from the demonstration in (2) above. Furthermore, an adequate demonstration may be physically identical to expected future commercial plants.)

(4) The 500 MW peak annual output goal should be shifted to Program Headquarters if it is meant as a passive standard against which to judge the success of the entire photovoltaic program (1 percent of the annual net additions to electrical generation capacity in the U.S.).* Other interpretations of the intent of this output goal lead to the conclusion that no specific production capacity should

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* Of course, LSSA is currently a major portion of the Photovoltaics Program and as such remains committed to Program goals, including any production capacity goals (e.g., 500 MW). The close contact between JPL and the photovoltaic array industry gives JPL a unique advantage for the accomplishment of certain tasks necessary to implement a capacity goal. In particular, the monitoring of current industry production techniques and quantities, industry views of future government and private markets, and industry willingness to invest in new technologies can probably best be accomplished within the LSSA Project.

be predetermined. Rather, this quantity should be set as the needs for demonstrations, tests, etc., surface.

These recommendations stem from a whole set of conclusions reached during the course of the study. The most important of these conclusions are:

(1) No significant supply-side barriers to the adoption and diffusion of new technology are anticipated other than those arising from government interference or the understandable reluctance of businessmen to invest in highly capital-intensive production processes in a regime of rapidly changing technology. In particular, neither information flow problems, industry structure nor capital availability are anticipated to be significant problems with respect to the adoption of new photovoltaic production technology. Thus, "technology transfer" is not felt to be a major problem. Nevertheless, given its importance, technology transfer must continually be addressed to insure the successful completion of Program and Project goals. Furthermore, the reluctance of businessmen to invest in highly capital-intensive production processes when technology is changing rapidly is socially desirable and should not be viewed as a barrier to be overcome.

(2) The length of time necessary to build a photovoltaic production facility is relatively short, with estimates ranging from 6 months to 2-1/2 years. It is generally agreed that as long as sufficient floor space is available, the actual assembly of a production line could take place in less than a year (construction of buildings would add 12-18 months to the necessary time). Historical evidence from the semiconductor industry as well as estimates from Theodore Barry and Associates (under contract to JPL) were used to support this conclusion.

(3) The most significant problems impeding the widespread adoption of photovoltaic systems arise from a high product price and the subsequent lack of demand for the product. Thus, the emphasis of the LSSA project on price reduction seems totally justified. If and when the price is reduced to a point where photovoltaics is cost-competitive with alternative energy sources, the photovoltaic supply industry will quickly respond to and meet all demands.

(4) Any subsidy to photovoltaics (justified on the basis that solar energy systems avoid some negative externalities involved in conventional sources) should be applied to the stimulation of product demand. That is, the purchase, not the production, of photovoltaics should be subsidized. This conclusion was reached on the basis that demand-side subsidies tend to enhance competition among suppliers, whereas either supply-side subsidies or government production are likely to significantly lessen the competitiveness of the industry.

(5) Pilot plants should have as their primary purpose the resolution of technological problems. To facilitate this they should be as small as feasible, have a flexible design, and maintain a low political profile. It should be expected that there will be frequent shutdowns and modifications of facilities. Experimentation and innovation are encouraged in pilot plant facilities.

(6) Demonstrations, on the other hand, should be used to produce information (reduce uncertainty) in dimensions other than technology development. These include uncertainties with respect to (a) product cost, (b) product demand, (c) institutional barriers or impediments, and (d) externalities (e.g., pollution). A demonstration should not be undertaken until the technology is well in hand--that is, until the technology is tested, understood, and stable.

Note, however, that demonstrations are intended primarily for the production, not the dissemination, of information. As mentioned above, technology transfer is not anticipated to be an important problem.

Furthermore, resolution of the large uncertainties surrounding cost, demand, reliability, etc., requires that the demonstration be as close to an "authentic" commercial scale plant as possible. Essentially, it must represent the government's attempt to build a viable commercial plant for the production of photovoltaic arrays. Thus, it will be sized in the range considered optimal for commercial production and it must demonstrate reliable operation for a significant period if it is to accomplish its purpose. Hence, quite significant quantities of arrays will be manufactured by this plant. To reiterate, it is the purpose of the plant which distinguishes a demonstration from a commercial plant. Even though they may be physically identical, a demonstration plant is built primarily to produce information, whereas a commercial plant is built to produce arrays.

Pilot plants are also distinguished from demonstrations according to function--a pilot reduces technological uncertainties whereas a demonstration reduces other types of uncertainty. Put differently, a demonstration is not simply a large pilot plant. An oversized pilot plant will fail as a demonstration and will function inefficiently as a pilot plant. Finally, pilot and demonstration plants should be built sequentially--the results of the pilot are necessary inputs to the design of a successful demonstration.

(7) A demonstration must be able to demonstrate reliable operation. Since pilot plants will be frequently shut down,

they cannot perform this function. Demonstrations undertaken before the technology is well in hand have a high probability of failure.

(8) If the 500 MW peak/year production goal is viewed as an aid to supply-side acceptance of new technology, it is redundant--supply-side acceptance or "technology transfer" is not anticipated to be a significant problem. If the goal is viewed as a means by which one can attain the price reduction goal (50¢/peak watt) through the learning curve, then it is a cost-reduction tool and should be treated as one. That is, output targets should be established concurrently with other project actions intended to lower product costs.

LSSA is also addressing two additional output quantities, sometimes referred to as the "X" and "Y" quantities. The most efficient size production plant appears to be 20-50 MW/year. Thus, production process demonstrations need to be sized in this range (the "X" quantity). Furthermore, JPL currently is responsible for supplying arrays to all final product demonstrations (the "Y" quantity). JPL is ready to insure that the combined output from private and governmental production is at least equal to the quantity of arrays necessary to supply all final product photovoltaic demonstrations (the "Y" quantity).

Considerable evidence exists to support the conclusions and recommendations given above. Much of this evidence comes from two previous studies: John Tilton's book, International Diffusion of Technology: A Case Study of the Semiconductor Industry and a Rand Corporation report, Analysis of Federally Funded Demonstration Projects. A summary of much of this evidence follows.

Semiconductor Industry. It is argued that the history of the semiconductor industry can supply insight into the expected development of the photovoltaic supply industry. The two industries are expected to have many of the same characteristics. Both are highly research-intensive industries, both are based on the refining and processing of semiconductor material (silicon), and both have (or had) high and rapidly changing technological bases. Thus, both industries deal with the same suppliers and are expected to operate in the same business environment. Furthermore, it is anticipated that the optimum size plant for the production of photovoltaic arrays is fairly small compared to the anticipated market--between 20 and 50 MW/peak production per year--again quite similar to the semiconductor industry. Thus, the photovoltaic industry structure should be very much like that of the semiconductor industry. (Of course, there are some differences, the most important of which is the constraint placed on photovoltaic manufacturers by the requirement to cover a given area with silicon material. That is, the opportunities for miniaturization of photovoltaics and the associated cost reduction potential are much smaller than in the semiconductor trade. However, this should impact cost reduction potential much more than industry structure.)

In any case, evidence on the introduction and diffusion of semiconductor innovations is used to infer an expected rate of diffusion of photovoltaic innovations. It is shown that the longest time elapsed between the date of development of a new process or product and its subsequent commercial introduction for six new processes was one year (in some cases it was a matter of months). Innovation and diffusion was shown to occur very rapidly; new firms often took the lead in introducing new products and other firms imitated the innovator, becoming second sources, sometimes within six months.

The semiconductor industry was shown to have a highly flexible structure with new firms entering and growing to a large size quite rapidly (e.g., Texas Instruments, Transitron). Liberal patent licensing policies have prevailed, with many patents simply being ignored altogether. The industry is highly competitive and encounters little governmental interference. Venture capital was easily available to new semiconductor firms, and there were no significant barriers to entry. During the time of most rapid technological change and product innovation (1952-65), the semiconductor industry remained labor-intensive. Only after the technology began stabilizing did semiconductor firms invest in highly automated production facilities.

All of these conditions prevail or are expected to prevail in the photovoltaic supply industry.

<u>Petroleum Refining and Steel Industries.</u> Although there is little existing evidence of industrial product or process diffusion in industry in general, evidence was found of innovation and diffusion of new technology in the oil and steel industries. Studies of both industries are quoted which imply that long lags existed between invention and first adoption (innovation) and also between innovation and the subsequent product or process diffusion. However, in both cases it is shown that the evidence is not applicable to the photovoltaic industry. In the oil industry study, the definition of invention placed "product readiness" long before much of the necessary development work had taken place. Reconstruction of the data to fit our purposes indicated that the actual lag between product readiness and introduction was quite short.

The steel industry results do not apply because that industry is characterized by a highly capital-intensive existing capital structure which is replaced quite slowly. Additions to production capacity are minor. The industry structure is oligopolistic and highly stable. There are barriers (tariffs, quotas) to foreign competition and difficult entry problems for domestic firms. Thus, the large lags in the steel industry are understandable but not important for conclusions about the rate of adoption of new technology in the photovoltaic supply industry.

Previous Federal Demonstrations. Many conclusions about the prospects for successful industrialization of new photovoltaic technology are drawn from a Rand study of 22 previous federally supported demonstrations projects. Projects were judged as to their success in three dimensions: (1) reducing uncertainties with respect to cost, demand, externalities, technology and institutional problems (information success), (2) producing a useful output (application success), and (3) stimulating subsequent diffusion of the product (diffusion success).

The results of the study show that a demonstration project is more likely to be successful in these three dimensions if:

(1) Preproject technological uncertainties are low.

(2) The project had a low political profile.

(3) External time constraints were not important.

(4) The project had cost-sharing with private industry.

(5) The initiative for the demonstration did not arise within the federal government.

(6) The technology delivery system was strong, and all its components were included in the demonstration.

Thus, the three projects with 100 percent federal funding were total failures at promoting subsequent diffusion of the product. Furthermore, those projects that originated from or were initiated by nonfederal actors enjoyed a significantly higher rate of success in all three dimensions. Those projects which excited a high level of non-federal participation, either through cost-sharing or project initiation, proved to have a higher probability of success.

Further, the four projects judged to have been conducted under significant time constraints were judged to have been complete failures in both the information and diffusion dimensions (one of these was the Morgantown rapid transit demonstration).

Finally, in no demonstration where preproject technological uncertainty was high was there success at either reducing uncertainty to low levels or stimulating subsequent diffusion of the technology.

Besides Morgantown, some of the federal demonstrations analyzed in this study included water desalinization plants at Freeport, Texas and at Point Loma, California, a fish protein concentrate plant in Washington state, and the Nuclear Ship Savannah.