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Photovoltaic Venture Analysis

Final Report
Volume I

SERI

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PHOTOVOLTAIC VENTURE ANALYSIS

FINAL REPORT
VOLUME I

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Under Contract EG-77-C-01-4042

PREFACE

This final report presents the completed analysis of the Photovoltaic Venture Analysis. The report is presented in three volumes. The body of the report and the executive summary are in Volume I. Volumes II and III present details of the analytical assumptions, results, and background information.

Primary SERI staff contributing to this report were Mr. Dennis Costello (Project Leader), Mr. David Posner, Dr. Dennis Schiffel, Dr. James Doane, and Dr. Charles Bishop. Assistance was provided by Ms. Susan Christmas, Dr. Lawrence Kazmerski, Dr. Sigurd Wagner, Dr. Thomas Reed, Dr. Charles Benham, Dr. Donald Hardy, Dr. T. S. Jayadev, and Ms. Kathryn Lawrence. Dr. Melvin Simmons, Dr. Michael Noland, and Dr. Paul Rappaport supported the study with important management assistance.

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A Department of Energy Review Group was formed to assist in the Venture Analysis. The Review Group included representatives of many parts of the DOE organization. The group reviewed each report and provided both verbal and written comments. The group included Martin Adams, Paul Maycock, Al Clorfeine, Clark Bullard, Frank Goldner, George Jordy, Jacques Gros, Richard Lewis, Bruce Robinson, and Elaine Smith.

A number of other individuals also provided helpful comments and suggestions. Participants in the supply workshop deserve special thanks: Bob McGinnis (Motorola); Ted Blumenstock (Solarex); Bob Weinberg (RCA); A. I. Mlavsky (Mobil Tyco); John Jordan (Photon Power); Pesho Kotval (Union Carbide); Anthony Bonora (Siltec); and John Heldack (Varian). All of the participants in the demand workshop also deserve our thanks. Comments on reports were received from Gary Lilien (MIT), Henry Jacoby (MIT), Richard Blieden (Atlantic Richfield Company), Charles Craig (Federal Highway Administration), and John Arens (Federal Highway Administration).

Special thanks is again due to the SERI Word Processing Center (Nancy Ballard, Laurie Duff, Judy Davis, and Glenna Anton), Graphics Department, Reproduction Department, and Mrs. Barbara Glenn for performing well under severe time constraints.

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Project Leader

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ABSTRACT

This report presents the results of the Photovoltaic Venture Analysis. The objective of the study, government programs under investigation, and a brief review of the approach are presented. Potential markets for photovoltaic systems relevant to the study are described. The response of the photovoltaic supply industry is then considered. A model which integrates the supply and demand characteristics of photovoltaics over time was developed. This model also calculates the economic benefits associated with various government subsidy programs. Results are derived under alternative possible supply, demand, and macroeconomic conditions. A probabilistic analysis of the costs and benefits of a $380 million federal photovoltaic procurement initiative, as well as certain alternative strategies, is summarized. Conclusions and recommendations based on the analysis are presented.

PHOTOVOLTAIC VENTURE ANALYSIS

Final Report

EXECUTIVE SUMMARY

A. INTRODUCTION AND OBJECTIVES

A variety of federal programs have been proposed to accelerate the market and industrial development of photovoltaic systems. This study investigates the costs, benefits, and risks of one proposed program. In particular, the option under study is an eight-year $380 million program (Fiscal Years 1979 to 1986) in which the federal government subsidizes the difference between the price charged by photovoltaic producers and the maximum price the consumer will pay. The program is called the "procurement initiative" or the "market pull initiative" in this report.

The market pull initiative is designed to reduce photovoltaic system prices from their present levels to the range of $1 to $0.50/Wp by stimulating a large demand for photovoltaics at relatively high prices. The stimulated demand will then presumably induce the industry to make production investments that will achieve lower unit costs. Lower costs and competition among suppliers should result in lower prices which will then stimulate additional demand and lead to further investment. These reinforcing events are assumed to continue until grid-connected markets are penetrated and photovoltaics begin to replace conventional energy supplies.

The primary objectives of the venture analysis are to:

- estimate the benefits and the costs of the market pull initiative; and

- compare the procurement initiative to a limited number of alternative government approaches to accelerating the commercial development of photovoltaics.

These are achieved by: (1) estimating the expected responses of photovoltaic producers and markets to the market pull initiative, (2) assessing the initiative's effect on photovoltaic system prices and sales over time, and (3) clarifying the uncertainties that will influence the initiative results.

B. APPROACH

The main focus of the venture analysis is on the incremental costs and benefits of the initiative. To accomplish this, a "base case" strategy of continued federal R&D without the initiative is first analyzed. Next, the eight cycles of the initiative are added to this base case, and the changes in photovoltaic prices, production, and sales are examined. To add perspective to the analysis, an alternative program of increased R&D (over the base case) without the initiative is also considered.

The venture analysis consists of three major parts: estimation of (1) supply responses, (2) demand responses, and (3) net benefits. Within each of these major parts, multiple parallel approaches were used to estimate key parameters.

The estimate of the photovoltaic supply response is derived using three approaches including: (1) a workshop with representatives of photovoltaic industry decisionmakers, (2) an assessment by an independent market research firm with experience in photovoltaics, and (3) a SERI/JPL analysis of photovoltaic industry responses. Two approaches were used to assess the markets for photovoltaics, including reviews and comparisons of available market studies, and a workshop attended by representatives of potential buyers in selected markets. The study involved almost all organizations that have conducted photovoltaic market studies to assist in this task.

The integration of the supply and market information was completed by building a computerized model, termed the integrating model, that systematically transforms all the available market and supply information into a consistent set of photovoltaic price and quantity forecasts over time.

This model reflects the state-of-the-art in modeling the diffusion of new innovations. Sales and price estimates are derived for 14 separate photovoltaic markets from 1978 to 2006. The model uses the changes in price and quantity estimates resulting from the initiative to calculate its expected marginal net benefits. The benefits methodology is based primarily on the consumer surplus concept. The model was exercised for a broad range of possible market conditions, supply responses, and macroeconomic trends to derive an estimate of the most probable benefits and costs. No direct estimates were made of the social benefits of increased energy independence, energy decentralization, or decreased reliance on nonrenewable energy sources.

C. SCOPE AND LIMITATIONS OF THE STUDY

The venture analysis is not intended to be an evaluation of photovoltaics as a potential energy source. Nor is it a search for the best government actions to help stimulate the commercial development of photovoltaics. Rather, the study is a six month effort limited primarily to an examination of the market pull initiative as one strategy for stimulating the commercial development of photovoltaics.

In this regard, it is important to emphasize a subtle distinction. The focus of this analysis is answering the question: "What are the likely net incremental benefits of a government procurement initiative?". This is a very different question from: "What are the potential benefits of photovoltaics as an energy source?". Often, even though the results of the analysis do not show significant benefits from the initiative, the photovoltaic industry is very successful.

D. SETTING FOR MAJOR CONCLUSIONS

To place the major conclusions of the venture analysis in the proper perspective, it is important to summarize the findings concerning the future potential of photovoltaics as an energy source, the current status of the industry, and the content of the national photovoltaic plan. These findings are not major conclusions of the analysis. However, they do provide a context in which the major conclusions should be interpreted.

Discussions with the research community, photovoltaic suppliers and potential buyers, as well as the analytical results of the venture analysis, show that photovoltaics has the potential to be a significant source of electrical energy for the United States. There is disagreement, however, concerning how large this potential contribution could be and when it can be realized.

The current photovoltaic industry is characterized by high prices for its product and commercial sales limited to small remote markets, primarily communications and cathodic protection. For small purchases (50-100 Wp), current commercial module prices typically range from $24/Wp to $10/Wp (FOB factory, 1975 dollars). The high prices of photovoltaic arrays and power systems relative to other energy technologies are key obstacles that must be overcome before widespread use of photovoltaics will occur.

The current national photovoltaic program attempts to reduce the current high prices of photovoltaics through three parallel approaches. First, research is conducted on new photovoltaic technologies (such as thin films and advanced material devices) with the potential for very low costs. Second, continued development of current photovoltaic technologies (e.g. single crystal silicon, both flat plate and concentrators) is undertaken to achieve cost reductions through improvements in array design and production techniques. The third element is a market pull strategy aimed at stimulating markets and private sector investment in cost-reducing production facilities.

As stated previously, the main question addressed by the venture analysis concerns the effectiveness of the market pull strategy in achieving the price reductions necessary to penetrate large energy markets. The first three conclusions deal specifically with the market pull initiative. The remainder deal with alternatives to the market pull strategy.

E. MAJOR CONCLUSIONS

The Market Pull Initiative is Not An Effective Mechanism to Achieve the Required Photovoltaic System Price Reductions

Market studies undertaken for DOE have identified a large number of potential intermediate photovoltaic markets. The ranges of market size estimates and competitive photovoltaic price estimates contained in existing studies are very large. Discussions with representatives of potential intermediate markets during the market demand workshop and other meetings reinforced the uncertainty in the intermediate markets.

Because of this uncertainty, the effectiveness of the initiative was analyzed under a range of possible market scenarios. If the intermediate markets are large (i.e., 250 MWp/yr or larger at system prices above $1/Wp), the integrating model showed the photovoltaic industry would grow rapidly even without the added stimulus of the market pull initiative. As a result, the incremental benefits of the initiative under large market scenarios did not offset the initiative's cost. If the intermediate markets are small or do not materialize (i.e., annual markets of less than 40 MWp at system prices above $1/Wp), then the market pull initiative will probably have little impact on "pulling" photovoltaic prices into the range needed to penetrate large energy saving markets. Only under a very restrictive set of circumstances did the procurement initiative significantly accelerate the penetration of grid-connected markets. These circumstances simultaneously require: a very small intermediate market; a rapid rate of escalation of electricity price, (nearly a threefold real increase by 1990); and no array price breakthroughs resulting from photovoltaic research and development. The large benefits of the initiative under these circumstances occur because the photovoltaic price reductions caused by the initiative enable today's photovoltaic technology to make energy contributions earlier than in the base case.

The size of the U.S. outdoor lighting market and the international pumping market could make them significant for the development of the photovoltaic industry. There have been no U.S. supported system tests or experiments in either of these markets. U.S. photovoltaic suppliers will have to compete with foreign suppliers in international markets.

The Impact of the Initiative on Grid Competitive Markets is Probably Small

Under most scenarios, the market pull initiative has very little effect on the penetration of photovoltaics into U.S. grid-connected markets. The initiative is ineffective because it does not reduce photovoltaic prices to the range needed to penetrate those markets. Most studies, including this venture analysis, indicate that photovoltaic system prices without storage must reach \$0.50 to \$1/Wp before they are grid competitive in the United States, barring a sharp escalation in electricity prices.*

The initiative can impact grid-connected markets only if electricity prices show very high escalation rates, intermediate markets develop slowly, and no array price breakthroughs are achieved. If these circumstances occur, the initiative may permit photovoltaic systems to compete earlier than they would without the program. This conclusion does not imply that the

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* The first photovoltaic systems installed in the grid will probably not have on-site storage. Rather, they will use the grid as a substitute for storage (i.e., the system will sell excess electricity to the grid when it is not needed on site and buy grid electricity when the photovoltaic system does not supply the total demand). If storage is added, those costs will be a significant portion of the balance of the system. If the grid systems considered in this analysis included storage, the allowable price of the array would be lower than those indicated.

initiative is necessarily the lowest cost means of insuring that photovoltaics is available to the grid market. For example, a price reduction breakthrough resulting from research or technology development may produce a lower cost than possible from production experience in intermediate markets using existing technologies.

The Value of the Market Pull Initiative Depends on the Goals of the Department of Energy

An explicit goal of the Department of Energy in the area of photovoltaics is the displacement of conventional energy sources, especially imported fuels. Under most scenarios examined by the venture analysis, the energy displacement benefits of the initiative do not justify the program's cost. The net loss is due primarily to the nature of the U.S. markets that the initiative will be able to stimulate. Most current photovoltaic applications either use very little energy (e.g., remote communications) or, until penetrated by photovoltaics, used no energy at all (e.g., new applications of cathodic protection).

The initiative can also be judged by its effect on sustaining the photovoltaic industry through a discontinuity in market demand between current prices and the $0.50 to $1/Wp system prices necessary to penetrate large energy saving markets. The initiative is of value in achieving this goal only if near-term and intermediate markets are very small. If large intermediate markets develop, these nonsubsidized markets alone should accelerate the development of a larger photovoltaic industry. Under this latter situation, the marginal benefits of the initiative do not outweigh its cost. In fact, the program could be detrimental to the industry because it would add more demand to an industry that is already expanding very rapidly.

Other criteria for judging the initiative are how it benefits foreign markets, how it affects U.S. exports of photovoltaic systems, or how the indirect benefits of foreign sales affect U.S. intermediate markets. The indirect benefits of foreign sales on U.S. intermediate markets are expected to be small. If some fraction of gross benefits to other nations (measured as consumer surplus) is added to the U.S. benefit calculation, the initiative could become more attractive, especially if intermediate foreign markets prove to be very large. Most of the intermediate photovoltaic markets may be overseas. Therefore, most of the benefits from reducing prices would be accrued overseas.

The Benefits of a Price Reduction Breakthrough Outweigh the Benefits of the Market Pull Initiative

An array price reduction breakthrough in photovoltaics would have a major impact on achieving the DOE program goals and in displacing conventional energy sources. Therefore, federal funding of photovoltaic research and technology development to achieve this breakthrough has the potential to yield benefits in excess of the cost of these research and development programs. The breakthrough needed is a discrete change in array price, not in technology. Thus, the achievement of low-cost arrays is just as important whether the basic devices are single crystal silicon or thin film.

The results of the integrating model indicate that under almost all scenarios, the benefits of a price reduction breakthrough range from several hundred million to several billion dollars. The integrating model also indicated that the timing of the breakthrough is not as important as the fact that one occurs in the time period when grid-competitive markets are developing (i.e., in the 1990s).

A Series of Field Tests and Experiments Explicitly Directed Toward Ascertaining Performance and Market Information is Necessary

Only very limited information is currently available on the potential size of intermediate markets and the performance required by potential purchasers in each market. There is also very little information on the performance of alternative photovoltaic designs in different applications. The need to address the performance uncertainties is also important in U.S. grid-connected markets. Discussions with utilities during the market workshop highlighted the need for performance data over a period of 10-20 years.

F. RECOMMENDATIONS

Currently available information does not support an affirmative decision on the market pull initiative. Therefore, the project team recommends that the initiative not be implemented until and unless the conditions necessary for its success arise.

The project team also recommends that research and technology development on both silicon and competing photovoltaic technologies be accelerated. A series of moderately funded field tests and experiments should also be continued, with the explicit objective of obtaining market and performance information rather than the encouragement of private sector investment and price reduction through market pull. These tests should include grid-connected applications of sufficient size to obtain realistic information on the interaction between the photovoltaic systems and the grid servicing these systems.

The project team recommends that these experiments be augmented by market studies designed to reduce the market uncertainty that photovoltaic vendors face. These studies should include a major investigation of international markets for photovoltaics. Reducing this uncertainty by demonstrating that markets exist in the system price range above $1/Wp will encourage investment and production by vendors and insure that a healthy industry exists to service the energy savings markets in the future. If markets are proven not to exist in this price range, then a more serious problem requiring changes in the national photovoltaic program may have to be addressed.

The venture analysis primarily investigated one strategy to accelerate the commercial development of photovoltaics. The potential of photovoltaics as a U.S. energy resource underlines the need for further investigation of alternative government strategies. For example, end-use incentives, incentives to stimulate foreign sales, alternative federal array or system purchase programs, and incentives to stimulate investment by the photovoltaic industry should be investigated. The results of the venture analysis suggest that no critical decisions concerning the commercialization of photovoltaics have to be made immediately. Therefore, it is recommended that the available time be used to identify effective policies for accelerating the commercial development of photovoltaics.

PHOTOVOLTAIC VENTURE ANALYSIS
Task 5217
Final Report
July 31, 1978

I. INTRODUCTION

A. STUDY OBJECTIVES

The Department of Energy (DOE) is currently investigating the advantages and disadvantages of offering a temporary subsidy for the manufacture and purchase of photovoltaic systems. One option that has been forwarded is an eight-year program which matches photovoltaic producers with consumers and subsidizes the difference between the price charged by manufacturers and the maximum price the buyer will pay. The program is planned to take place from FY79 to FY86 with a total direct cost estimated to be $380 million (in nominal dollars). The primary objective of the venture analysis is to estimate the expected responses of photovoltaic producers and markets to this program (termed the procurement initiative or the market-pull initiative in this report), the program's effect on photovoltaic costs, the cost to the government, and the expected benefits to society. A secondary objective of the study is to investigate a limited number of alternative strategies to compare their expected results with the procurement initiative.

One of the ways in which the eight-year procurement initiative must be evaluated is in terms of stated program goals. The initiative is expected to increase the probability of meeting price and system goals outlined for the base program. These goals are shown in Table 1.

TABLE 1

SELECTED PRICE AND QUANTITY GOALS OF THE FEDERAL PHOTOVOLTAIC PROGRAM

Goal	FY82	FY86
Array Price $/Wp (1975)[1]	2.00	0.50
P.V. System Energy Costs (Mills/kWh)	100-200	60-80
Total Annual Array Production (MW/Yr)	20	500

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[1] System price goals expressed in $/Wp are not stated in the Program Plan

Source: National Photovoltaic Program Plan, February 3, 1978, U.S. Department of Energy, Assistant Secretary for Energy Technology, Division of Solar Technology, DOE/ET-0035(78), March 1978, p. 12.

Table 2 summarizes the results of a SERI survey of current photovoltaic module prices in 1978 dollars. If these prices are expressed in 1975 constant dollars, FOB factory, they range from $10 to $24/Wp for small orders of about 100 Wp. Hence, significant reductions in module prices will need to be achieved to reach the DOE goals.

The study uses the term "venture analysis" in a slightly different context than does most literature on the subject. The primary venture under investigation is a public sector investment in the eight-year photovoltaic procurement program. The perspective of the study is therefore social costs and benefits rather than those of a single firm, as traditionally treated in venture analyses. The venture analysis is similiar to traditional venture analyses in that it attempts to measure all costs and benefits over the life of the program and explicitly treats uncertainty and risk as a key element of the problem.

A number of problems arise when the venture analysis is done from a public rather than a private sector perspective. First, the identification and measurement of benefits are less precisely handled than in private sector venture analyses. The reasons for this problem include: (1) the objectives are less well-defined than for a private venture; and (2) benefits are more numerous and more diffuse than private benefits. Second, cost calculations are more difficult because the social costs are less tractable than costs to a private firm. In fact, the measurement of social costs and benefits/externalities is extremely difficult precisely because no market exists for these benefits. Therefore, no observable prices or quantities are available. Third, the response of private sector producers, and consumers must be assessed. These responses are fraught with uncertainty. Finally, this venture analysis must include the same type of venture

TABLE 2

RESULTS OF SERI TELEPHONE SURVEY ON CURRENT PRICES OF PHOTOVOLTAIC MODULES--JUNE 1, 1978

COMPANY	MODULE SIZE	PRICE QUOTES ($/Wp)	QUANTITY	COMMENTS
A	24 Wp	$ 27.90/Wp 24.70 22.45 - 14.00	1 - 9 modules 10 - 24 25 - 99 100 -999 > 1000	End user prices are provided here. Distributor prices are about 20% less.
B	9.6 Wp 25 Wp 33 Wp	over $20 to $17/Wp - $15 to $10/Wp	Price dependent upon quantity	These are OEM (i.e., wholesale to Original Equipment Manufacturers) prices. The end user will generally pay between 10-25% more. Large purchases by end user will approach the OEM prices.
C	20 Wp	$ 15/Wp $ 14 $ 13 $ 12 $ 11 $ 10	100 Wp order 500 Wp order 1.5-2 KWp order 5 KWp order 7 KWp order 10 KWP order	These are end user prices. A discount of 15-20% is given to distributors.
D	4.32 Wp	$ 36.0/Wp 32.4 28.8 26.1 23.8	1 - 9 modules 10 - 49 50 - 99 100 -249 250 - 499	End user prices. Other sized modules are manufactured but these are the two best sellers.
	10.56 Wp	$ 30 /Wp 27 24 21 20	1 - 9 modules 10 - 49 50 - 99 100 - 249 250 - 499	
E	20 Wp	$ 31.2/Wp 15.6	Small > 50 modules	End user prices. The company manufactures a variety of panels. These two examples show the price structure: panels larger than 20 Wp. 50% discount on orders of 50 modules or more (52% for GSA orders); panels smaller than 20 Wp, 50% discount on orders of 100 modules or more (52% for GSA orders). Distributor prices are 50% off listed prices.
	12 Wp	$ 32.0/Wp 16.0	Small > 100 modules	

analysis done by a private firm because estimates of the probable responses of the private sector to procurement initiative must be derived. In this latter sense, this study contains venture analyses from both the public and private perspective.

B. GOVERNMENT STRATEGIES UNDER STUDY

The primary strategy being studied is an eight-year photovoltaic procurement initiative. The venture analysis of this initiative is limited to estimation of the incremental costs and benefits of the initiative over and above the benefits and costs of a more limited photovoltaic program without the initiative (termed the base case).

The base case strategy includes a continued federal R&D program and whatever action the private sector will take in the presence of that program. The base case is represented by most of the elements of the National Photovoltaic Program Plan of February 3, 1978.[1] The plan covers fiscal years 1978 to 1986. The plan contains activities in technology development, research and advanced development, system support, quality assurance, program management and analysis, and system tests and applications (federal purchases only). The exact dollar outlays of the base case strategy are presented in Table 3. These planned outlays are changed continuously due to DOE yearly budget exercises as well as actions of Congress. However, the outlays shown in the table were operable at the time of this study and changes in the base budget do not have a direct impact on the benefits of the market pull initiative.

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[1] National Photovoltaic Program Plan, February 3, 1978, U.S. Department of Energy, Assistant Secretary for Energy Technology, Division of Solar Energy, DOE/ET-0035(78), March 1978.

TABLE 3

FEDERAL OUTLAYS OF THE BASE CASE PHOTOVOLTAIC R&D STRATEGY
($ in Millions)

Program Activity	FY 77	FY 78	FY 79	FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 77-86
Technology Development	33.7	36.0	27.0	40.0	50.0	60.0	60.0	50.0	40.0	30.0	426.7
Research and Advanced Development	6.2	8.7	13.5	20.0	25.0	30.0	30.0	35.0	35.0	25.0	228.4
Systems Support	7.0	9.0	9.7	10.0	10.0	8.0	8.0	6.0	6.0	4.0	77.7
Quality Assurance	0.0	1.0	2.0	3.0	4.0	4.0	4.0	3.0	2.0	2.0	25.0
Program Management and Analysis	2.0	2.3	1.6	2.0	2.0	2.0	2.0	2.0	2.0	2.0	19.9
ST&A--Federal Purchases	0.0	12.2	20.0	20.0	40.0	20.0	0.0	0.0	0.0	0.0	112.2 (13.5)
TOTAL	55.4[1]	76.2[2]	73.8	95.0	131.0	124.0	104.0	96.0	85.0	63.0	903.4

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[1] Includes $6.5 million in nonfederal ST&A not shown in table.

[2] Includes $7.0 million in ST&A not shown in table.

Source: DOE National Photovoltaic Program Plan, February 3, 1978, p. 8.

The base case strategy contains $19 million in FY78 supplemental funds. It also includes the $100 million Federal Photovoltaic Utilization Program (FPUP) which is currently planned to occur between FY79 and FY82. FPUP is currently before Congress as part of the "National Energy Act" bills. System Tests and Applications include $13.5 million accrued in FY77 and FY78 but exclude nonfederal applications after FY78.

The second strategy to be investigated is the base federal R&D program plus the eight-year procurement initiative. The second strategy contains all the federal R&D outlays in Table 3 plus a system tests and applications activity enhanced by the eight-year initiative. Table 4 summarizes the second strategy. The eight-year procurement initiative does not specify the type of technology to be utilized or the mix of concentrating and flat-plate systems subsidized (after FY80). Rather, system-application combinations are planned to be chosen based on an evaluation scheme with six criteria. The criteria are: (1) the energy saving potential of the application; (2) leverage of the application (the potential for stimulating private sector markets); (3) visibility; (4) cost competitiveness and level of proposed cost sharing; (5) relationship to the planned eight-year program; and (6) maintenance of an appropriate mix of private and federal applications.[2] The relative importance of each of these six factors has not yet been specified.

The cycles vary over time in both emphasis and the amount of cost sharing expected.[3] Cycle 1 (FY79) is designed to establish system

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[2] DOE Information Memorandum to the Undersecretary from the Acting Program Director for Solar, Geothermal, Electric, and Storage Systems, December 21, 1977 p. 3.

[3] The discussion of cycle emphasis and cost sharing is paraphrased from the DOE Information Memorandum of December 21, 1977, op. cit.

TABLE 4

FEDERAL OUTLAYS OF THE PHOTOVOLTAIC INITIATIVE STRATEGY
($ in Millions)

Program Activity	FY 77	FY 78	FY 79	FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 77-86
Base Case R&D Outlays	55.4	76.2	73.8	95.0	131.0	124.0	104.0	96.0	85.0	63.0	903.4
ST&A--Flat Plate	0.0	0.0	10.0	20.0							
					50.0	60.0	60.0	60.0	50.0	40.0	380.0
ST&A--Concentrators	0.0	0.0	10.0	20.0							(2.0)
TOTAL	55.4	76.2	95.8[1]	135.0	181.0	184.0	164.0	156.0	135.0	103.0	1,285.4

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[1] Includes $2.0 million in ST&A not shown in table.

Source: DOE *National Photovoltaic Program Plan*, February 3, 1978, p. 8 (with minor rearrangements) experiments for the test and application program. The cost sharing goal is 5%. Cycle 2 will concentrate on first-of-a-kind energy saving applications with the potential for early market acceptance. Cost sharing is expected to range from 5% to 10%. Performance specifications (generated partly from the first two cycles) are planned to be complete before the third cycle. The systems subsidized in Cycle 3 will have to meet these performance specifications and be fully compatible with the proposed applications. They are expected to be advanced enough to be ready for private market introduction. Cycle 3 (FY81) cost sharing should increase to between 10% and 15%. Cycles 4 through 6 will continue to focus on systems that are ready for market introduction. During these cycles the number of applications subsidized will expand, and cost sharing will increase steadily. The cost sharing goals for Cycle 4 (FY82), Cycle 5 (FY83), and Cycle 6 (FY84) are 15% to 25%, 20%, and 25%, respectively.

Cycles 7 and 8 will focus on experiments in residential applications. According to the DOE Information Memorandum on the initiative, "The last 2 cycles would consist of applications experiments aimed at meeting the 1986 goal of $.50/watt (array), at which point the residential market may open to photovoltaic systems."[4]

Evaluation of the two strategies discussed above (i.e., base case and base case plus market pull) is the major emphasis of the venture analysis. However, to put these two alternatives in perspective, a limited number of alternative federal government options are reviewed. It is impossible to treat these additional options with the same level of detail as the first two strategies in the five months allowed for this venture analysis.

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[4] DOE Memorandum of December 21, 1977, op. cit., p. 4.

Nonetheless, a brief treatment of them adds significant insights. In particular, the venture analysis includes a brief examination of:

(1) A major increase in federal R&D expenditures on photovoltaics without the federal market pull strategy;

(2) A federal incentive to end-users which has the effect of reducing the life-cycle cost of a photovoltaic system;

(3) A federal buy of sufficient size to allow industry to invest in large automated manufacturing facilities.

The analysis of increased R&D is an integral part of the venture analysis. The analysis of end user incentives are treated only by the participants in the photovoltaic industry workshops (see Chapter III). The federal buy is treated as a sensitivity case in Chapter V.

C. SCOPE AND LIMITATIONS OF THE VENTURE ANALYSIS

It may be tempting to generalize the conclusions of the venture analysis to the entire photovoltaic program or to trends in the current industry. This mistake should be avoided. The venture analysis was not intended to be an evaluation of photovoltaics as a potential energy source. The scope of the analysis was deliberately limited in several key respects to answer the question specifically asked within the available time (February to June 1978).

Scope

1. Only a limited number of government roles were examined. The major effort was spent on measuring the marginal net benefits of the proposed market pull strategy.

2. The study estimated the economic and environmental benefits of the market pull initiative. No direct estimates were made of the value of increased energy independence, decentralization of energy generation, or decreased reliance on nonrenewable sources were made.

3. Implementation of the initiative was assumed to work perfectly, without any negative side effects such as demonstrating technical failures. Cost of administering the initiative was assumed not to exceed $12 million over the eight year cycle.

4. The venture analysis did not attempt to predict the competitive structure of the U.S. photovoltaic industry or predict how well the industry would compete in international markets. In general, it was assumed that the industry would be competitive enough that production cost reductions would lead to corresponding price reductions to the final consumer and that U. S. companies would be a major factor in international markets.

5. The study did not explicitly predict which of the photovoltaic technologies will dominate the industry over time. In addition, it was not necessary to explicitly model the relative merits of flat-plate versus concentrating photovoltaics in each market application. Rather, price trends and lower bound

prices are handled generally and sensitivity analyses were prepared.

Limitations in Data

1. The study did not attempt to consider every conceivable application which could use photovoltaics. Previous market studies contained tasks to identify all possible markets. This study did not try to duplicate that effort. Rather, emphasis was placed on those potential markets which appeared to be of significant potential size and about which some previous knowledge had been gathered.

2. Market data are limited in both quantity and quality, even for those applications which are currently served, and especially for intermediate and long-term markets. The credibility of the market estimates is in question. Extensive sensitivity analyses on market parameters and a workshop with potential buyers were in the venture analysis to overcome this limitation.

3. Although serious effort was devoted to investigating the actual engineering and cost characteristics of photovoltaic systems that might be purchased, extensive information was not available. Many of the photovoltaic systems that are predicted to be used in intermediate and long-term markets have not yet been designed or tested. The study is therefore limited to defining these systems in general terms with only a modest amount of engineering and cost detail.

Limitations in Methodology

1. Future market penetrations and prices of photovoltaics are represented in the venture analysis with state-of-the-art models for the diffusion of new innovations.

2. Single estimates of the future market penetration and prices of photovoltaics in the study should not be interpreted as absolute predictions. Rather, numerical results from sets of alternative scenarios reflect the range of uncertainty in future sales and prices.

3. The integrating model does not model in detail the dynamics of the photovoltaic supply industry. The future responses of the supply industry are analyzed qualitatively using a variety of approaches in Chapter III.

D. SUMMARY OF APPROACH AND REPORT ORGANIZATION

SERI's approach to the photovoltaic venture analysis is based on four guiding principles.

First, the venture analysis is limited to estimation of the incremental costs and benefits attributable to the procurement or to other initiatives rather than to total costs and benefits of the photovoltaic program.

Second, it must be realized that other photovoltaic R&D efforts are being funded and will continue to be funded by government and industry. The costs and benefits associated with those actions are considered in the venture analysis, but the benefits of those efforts are not added to the marginal benefits associated with the eight-year photovoltaic initiative because they would occur anyway. For example, the analysis shows that under a scenario of large intermediate markets, the marginal benefits of the initiative are low because the industry develops even without federal aid. This is a case in which the marginal benefits to the government are low but the industry is prosperous.

Third, market mechanisms within the U.S. private sector will force the replacement of obsolescent technologies with superior ones without active government intervention. In fact, this replacement of new technologies for old has consistently happened in the United States for two centuries. The initiative strategy must only be considered as a stimulus to accelerate this mechanism. The benefits of the program are only those associated with the time that the process is accelerated, not the total benefits of the innovation.

Finally, the venture analysis reflects both the uncertainty concerning the demand and supply of photovoltaic systems and the risks taken by the industry and the federal government. Uncertainty and risk on the supply side primarily surround production technology advances and responses of producing firms to government programs. Demand uncertainties arise from the lack of complete knowledge about future prices, characteristics of photovoltaic systems, and prices of competing technologies or fuels. These uncertainties and risks are handled in the study through the development of possible scenarios (using probability trees) and sensitivity analyses.

An overview of the approach used in the venture analysis is displayed in Figure 1. The approach contains three main parts; supply related tasks, market related tasks, and integrating tasks.

Three approaches were used in the estimate of the photovoltaic supply response. A cross-impact workshop was held with

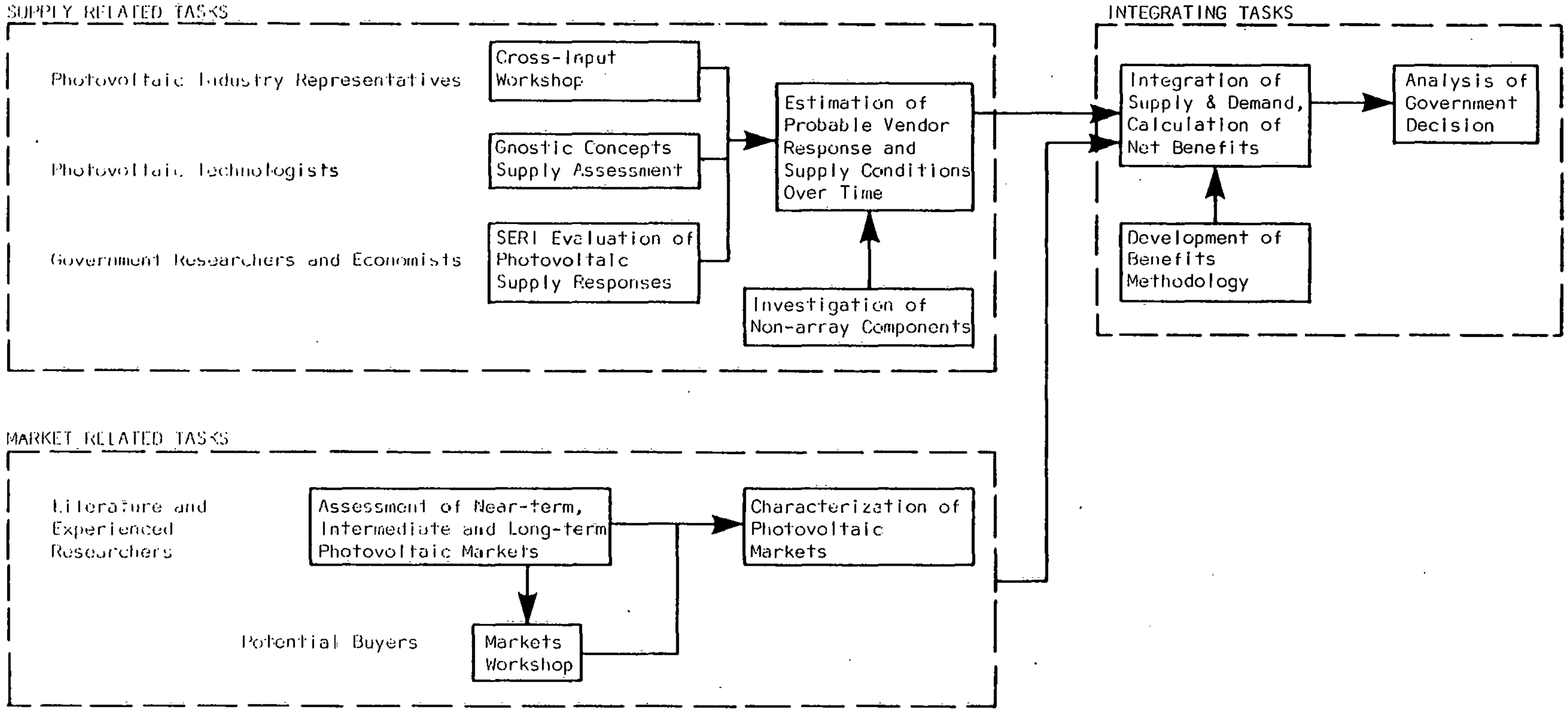

Figure 1. Overview of Venture Analysis Methodology

representatives of photovoltaic industry decisionmakers. Gnostic Concepts, Inc., compiled an independent assessment of trends in the industry based on interviews with photovoltaic technologists and their own judgments. The possible types of photovoltaic industry responses were also analyzed by SERI with information provided by the Low-Cost Silicon Array Project at the Jet Propulsion Laboratory (JPL). Chapter III contains the results of these analyses.

Two approaches were used to assess the markets for photovoltaics. The DOE-funded market studies were reviewed and compared, and a limited amount of follow-up analyses based on those studies was conducted. A workshop attended by representatives of potential buyers in selected markets was also held. The objective of the workshop was to check the existing market studies for accuracy. The results of the market investigation are in Chapter II.

The final tasks of the project were to integrate the supply and demand information and analyze the ramifications of alternative federal actions. The benefits methodology is based on the consumer surplus concept. The main integrating structure is a computerized integrating model. The backdrop for the integrating structure is a macroeconomic scenario of future GNP and energy price trends. This scenario enters the integrating model primarily through electricity price escalations and is subjected to considerable sensitivity analyses. Both the benefits methodology and the integrating model are discussed in Chapter IV. The analysis of the government decision and the conclusions drawn from the analysis are in Chapters V and VI, respectively.

The main report is contained in Volume I. The report is supported by a set of analytical appendices contained in Volumes II and III.

II. PHOTOVOLTAIC MARKET RESPONSE

This chapter summarizes information relevant to the response of photovoltaic markets to the procurement initiative. In Section A, the approach used to characterize photovoltaic markets in the venture analysis is described. Available information on near-term, intermediate, and long-term markets for photovoltaics is then reviewed in Section B. In Section C, a range of potential market scenarios is presented. In Section D, comments on the effectiveness of the procurement initiative made in the market demand workshop are summarized.

Throughout this chapter, the major uncertainties in the available information on photovoltaic markets are highlighted. Completed photovoltaic market research, while sufficient to provide a rudimentary indication of how markets for photovoltaics might develop, does not allow the construction of any single market scenario in which a high level of confidence can be placed. Rather, a broad range of market scenarios exist, with little evidence to suggest which scenario is most credible.

A. CHARACTERIZATION OF MARKET RESPONSE

A set of key parameters which affect the rate of photovoltaic penetration into current and future markets is used to characterize the market response to photovoltaic systems in the venture analysis. These parameters are then combined into a simple analytical framework which relates potential markets for photovoltaics to expected sales under alternative photovoltaic supply conditions.

Key Market Parameters

Five basic sets of parameters can be used to characterize a potential market.

Energy Demand Data

The first set of parameters specifies the job that would be done by a photovoltaic system (i.e., the specific application). The operating cycle, including peak and average power requirements; daily use schedule; periodic energy consumption; and reliability requirements are the data necessary to choose a power system.

Competitive Power System Description

Photovoltaic power systems will usually compete with some currently available power system or other new energy technology.[1] Evaluation of the market potential of photovoltaics requires specification of the major alternatives. The physical characteristics, equipment requirements, and installation requirements of the most attractive competitive power system capable of satisfying the energy demand of the application must be determined, and the initial costs and operating and maintenance costs (including replacement requirements) of the system estimated. Estimates of the future price trends associated with the power systems are also needed.

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[1] For some applications, photovoltaics may not actually compete with specific alternative power systems. In these cases, the attributes of the photovoltaic system may cause power to be used in markets where no equivalent alternative power system is available (i.e., float charging a battery on a boat or powering a recreational vehicle). It is particularly difficult to assess the market potential of photovoltaics in these situations where, for example, an estimation of the value of less noise associated with a photovoltaic powered recreational vehicle is required.

Photovoltaic Power System Description

A detailed design of the photovoltaic power system and estimation of its costs comprise the third set of parameters. The system must be designed to meet the energy demand and reliability requirements specified. Components of the photovoltaic system may consist of the photovoltaic array, the structure to support the array, power conditioning, storage, and installation. Exact system components vary considerably from application to application.[2] Current and expected future costs of each of these components are estimated in the same way as the costs of competitive systems.

Market Size Data

Associated with each specific photovoltaic application is a potential market. The potential market can be visualized as the number of units with the energy requirements specified in the first set of parameters. Prospective purchasers of a power system in a given market may choose among the conventional power system, a photovoltaic system, or possibly another new technology. Definition of the potential market exposes the limitation that characterizing the market response to photovoltaics involves some degree of generalization. That is, the specified alternative power systems and the photovoltaic system are supposed to be typical systems representative of a large number of systems that constitute a potential market. In many markets, there is a wide range of system sizes and types. In fact, a wide range of specific applications may comprise a market such as agricultural pumping. Limitations in time and resources require that

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[2] Several examples of photovoltaic power system designs are contained in Chapter III, Section F.

reasonable approximations of typical systems and corresponding markets suffice. Market size estimates are usually divided into annual new installations and annual retrofits. Statistical data on the annual demand for equipment and expected future growth rates are the information sources used to define the potential market. The fraction of this market likely to be suitable for photovoltaics must also be estimated.

Market Decision and Response Parameters

The potential market represents an upper limit on the annual sales of photovoltaic systems. However, it is unlikely that photovoltaics will immediately penetrate the entire potential market. The quantity of successful photovoltaic sales depends on several factors. The attractiveness of a photovoltaic system must be compared to conventional power systems or to other new technologies. The comparison should be based on the decision criteria used by prospective buyers who make up the potential market. For example, in remote microwave repeater applications, the cost of a photovoltaic system may be compared with the cost of using a thermal electric generator. This comparison could be made on a first cost, payback, or life-cycle cost basis. However, market studies to date indicate that purchasers of microwave repeaters are likely to compare competitive power sources on a five-year payback basis. That is, the initial capital and operating costs of the photovoltaic system would be compared with the initial capital and operating costs of a thermal electric generator over a five-year time horizon. The five-year cost of the photovoltaic system performing the same function as the thermal electric generator would have to be equal to or less than the five-year cost of the thermal electric generator to be competitive.[3]

The ability of photovoltaics to compete with the alternative systems will have a major impact on the rate of sales. Other factors that will affect photovoltaic market penetration are the price sensitivity of the market and the responsiveness of the market to the introduction of a new technology. These factors are particularly difficult to specify because empirical information on them is usually not available.

Structure for Treating Markets

The five sets of parameters described above are all related through an analytical framework. This framework is shown in Figure 2. Typical designs for photovoltaic power systems and other candidate power systems can be developed by using the energy demand data. The designs represent a typical power system that serves the needs of a particular potential market. Based on the decision criteria of each market, a comparison between photovoltaics and other alternative power systems can be

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[3] It is important to note that the exact nature of this economic comparison differs considerably from market to market. First, the decision criteria used in different markets vary. Second, the specific components and costs of the competitive systems vary. In the utility sector, for example, a sophisticated analysis was conducted to compare the value of a photovoltaic system to the utility with other options for utility system expansion. In dispersed, grid-connected markets, such as a photovoltaic residence, the value of the photovoltaic system to the homeowner is determined by valuing the energy produced by the photovoltaic system according to the utility rate structure. Obviously, the rate structure and decision criteria assumed affect the results of this comparison. Further explanation of the competitive analysis for utility grid-connected systems is contained in the discussion of long-term markets in Section B.

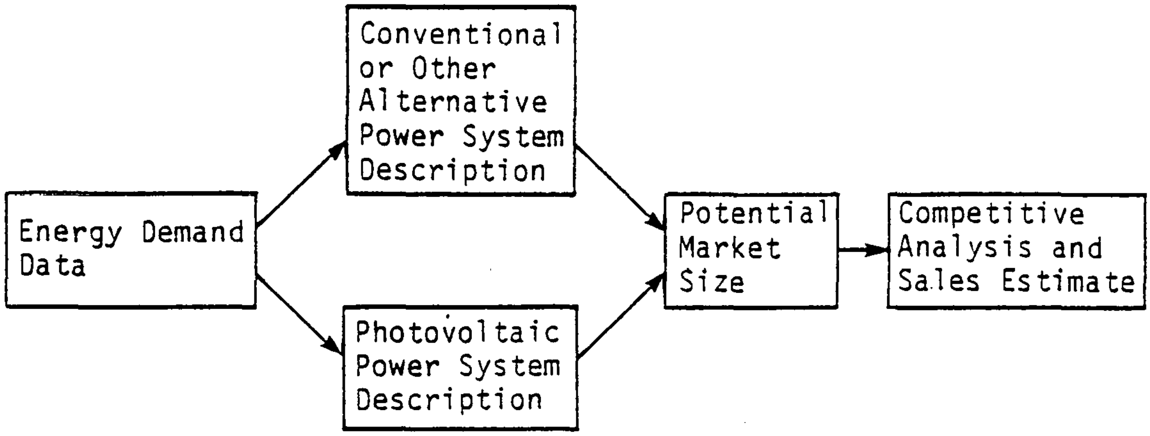

Figure 2. Structure for Treating Markets

conducted. The price at which the photovoltaic system is equal to the price of the competitive system is termed the photovoltaic breakeven system price.[4] Taking into account the price

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[4] The following example illustrates how the photovoltaic breakeven system price is calculated. The decision criteria typical of the microwave repeater market is a five-year payback comparison. The five-year cost of a 120 watt thermal electric generator (the competitive system) has been estimated by BDM Corporation to be \$14,650 (\$7,500 initial capital cost and \$1,430 annual cost). This is the total allowable cost for the photovoltaic system (i.e., the photovoltaic breakeven system price). To translate this into the system breakeven price per peak watt, this total breakeven price is divided by the peak rating of the photovoltaic array capable of powering the microwave repeater, which is 600 Wp.

$$\underset{(\$/\text{Wp})}{\text{Breakeven system price}} = \frac{\$14,650}{600\ \text{Wp}} = \$24.42/\text{Wp}$$

This price is the allowable price per peak watt of array rating for the photovoltaic array; all balance-of-system components (storage, power conditioning, structure, etc.); and installation. Subtracting the balance-of-system costs and installation costs (expressed in \$/Wp of array rating) yields the allowable price of the photovoltaic array alone. Specific systems assumptions supporting this calculation and all breakeven calculations are contained in Appendix D.

of the market and its receptivity to new technologies, estimates of expected sales of photovoltaics are made. This analytical framework is the basis for the approach to treating photovoltaic markets in the integrating model as described in Chapter IV.

B. MARKET DATA SUMMARY

Potential markets for photovoltaics can be categorized by the photovoltaic system prices at which significant photovoltaic sales might be made. For presentation, markets have been divided into near-term, intermediate, and long-term categories. Photovoltaic sales are currently being made in those markets in the near-term category, and significant penetration of these markets can be anticipated at today's photovoltaic prices or with moderate photovoltaic price reductions. In the intermediate category, substantial reductions in photovoltaic prices would be necessary for significant photovoltaic market penetration to occur. This does not mean, however, that isolated photovoltaic sales are not being made in the intermediate markets today. For photovoltaics to be used to any significant extent in long-term markets, major reductions in photovoltaic prices will need to be achieved.

A review of completed studies on photovoltaic markets was conducted to describe potential markets using the structure discussed above. Within the time constraints of this study, only a very limited amount of additional investigation was feasible on near-term and intermediate markets. For the long-term markets, an analysis of the economic requirements for photovoltaics to be competitive was undertaken. A market demand workshop was held to review the market descriptions being used in the venture analysis. The information derived from these various sources is contained in the following discussions of each market category. Emphasis is placed on the size of potential markets of photovoltaics and on the prices at which photovoltaics become competitive because these are the key input parameters for describing markets in the analysis. Estimates of the size of the potential market and breakeven prices from various sources are often conflicting. These discrepancies are discussed in the summary of major uncertainties for each market category. Resolution of discrepancies is treated through alternative market scenarios presented in Section D.

Near-Term Markets

Market Studies

The sources of market data on near-term markets are the previous work by the BDM Corporation,[5] InterTechnology/Solar Corporation,[6] and Aerospace Corporation.[7] Aerospace, in an overview of these studies, attempted to compare their results.[8] However, the conflicting scopes, definition of markets, and approaches used in these studies, made a meaningful comparison difficult.

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[5] BDM Corporation *Photovoltaic Power Systems Market Identification*, Draft Report submitted to DOE, Volume I, May 1977, Volume II, November 1977, Volume III, February 1978; and *Draft Final Report for the Program to Develop a Preliminary Implementation Plan for the Federal Photovoltaic Utilization Program*, prepared for MERADCOM and DOE, April 1978.

[6] InterTechnology/Solar Corporation, *Photovoltaic Energy Technology Market Analysis*, Draft Report to DOE, January 1978.

[7] Aerospace Corporation, *Mission Analysis of Photovoltaic Solar Energy Conversion*, Volume II, Survey of Near-Term (1962-1985) Civilian Applications in the United States, prepared for ERDA, March 1977.

[8] Aerospace Corporation, "Overview of Photovoltaic Market Studies," prepared for DOE, May 1978.

The authors of these previous market studies, under contract to SERI, were each requested to summarize their previous research in a format consistent with the structure for treating markets described above. The responses to this request revealed that the BDM data were most easily adapted to the needed format.[9] In addition, the BDM study appeared to provide the most detailed and comprehensive description of potential markets. The ITC and Aerospace studies yielded information on only a limited number of markets. As a result of this effort, it was decided that the BDM data would be relied on as the primary data source. ITC and Aerospace data, where available, would be used to support or dispute the BDM market data.[10]

A preliminary screening of potential near-term markets resulted in the selection of approximately 17 markets for further consideration. Table 5 summarizes the available data on potential near-term markets. Appendix D contains detailed market data summary sheets which describe the typical energy demand, conventional and photovoltaic power systems, market size estimates, and decision factors that characterize each market. These data were used to develop the breakeven prices shown in the table. Detailed estimates of the balance of systems costs for selected markets are contained in Chapter III.

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[9] Summaries of the BDM data were prepared jointly by the BDM Corporation and Orin Merrill of Science Applications, Inc., who was the principal author of the BDM market study.

[10] It should be recognized that these market studies were not intended to be exhaustive market analyses of the most promising market for photovoltaics. Each study invested a substantial portion of available resources in identifying a large number of candidate markets for photovoltaics. Only a part of the resources, therefore, were used for in-depth research on the characteristics of the most promising markets.

TABLE 5

SUMMARY OF NEAR TERM MARKET DATA[1]

Market	System Breakeven Price: 1976 ($/Wp)			Current PV System Price: 1976 ($/Wp)			Annual Market Potential: 1976 (MWp)			Annual Market Potential: 1985 (MWp)		
	BDM[2] SAI	AS[3]	ITC[4]	BDM SAI	AS	ITC	BDM SAI	AS	ITC	BDM SAI	AS	ITC
Radio Repeaters-U.S.	26	4	8	28	20	18	2.3	.8	.2	7.1	2	.5
Microwave Repeaters-U.S.	24	9		24	20		.3	.7		1.1	.9	
Telemetry-U.S.	207			75			.05			.07		
Navaids-U.S.	112	67		38	22		.2	.06		0^5	.06	
Remote Sensing-U.S.		235			32			0			.04	
Radio Repeaters-Foreign	28			31			1.2			6.2		
Microwave Repeaters-Foreign	26			27			.4			3.2		
Telemetry-Foreign	86			82			.08			.4		
Rural Telephones-Foreign	20			23			.06			1.3		
Education TV-Foreign	21			27			.2			1		
ICP Shallow Wells-U.S.	15^6	227^7		30^6	28		.9	.07		1	.14	
ICP Deep Wells-U.S.	11^6	22^7		26^6	28		3.4	1.1		4	1.7	
ICP Pipelines-U.S.	27	$3\text{-}7^7$	8	28	20	25	.9	.08	24	1.2	.08	.24
ICP Bridges-U.S.	8	113^7		21	28		-	.02		-	.02	
ICP Shallow Wells-Foreign	20^6			35^6			.6			.7		
ICP Deep Wells-Foreign	16^6			32^6			4.6			5.4		
ICP Pipelines-Foreign	27			37			.9			1.3		

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1. Unless noted otherwise, all prices are 1976 estimates in 1975 constant dollars. See Appendix D for systems descriptions and other information used to construct this table.
2. Indicates BDM/SAI data. These data are primarily summaries of the previous BDM study but in some instances are based on limited follow-up research. The data were prepared jointly by BDM and Science Applications, Inc.
3. Indicates Aerospace data.
4. Indicates InterTechnology/Solar Corp. data.
5. Market is primarily retrofit and is expected to be saturated by 1985.
6. These prices are for 1978 in 1975 constant dollars.
7. Assumes that a one mile utility line extension is required.

From Table 5 it can be seen that the major near-term markets are estimated to be in remote communication facilities and corrosion protection systems. The repeater markets are the major components of both the United States and foreign communications market. Cathodic protection of wells using impressed current protection (ICP) appears to be the major component of the corrosion protection market.

Although the breakeven prices in most of these markets are generally high, none of these near-term markets is estimated by market studies to be very large. No single market has a potential for photovoltaic sales in the near term of significantly greater than 5 MWp.

Market Demand Workshop

Two sessions in the market demand workshop held on June 1 and 2 addressed near-term photovoltaic markets.[11] One session examined communications markets, and another session examined cathodic protection markets. The participants in these sessions were primarily current suppliers and users of equipment in these markets. The major conclusions of these two sessions are briefly summarized here.

Communications: According to the communications working group, the principal photovoltaic electric power system application in communications is for remote sites associated with microwave or radio repeater stations. Most of the potential site applications are outside the United States. Sales of photovoltaic systems are being made today in this market. The group estimated that in 1977

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[11] A detailed summary of the market demand workshop is contained in Appendix F.

approximately 1,150 remote microwave repeater sites, at both new and existing sites, were candidates for photovoltaic electric power systems. Remote installations should increase to approximately 1,350 sites annually by 1990. Radio repeaters would add 100 new sites annually that would also be suitable for photovoltaics.

The average microwave repeater site was estimated to require approximately 2 kW of continuous power. Considering the geographic locations of the potential sites, this translates to a requirement for approximately 10 kWp of photovoltaic arrays for each site. Thus, annual worldwide installations suitable for photovoltaics in 1977 represent a maximum market of approximately 12 MWp of photovoltaic arrays annually. The foreign market was estimated to be the major portion of this worldwide market--approximately 10 MWp.

Penetration of this potential market was believed to be directly dependent upon the relative price of photovoltaics compared with prices for alternative power sources. At a photovoltaic array price of $15/Wp, the panel felt that a penetration of up to about 5% of the total market could be achieved. At $10/Wp, penetration was estimated to be 20% to 30%; at $8/Wp, penetration would increase to 30% to 40%; and at $5/Wp, an 80% to 100% penetration was estimated.

The panel also listed a number of new or emerging communication markets, some of which were generally not considered in previous market analyses. Of these, by far the largest potential was in a photovoltaic electric power source to operate television receivers at remote locations in developing countries. It was estimated that there could be a market of approximately 20,000 systems per year at an average load of 35 W to 50 W corresponding to a potential market of 1.2 MWp.

Corrosion Protection: According to the corrosion protection working group, the principal markets for cathodic protection systems are well casings (generally gas and oil wells), pipelines, storage tanks, wharfs and piers, and bridges. Only the first two markets were felt to represent significant potential applications of photovoltaic electric power systems. The reason is that a significant portion of cathodic protection systems are used in remote areas where grid hookups or other principal power sources are not available. The latter three cathodic protection system markets are almost always close to electric grid connections or large motor generators and, hence, are not realistic photovoltaic applications.

The maximum potential market for photovoltaics in corrosion protection systems was estimated to be 0.42 MWp in 1977. However, the actual sales were estimated at only 32 kWp in 1977, mostly U.S. well casing systems. In 1990, the maximum potential market for photovoltaics was estimated to be 0.80 MWp, while sales are estimated at 0.46 to 0.48 MWp. The majority of 1990 sales are expected to be for foreign well casings. By comparison with the previous communications market estimates, this was obviously thought to be a very modest market for photovoltaics.

The panel generally believed that the market estimates were not particularly dependent on substantial price reductions in photovoltaics. The major issue in the use of photovoltaics was the desire on the part of cathodic protection users to install systems in remote areas where power was a major cost element. While those decisions were somewhat dependent on the price of the total system, it was believed that only modest reductions below current photovoltaic prices, together with the increased emphasis on corrosion protection, would result in 100% use of photovoltaics for most remote applications overseas and a 10% use for remote applications in the United States.

Major Uncertainties

Comparison of the information gained in the market workshop to the data from the market studies suggests that a considerable amount of uncertainty exists in the available information on near-term markets.

In the communications market, both the market studies and the workshop estimated the major market to be in repeaters. The size estimates of the U.S. communications market were approximately equivalent. However, the price at which photovoltaics would successfully penetrate this market was estimated to be somewhat lower by the workshop than by the market study data. The workshop estimate of the potential size of the foreign communications market was approximately 10 MWp, considerably larger than the market study data. The price at which photovoltaics would become competitive, however, was again estimated by the workshop to be lower.[12] The workshop estimates of the potential size of the corrosion protection markets were much lower than estimates from available market data. Market data estimates of the total annual potential worldwide corrosion protection market are approximately 10 MWp today, while the workshop estimates of the annual potential market through 1990 do not exceed 1 MWp.

It is impossible to satisfactorily resolve these discrepancies in descriptions of the near-term market at this time. A better understanding of those markets will only emerge after more detailed market research. For the purposes of this study, discrepancies in market data will be treated through use of alternative market scenarios as presented in Section C below.

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[12] The growth rate of the foreign communications market in the market study data would result in a potential market approximately equal to the workshop estimate in the mid-1980s.

Another uncertainty with respect to the near-term market is the extent to which other new technologies might be effective competitors with photovoltaics. The SERI Research Division reviewed the near-term markets for photovoltaics to evaluate where other solar technologies might compete. The results of this review suggested that liquid fuels from biomass sources, such as ethanol or methanol, would be suitable substitutes for fossil fuel sources currently used with thermal electric generators and gas or diesel generators, which are often used in these markets. The reliability and cost characteristics of biomass-fueled generators would not be significantly different from those of conventional systems. Wind systems were also evaluated to be an effective competitor in these near-term markets where adequate wind is available. However, neither wind systems nor a biomass-fueled generator is likely to have the attribute of a photovoltaic system that is attractive in remote sites--no moving parts. Solar thermal systems were not thought to be a potential competitor in any of these near-term markets.

Intermediate Markets

Market Studies

As in the case of near-term markets, the primary source of information on intermediate photovoltaic markets is work by the BDM Corporation.[13] However, data on only a few intermediate markets were contained in this work. Therefore, information on several intermediate markets presented here was assembled in a limited amount of time. It represents a very rough description of these markets and cannot be substantiated by detailed market research.

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[13] BDM Corporation, Photovoltaic Power Systems Market Identification, and FPUP, op. cit.

Table 6 summarizes available data on intermediate markets that were believed to be important to the venture analysis. Descriptions of the market data and photovoltaic and conventional power systems used to construct this table are contained in Appendix D. Chapter III describes the balance-of-system costs for photovoltaic systems in selected intermediate markets.

The largest potential U.S. intermediate market appears to be street and highway lighting and outdoor area lighting. The total annual size of this market has been estimated by BDM to be almost 300 MWp in 1976. The future development of this market, however, is highly uncertain. A meeting held with representatives of the Federal Highway Administration, Street and Highway Lighting Branch, suggested that the BDM estimates of the size of the potential market and the breakeven price may be somewhat optimistic.[14] More critically, the design and construction of a photovoltaic system that corresponds to the BDM cost estimates have not yet been achieved. No photovoltaic lighting systems have been built to date. Vandalism as well as user acceptance may be a problem.

Other potential U.S. intermediate markets are not well defined. The DOD mobile generator market might be nearly 100 MW, or it might not develop at all. User acceptance and the feasibility of photovoltaics in these applications are uncertain. Similarily, other federal applications could be either a very small market or a significant market.

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[14] Meeting with Charles Craig, and John Arens, Street and Highway Lighting Branch, Federal Highway Administration, Washington, D.C., June 9, 1978.

TABLE 6

SUMMARY OF INTERMEDIATE MARKET DATA[1]

Market	System Breakeven Price: 1976 ($/Wp)	Current PV System Price: 1975 ($/Wp)	Annual Market Potential: 1976 (MWp)	Annual Market Potential: 1985 (MWp)
DOD Mobile Generators-U.S.	3.4-4.3[2]	19[2]	0-86	0-98
Federal (Non-DOD)-U.S.	6-8[3]	24[3]	.6-6	.7-7
Outdoor Lighting-U.S.	2.8	22	290	400
Small Water Pump-U.S.	2	21	1.5	2.1
Recreational Vehicles-U.S.	NA	20	15	21
Sailboat Panels-U.S.	NA	25	.2	.25
Small Consumer Products-U.S.	20-50	21	1-10	1.5-15
Battery Charger-U.S.	1[4]	18[4]	NA[4]	NA[4]
Small Refrigerators-U.S.	NA[4]	18[4]	22[4]	22[4]
Low Lift Pumping-Foreign	3-8[5]	20[5]	50[5]	50[5]
Medium Lift Pumping-Foreign	8	23	50-200	60-120
Remote Power-Foreign	10-12[6]	25[6]	5-40	6-45
Village Power-Foreign	.4-1.5	22	100	100

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1. All prices are 1976 prices in 1975 constant dollars unless otherwise indicated. Data are from BDM Corporation and Science Applications, Inc. unless otherwise indicated.
   See Appendix D for systems descriptions and other information used to construct this table.
2. 1982 price estimates in 1975 constant dollars. $15/Wp array price is assumed.
3. 1979 price estimates in 1975 constant dollars. $15/Wp array price is assumed.
4. ITC data.
5. Data from Smith and Allison, "Micro Irrigation with Photovoltaics" MIT Energy Lab. Draft, February 1978.
6. Prices for 1978 in 1975 constant dollars. $15/Wp array price is assumed.

A variety of potential U.S. consumer markets is contained in Table 6. The consumer products market, for example, is intended to represent watches, calculators, and toys in which a small photovoltaic array is used to charge batteries. Again, only a wide range of estimates of the size of this market is available. The breakeven price of this market also exhibits a wide range. It is believed that a breakeven price for this market well below $20/Wp is also possible. Other consumer applications such as battery chargers for sailboats and recreational vehicles, while possibly being significant potential markets, also have uncertain breakeven prices. A substantial amount of market research must be done before more credible descriptions of these markets can be developed.

Currently available descriptions of foreign intermediate markets are also highly uncertain. Table 6 shows that the pumping markets may exceed 150 MWp annually. Remote photovoltaic power facilities could be a potential market approaching 50 MWp. The breakeven prices for these potential pumping markets and the remote power market are shown in the table to be in the $8 to $12/Wp range. This clearly would be an attractive intermediate market. However, the availability of funds for purchase of a photovoltaic system, the possible first-cost sensitivity of these buyers, and a large number of other factors reduce the confidence that these markets will develop at the indicated prices and sizes.

Market Demand Workshops

The only potential intermediate markets examined in the market demand workshop were associated with agricultural applications. The agricultural working group was made up of irrigation equipment and pump suppliers and researchers knowledgeable of agricultural operations and irrigation practices.[15]

The working group concluded that there is no significant market for photovoltaics in U.S. agricultural water pumping applications, including irrigation until photovoltaic array costs drop below the $1/Wp level. A sizable market (possibly 25 MW) may develop for irrigation applications in the range of $0.60/Wp to $0.90/Wp, slightly before photovoltaics become competitive with grid-interconnected electric generation.

It was believed that there may be a small U.S. market for 0.5 to 3.0 hp water pumps for remote livestock watering, potable water for homes isolated from the electric utility grid or other miscellaneous remote applications. Savings on labor to visit or maintain liquid fuel pumps might motivate penetration of these applications at photovoltaic array prices above $1/Wp to $2/Wp. Wind energy systems were believed to be a strong competitor in this market.

Foreign markets in developing countries without grid electricity were believed to be a potential market for lower power (fraction to 10 hp) applications. However, no estimate of this market was made by the panel. Manufacturers in the United States are not presently supplying these markets.

Major Uncertainties

Descriptions of intermediate markets for photovoltaics both in the U.S. and foreign countries are speculative at this time. Both the workshop and the market studies suggest that an intermediate

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[15] See Appendix F for a complete summary of the market demand workshop.

agricultural market in the United States does not exist. A variety of possible United States and foreign intermediate markets has been identified. There is a small amount of evidence to suggest that some of these markets may be large and that photovoltaics may compete in the $3 to $10/Wp range. Because of the wide range of market descriptions and their uncertainty, alternative market scenarios will be used to characterize the intermediate markets in the venture analysis. These scenarios are presented in Section C.

The SERI Research Division review suggested that several other solar technologies are likely to be effective competitors. Wind will be important in all pumping markets where wind is available. Solar thermal might also compete in the water pumping markets. Where generators are currently used, fuel from biomass might be substituted for fossil fuels. Thus, competition from other solar technologies should be expected to have a significant impact on the intermediate market.

Long-Term Markets

MIT Results

Under contract to SERI, the MIT Energy Laboratory conducted an economic analysis of the allowable costs for a photovoltaic system in three different settings: (1) single family residences; (2) institutional buildings represented by a school; and (3) central utilities. The analyses were done on a regional basis. Where possible, approximations of the maximum potential market for photovoltaics were made for each region examined. A complete summary of the MIT analysis is contained in Appendix I.

Single Family Residences: Table 7 summarizes the major assumptions used in the single family residence analysis. The system has a peak array rating of approximately 3.2 kW and contained no storage capacity. Simulations of the performance of this system were made for five cities representing five regions where photovoltaics might be competitive in the future. All calculations of the economic value of the photovoltaic system are based on a 20-year life-cycle cost analysis. The photovoltaic system provides electricity to the load when there is sufficient insolation. When insufficient insolation exists, the load is supplied from the grid in whole or in part. A time-of-day pricing utility rate structure is assumed. The electricity rates for the five regions are also shown in Table 7.

A key assumption of the analysis is that the homeowner is able to provide power back to the utility when he has excess capacity relative to his own demand. Three alternative rates at which the utility would buy back power from the homeowner were considered. The first rate is a 0% buyback (i.e., no credit to the homeowner for excess generation). The second rate is a 50% buyback (i.e., the utility is willing to buy from the homeowner at half the time-specific price that the utility charges). The third possibility is a 100% buyback (i.e., the utility is willing to pay the homeowner exactly what it charges). An analysis on a utility by utility basis is required to justify the precise value of excess power to the utility. In the absence of that analysis, a 50% buyback is believed to represent a fair approximation of the fuel and operating costs of a utility. The uncertain future actions of

TABLE 7

RESIDENTIAL SIMULATION ASSUMPTIONS

Array Size	$33M^2$
Array Tilt Angle	Latitude less 10^o
Encapsulated Cell Efficiency	.12
Wiring and Mismatch Efficiency	.95
Inverter Efficiency	.88
Packing Factor	.80
Storage	None
Cell Degradation Rate	5% years 1 and 2 0.7% years 3 to 20
System Lifetime	20 years
Discount Rate	3% (Real)
Electricity Escalation Rate	3% (Real)

SAMPLE TIME-OF-DAY RATE STRUCTURES

	Base	Shoulder	Peak
Phoenix			
Price (¢/kWh)[1]	2.43	--	20.05
Times in Effect	11/1-3/31, all day; 4/1-10/31, 6 p.m.-1 p.m. weekdays, all day weekends and holidays		4/1-10/31, 2-5 p.m.
Boston			
Price (¢/kWh)[1]	2.60	--	6.73
Times in Effect	Year-round, 10 p.m.-6 a.m. weekdays, all day weekends and holidays		Year-round, 7 a.m.-9 p.m. weekdays

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[1] Prices are 1976 prices expressed in 1976 dollars.

Source: MIT Energy Laboratory

public utility commissions, and the utilities themselves, make it difficult to specify a probable buyback rate at this time.[16]

Table 8 summarizes the results of the MIT analysis. These breakeven system prices represent the net present value over a 20-year period of a photovoltaic system installed in 1978 divided by the peak power rating of the photovoltaic array.[17] The net present value of the photovoltaic system was determined through hourly simulations during a typical year of the output of the photovoltaic system and the electrical load of the house. Electricity produced by the photovoltaic system that can be used by the house in a given hour is valued at the time-of-day utility

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[16] Southern California Edison has adopted a policy which purchases power back from a homeowner at a 100% buyback rate once a minimum charge has been paid. A 100% buyback rate essentially provides the homeowner with free storage and does not account for efficiency losses in transmission and subsequent redistribution of the repurchased power. The rate also assumes that the utility is able to resell the power when it is received from the homeowner. Up until the time that residential systems (or other dispersed systems) achieve significant market penetration, other utilities may also adopt a 100% buyback policy. However, should dispersed photovoltaic systems become a significant energy source in the utility, this policy will have to be reversed unless an explicit decision is made to subsidize photovoltaic users at the expense of all other customers.

[17] It is also possible to express breakeven system prices in terms of the output per peak system watt, accounting for efficiency losses in the system. All system component prices would then be expressed in dollars per peak system watt rating. Our numbers are expressed in allowable dollars for the system per peak array watt. Our system component prices are also expressed in dollars per peak array watt. When breakeven prices are expressed in dollars per system peak watt, the breakeven prices appear higher due to efficiency losses in the system. The array and component costs, however, would also appear higher by exactly the same amount due to the same efficiency adjustments. These two methods differ only in language and have no impact on the allowable cost for the photovoltaic array or other system components so long as the analysis is internally consistent.

TABLE 8

SUMMARY OF MIT RESIDENTIAL ANALYSIS RESULTS

Region	Case City	Breakeven System Price ($/Wp[1]) 0% Buyback	 50% Buyback	 100% Buyback	Annual Potential Market (MW-1990)
Southwest	Phoenix	.91	1.08	1.25	365
South	Miami	.60	.72	.84	750
Northeast	Boston	.55	.72	.89	540
North Central	Omaha	.42	.55	.68	600
Texas	Fort Worth	.35	.41	.47	150

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[1] Breakeven prices are for a system installed in 1978 expressed in 1975 constant dollars. Breakeven prices are the net present value of the photovoltaic system over a 20-year period divided by the peak power rating of the photovoltaic array.

rate which the homeowner would experience during that hour. Excess power is valued at the appropriate time-of-day rate adjusted by the buyback rate. Electricity prices were escalated at an annual real rate of 3%, and future electricity savings were discounted at a real rate of 3%.

It is apparent from Table 8 that the various buyback rates do not have a huge impact on the breakeven price results. This is primarily because the systems examined in the MIT analysis were relatively small (approximately 3.2 kWp array rating). Therefore, excess power was rarely available to be sold back to the utility at the adjusted rate. The major portion of the system output was used at the home and was valued at the same rate under each of the buyback assumptions. Larger residential photovoltaic systems may be more sensitive to the buyback rate, as they could have a larger amount of excess power.

Table 8 also shows the annual maximum potential market size, based on a regionalized approximation of annual new single-family homes built in 1990. No estimate of the proportion of new housing starts suitable for photovoltaics has been made.

From Table 8, it is obvious that the potential size of the residential market is large. The allowable price for photovoltaic array requires a drastic reduction in array prices.[18] Estimates of balance-of-system prices for residential systems are contained in Chapter III. These estimates indicate that the lower bound balance-of-system price for this residential system is

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[18] Obviously, tax credits or other direct government incentives would increase these breakeven prices. Also, as discussed in Chapter IV, the breakeven price is the price at which economically justified sales would be made. Some initial sales, however, may be made at prices above these breakeven prices for other than strictly economic reasons.

approximately $0.50/Wp. This would suggest that a photovoltaic system with an array price of approximately $0.50/Wp might be competitive in Phoenix today. A rapid escalation of electricity prices would result in a substantially larger allowable price for the array in 1990.[19]

Institutional Buildings: A shortened version of the detailed simulation undertaken for single family residences was conducted for a school, representing institutional buildings. The same assumptions used in the residential analysis were repeated, except that the array had a peak rating of 52 kW.

Table 9 summarizes the results of the school analysis for 0%, 50%, and 100% buyback rates. The maximum potential market for photovoltaics in new schools, based on an approximation of the regional construction of new schools, is also shown in the table. Breakeven prices for the school are similar to those for single family residences. The maximum potential market associated with school buildings, however, is much smaller than for residences. The balance-of-system costs for a photovoltaic school may be slightly higher than for a single family home. If the photovoltaic array is assumed to be integrated into the roof of a house and a custom array support structure needs to be constructed

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[19] It should be pointed out that a residential time-of-day rate structure was used in the MIT residential analysis to reflect the marginal cost of electricity at different hours. The rate structure was not designed to reflect only the marginal cost of new utility capacity although new plant costs are averaged into the rate used. This rate structure was used because it most accurately reflects the rate that a homeowner would probably experience in evaluating a photovoltaic system. No method was available to this study to account for the marginal expansion impacts of dispersed photovoltaic systems and the resulting rate structure implications. The central utility analysis discussed below considers the worth of photovoltaics to the utility as compared with other new generating options.

TABLE 9

SUMMARY OF MIT SCHOOL ANALYSIS RESULTS

		Breakeven System Price ($/Wp[1])			
Region	Case City	0% Buyback	50% Buyback	100% Buyback	Annual Potential Market (MW-1990)
Southwest	Phoenix	.74	.91	1.08	25
Northeast	Boston	.63	.73	1.00	46
Texas	Forth Worth	.39	.69	.79	7
South	Miami	.50	.59	.68	42
North Central	Omaha	.46	.56	.66	15

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[1] Breakeven prices are for a system installed in 1978 expressed in 1975 constant dollars. Breakeven prices are the net present value of the photovoltaic system over a 20-year period divided by the peak power rating of the photovoltaic array.

on a flat roof school, the installation costs for the school are likely to be higher. Lower priced photovoltaic arrays, therefore, may be required for photovoltaic systems to be competitive in the case of a school compared to those for a residence.

Central Utility Power: A different type of analysis was conducted to estimate the value of a photovoltaic system to a central utility. This analysis involved detailed simulations of the capacity credit and fuel savings associated with a prespecified level of photovoltaic generating capacity in a regionally representative utility. Regionally representative utilities were constructed by matching as nearly as possible the regional generating mix within which each case study utility is located. It is important to realize that the resulting representative utilities do not match the operating characteristics of any specific utility. This analysis therefore gives only an approximation of the regional value of a photovoltaic system. Ultimately, the value of the photovoltaic system would have to be analyzed on a utility specific basis.

A detailed discussion of the assumptions and methodology used in the utility analysis is contained in Appendix I. Table 10 summarizes the results. The breakeven prices presented are for a U.S. composite of regional assumed penetration levels and the resulting allowable prices per peak watt for the photovoltaic system. Regional descriptions are provided in Appendix I. The installed capacity shown in the table does not represent any estimate of annual sales or of annual market potential. Rather, it represents the magnitude of U.S. photovoltaic capacity at which the breakeven prices would apply.

TABLE 10

SUMMARY OF MIT CENTRAL UTILITY ANALYSIS RESULTS

Breakeven System Price ($/Wp[1])	Total U.S. Photovoltaic Installed Capacity (MWp)
.49	27,000
.47	36,000
.46	44,000
.42	64,000

[1] Breakeven prices are at today's prices expressed in 1975 constant dollars.

The MIT analysis shows that the allowable costs for the photovoltaic system in the central utility environment are lower than those for both residences and schools.[20] As will be discussed in Chapter III, the balance-of-systems costs for a 10 MWp photovoltaic plant are expected to be a minimum of $0.38/Wp, leaving very little allowable cost for the photovoltaic array.

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[20] Some of this difference is accounted for by MIT as (1) the difference between the financing terms used in the residential and school analyses and the utility analysis and (2) the ability of the homeowner to shift his electricity loads to take maximum advantage of the photovoltaic system. The lack of a clear understanding of the buyback rate which most accurately reflects the value of dispersed generated photovoltaic power to the utility may also account for some of the differences. Because the residential and school analyses and the utility analysis used very different approaches, further analysis is required to quantify the causes of the different results.

MITRE Corporation Analysis

The MITRE Corporation, under contract to SERI, conducted a number of sensitivity analyses using the System for Projecting the Utilization of Renewable Resources (SPURR) Model. This model estimates the future market penetration of most solar energy technologies. A key element of the SPURR analysis is that solar technologies often compete with each other for the same markets. A detailed summary of the SPURR analysis is contained in Appendix J.

The MITRE analysis only considered photovoltaic systems in the central utility. Fuel savers, intermediate systems with storage, and semi peak systems with storage were all examined. Wind and solar thermal central receiver systems were the major solar competitors in the analysis. For the photovoltaic fuel saver, a fixed capacity credit equal to 37% of the nameplate rated capacity was assumed. Fuel savers of all types were not allowed to exceed 10% of the total nameplate system capacity in any one region.

Several insights into the effectiveness of the procurement initiative in accelerating the market penetration of photovoltaics in the utility sector resulted from the MITRE analysis. These include the following.

- The first commercial photovoltaic utility plant is not expected to be built until 1991, five years after the procurement initiative. At that time the effects of the initiative are expected to have dissipated.

- The procurement initiative is not expected to affect array prices below $0.50/Wp. Utility systems will require array prices of $0.20 to $0.30/Wp.

- Increases in expected purchases of photovoltaic arrays outside the electric utility sector improve the market penetration for photovoltaic utility systems in the early years. However, these sales would have to be for thin-film cells and occur when array costs have dropped below $0.50/Wp. The specific increase in outside sales examined was 20,000 MWp in the period 2000-2010.

- If the procurement initiative is aimed at the intermediate market, it will not provide any operating experience to utilities.

Market Demand Workshop

The working group concerned with electric utility grid applications developed no market estimates, since possible markets were believed to be well into the 1990 time period for photovoltaics.[21] The panel's opinion was that a suitable system demonstration to provide a data base for system planning would not come about, and photovoltaic prices would not be low enough to be economically viable within electric utility systems, until the 1990s. Thus, the panel concentrated on identifying technical, economic, and institutional issues that will be critical to the development of a photovoltaic market in electric utility grid applications.

The working group felt that the principal role of photovoltaics in grid-connected electric utility applications will be to save fuel. They also felt that, while theoretically possible, photovoltaics would not be provided capacity credits in system planning. Due to

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[21] See Appendix F for a description of attendees and a summary of the session.

a combination of technical and economic factors, the ultimate penetration limit of photovoltaics in satisfying utility power requirements would be on the order of 5%. This penetration, if realized at all, would not occur before the year 2000.

Industry representatives seemed to feel that a major problem with photovoltaics was the large land area requirement for even a modest-sized (5 MW to 10 MW) power substation. They generally agreed that roofs of residences and commercial/industrial buildings were acceptable sites for photovoltaic systems, as long as the electric utilities retain responsibility over control, dispatching, and maintenance of these dispersed facilities, regardless of ownership.

The working group strongly believed that a relatively long-term system test and application program--on the order of 10 years or longer--was essential for the development of this photovoltaic market. While utilities continue to be quite interested in new technologies, their planning cycles are 10 to 20 years. The risks of planning the installation of unproven technologies are great. Utilities will hesitate to incorporate new technologies, particularly if public utility commissions continue to exclude the financial risks of new technologies from the rate base. A relatively long-term utility system test and applications program would assist greatly in defining potential planning variables, as well as focus on and attempt to solve many major, critical institutional problems.

Major Uncertainties

A major uncertainty in the long-term markets is the exact prices at which photovoltaics will begin to penetrate these markets successfully. The MIT and MITRE analyses indicate that drastic photovoltaic price reductions will be required to compete in any of the grid-connected markets. The MIT analysis suggests that residences offer the most favorable economic conditions for photovoltaics. However, the relationship between the homeowner and the utility, particularly the buyback arrangment, has not yet been adequately defined to evaluate the exact economics of the photovoltaic residence. The MIT residential results are also based on a 20-year life-cycle cost analysis. Little information is available to support the reasonableness of this criterion. Historically, homeowners have weighted first costs more heavily than life-cycle costs in their purchasing behavior. However, life-cycle costs may determine the maximum that the homeowner would pay.

In the central utility market, the appropriate method for evaluating the worth to the utility is uncertain. The MIT analysis assigned a capacity credit to the photovoltaic system based on a detailed simulation. The workshop, however, suggested that no capacity credit would be assigned. It is possible that, as utilities gain experience with the impacts of photovoltaic systems, they will be more willing to give a capacity credit to photovoltaic systems in their planning.

The nature of the future competitive environment in grid-connected markets is also highly uncertain. A rapid escalation in electricity price would make it more feasible for photovoltaics to compete. As pointed out in the MITRE SPURR analysis, rapid escalation of conventional prices make a favorable competitive environment for all solar technologies. In all the long-term markets, the SERI Research Division review indicated that the other solar technologies are expected to compete with photovoltaics.

C. MARKET SCENARIOS

Uncertainty in the available descriptions of near-term, intermediate, and long-term potential markets requires that a range of potential market descriptions be considered in the venture analysis. Four market scenarios for the near-term and intermediate markets have been constructed by combining the range of market data presented in the previous section. Uncertainty in the descriptions of the long-term markets are handled through explicit sensitivity analyses of the escalation of electricity prices and breakeven prices in conjunction with the near-term and intermediate market scenarios.

Only those near-term and intermediate markets which appear to have significant potential are considered in the venture analysis. Many of the markets listed in Tables 5 and 6 are not large enough to have a noticeable effect on the development of the photovoltaic industry with or without the procurement initiative. Some markets have similar breakeven prices and photovoltaic system prices. These markets can, therefore, be consolidated into aggregated markets without loss of accuracy. Combining similar markets allows a simpler portrayal of market response.

Table 11 summarizes the potential market sizes and breakeven prices that define the four market scenarios to be considered. The breakeven prices and potential market sizes, as pointed out previously and in the description of the integrating model in Chapter IV, are the most important input parameters in characterizing how any market will develop. A higher breakeven price indicates higher costs of competitive systems. Photovoltaics, therefore, becomes a more effective competitor in the larger market scenarios. Market potential is the upper bound on potential sales and reflects the size of the market for which photovoltaics could compete.

TABLE 11
INITIAL (1977) BREAKEVEN PRICES AND MARKET POTENTIALS FOR FOUR MARKET SCENARIOS

MARKETS	Small Market Scenario		Moderate Market Scenario		Large Market Scenario		Very Large Market Scenario	
	System Breakeven Price ($/Wp)	Market Size (MW)	System Breakeven Price ($/Wp)	Market Size MW/yr.)	System Breakeven Price ($Wp)	Market Size (MW/yr.)	System Breakeven Price ($/Wp)	Market Size (MW/yr.)
1. U.S. Communications	20	2.5	20	2.6	20	2.6	26	2.7
2. U.S. Shallow Well Cathodic	35	.5	35	.7	35	.7	35	1.6
3. U.S. Deep Well Cathodic	11	.18	17	1	17	1.5	17	6.5
4. U.S. Outdoor Lighting	1.5	10	2.84	25	2.84	200	4	290
5. U.S. Government: DOD	0	0	4.3	4	4.3	8.5	4.3	86
6. U.S. Government: Non-DOD	6	.6	7	2	7	2	8	6
7. U.S. Consumer	4	1	6	1.8	6	1.8	20	3
8. Foreign Communications	10	1.7	20	2.5	20	4.5	27.5	10
9. Foreign Pumping: Low-Lift	3.5	10	3.5	20	3.5	37.5	4.25	75
10. Foreign Pumping: Medium-Lift	4	5	8	7.5	8	75	9	200
11. Foreign Deep Well Cathodic	15	.1	50	.75	50	.75	50	4.6
12. Foreign Remote Power	4	1	10	4	10	7.5	12	40
13. U.S. Grid: Sunbelt	1.05	390	1.05	390	1.05	390	1.05	390
14. U.S. Grid: Non-Sunbelt	.63	2145	.63	2145	.63	2145	.63	2145

Fourteen markets have been selected for inclusion in the analysis. Near-term U.S. markets are represented by a communications market and shallow well and deep well corrosion protection markets. Both the data from market studies and the workshop suggested that these were the most significant near-term markets in the United States. Near-term foreign markets are represented by a communications market and a well corrosion protection market. Again, both the market studies and the workshops support the assumption that they are the most significant near-term foreign markets.

Intermediate U.S. markets are represented by outdoor lighting, a Department of Defense federal market, a federal market for other applications, and a consumer market. It is believed that these four markets allow a fair representation of the U.S. intermediate market. Foreign low-lift pumping, medium-lift pumping, and remote power applications have been selected to represent the foreign intermediate market. While other intermediate markets may exist, these markets in combination allow ample flexibility for developing alternative intermediate market scenarios.

In all scenarios presented in Table 11, the assumption has been made that U.S. industry will be the dominant supplier in foreign markets. All market size estimates in the table reflect the assumption that 75% of the maximum potential of all foreign markets could ultimately be serviced by U.S. photovoltaic companies.

The small market scenario represents the possibility that the breakeven prices in the near-term markets are low and the size of the potential intermediate market is small. This market scenario can be supported by combining the most conservative market descriptions of both the market-demand workshop and the market studies.

The moderate market scenario has somewhat higher breakeven prices than does the small scenario. The size of the intermediate markets is also larger. U.S. and foreign intermediate markets are each approximately 30 MWp per year each. This represents a significant but still modest intermediate market.

In the large market scenario, the major changes are in the U.S. lighting market and the foreign pumping market. While the moderate market scenario might represent a sizable U.S. lighting market in isolated regions with high insolation and conventional lighting system costs, this large scenario represents a viable lighting market throughout the United States. Similarly, photovoltaics are assumed to be capable of competing with a large percentage of the conventional generator sales for medium-lift pumping abroad, and a major micro-irrigation market is assumed to develop. Breakeven prices in the large market scenarios are the same as those in the moderate scenario.

In the very large market scenario, the lighting market, the DOD market, and all the foreign intermediate markets are assumed to be very large. The breakeven prices have also been increased significantly. This scenario represents the possible existence of a large intermediate market which becomes competitive in the $4 to $12/Wp range.

It is difficult to label any one of these scenarios as a base case. Available data, however, do not support the very large market scenario. The other three scenarios are all thought to be possible based on available information.

D. MARKET WORKSHOP COMMENTS ON THE IMPACT OF THE PROCUREMENT INITIATIVE

In the market demand workshop, all four working groups, independently, concluded that the procurement initiative as proposed would not accomplish any significant market acceleration of the photovoltaic applications being considered that would not otherwise occur under the base plan.

Only two of the four principal applications for photovoltaics were believed to be economically viable in the near- and intermediate-term markets (through 1985) by the working groups (as previously discussed). These were remote communication repeater and cathodic protection applications for photovoltaics. As regards communications, the working group generally felt that photovoltaic markets would develop gradually as photovoltaic prices are reduced through current and ongoing technological developments. By contrast, the cathodic protection group felt that price was not the key variable for photovoltaic penetration of these applications. Thus, both groups generally felt that a large procurement with federal funds to effect a "demand-pull" would not significantly accelerate market development. Furthermore, the panels both felt that field experience with photovoltaic systems is presently being generated by the private markets, and government-subsidized sales are not necessary to keep the markets growing nor cause any noticeable additional market growth.

As regards photovoltaic applications in agriculture, the working group did not believe that the procurement initiative as proposed would have any effect on acceleration of these applications. The underlying reason for this judgment was the expectation that photovoltaic array prices would not reach the \$0.60/Wp to \$0.90/Wp price range until the late 1980s at the earliest and that market development through federal funding in the early 1980s would be too premature to make any significant impact in the late 1980s.

The electric utility representatives also felt that potential applications for photovoltaics were so far in the future that the proposed procurement initiative could not have any impact. There was a general feeling, however, that a program should be begun at a modest level and continued over a lengthy period of not less than 10 years to create the technical data base needed for utility planning, to assist in solving major institutional problems in the use of photovoltaics in electric utility systems, and to resolve overall market development issues.

Perhaps the most universal feeling from the working groups was that direct government involvement in market development by means of the procurement initiative would almost ensure poor results. The industry representatives all currently experience government involvement in product standards and other related issues, and almost all believe that government involvement has been a significant detriment to orderly economic development of their industries. As a result, the industry representatives were particularly wary of any government involvement in the marketplace. Thus, they felt that the proposed procurement initiative would not be helpful. In the event that the procurement initiative is implemented, the mechanism for distributing funds would require minimal industry investment for industry to participate in the program.

III. POSSIBLE INDUSTRY RESPONSES TO THE PHOTOVOLTAIC PROCUREMENT INITIATIVE

A. INTRODUCTION

According to the information memorandum proposing the federal initiative, photovoltaic technologies have progressed to the point where:

> The major issues are how best to stimulate the large investment in manufacturing facilities that is required to implement the projected cost reductions, and how to develop the infrastructure necessary to support a sustaining private market.[1]

The memorandum lists two alternative federal roles to perform this stimulation:

- Government-built advanced assembly lines to prove the feasibility of cost reduction; and
- Government initiatives to encourage industry to perform the required investment in manufacturing facilities and in infrastructure.[2]

Because "both the semiconductor and the solar industry operate in a highly competitive risk-taking environment," and are already investing, the memorandum recommends the latter federal role.[3]

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[1] DOE Information Memorandum to Under Secretary from Acting Program Director for Solar, Geothermal, Electric, and Storage Systems. Subject: A Strategy for a Multiyear Procurement Initiative on Photovoltaics (ACTS # ET-002), December 21, 1977, p. 2. (See Appendix L)

[2] Ibid.

[3] Ibid.

This chapter has two objectives. The first and primary objective is to determine if the procurement initiative is likely to stimulate large investments in manufacturing facilities which will lead to cost reductions and increased photovoltaic sales. The second objective is to provide some description of the conditions under which a photovoltaic plant could produce modules at prices of $2/Wp and to identify the nonmodule costs including marketing/distribution costs and balance-of-systems hardware costs and prospects.

The likely influence of the initiative on the decision of a private company to invest or not invest in new low-cost technology for manufacturing photovoltaics is examined in Section B. This section is primarily a discussion of the factors influencing investment in new technologies. A government procurement initiative, if it is to have any commercialization effects, must work by modifying these investment factors.

Section C summarizes the results of a workshop composed of current participants in the photovoltaic industry. The objective of the workshop was to obtain industry perceptions of the events necessary for rapid development of the photovoltaic industry. These perceptions form a second perspective from which to examine the likely effectiveness of the proposed initiative.

Section D is a summary of an independent assessment of the probabilities of reaching the photovoltaic program price and output goals, with and without the proposed initiative. The assessment was performed by a market analysis and forecasting firm specializing in the semiconductor industry (Gnostic Concepts, Inc.). This provides a third perspective from which to judge the initiative's potential effectiveness.

Section E adds concrete information to the discussion of investment by describing the capital cost and revenue requirements for a specific point design for a plant to produce low-cost arrays. The emphasis is on the relationship between amortization period and required selling price. In addition to specifying capital cost and revenue requirements, this section identifies and gives some estimate of the impact of nonarray and nonhardware costs on prospective photovoltaic prices. All of those costs must be considered in making an investment decision.

An important determinant of the ability to sell photovoltaic power systems is the nonarray portion of system cost, addressed in Section F. This importance derives from the growing proportion, as array prices fall, of overall system cost that is "balance-of-system," and from the already commercial nature of the nonarray components. The first consideration means that balance-of-system costs will rank increasingly large in the economic decision to adopt photovoltaics. The second point reinforces the first--the balance-of-system components are not new technology and are unlikely to experience the same reductions in cost as those expected for arrays.

Section G provides a synthesis and integration of the analyses of likely vendor response to the initiative.

B. DEMAND PULL AND VENDOR RESPONSE

The expressed purpose of the proposed photovoltaic procurement initiative is to "accelerate by several years the introduction of photovoltaic systems into the marketplace."[4] There are three distinct private responses required for the initiative to stimulate a substantial increase in photovoltaic sales.

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[4] Ibid, p. 1.

> First, it is necessary that vendors respond to the initiative by making investments in cost-reducing production facilities they otherwise would not make.
>
> Second, the reductions in manufacturing cost must be passed along to buyers as reductions in selling price, and not absorbed in either rapid investment writeoffs or increased profit margins.
>
> Third, the reductions in selling price must lead to large increases in private purchases of photovoltaic power systems. (The Information Memorandum envisions specialized near-term markets of 100 to 200 MW per year.) That is, demand for photovoltaics must be price elastic.[5]

This section addresses the first required response. The second response is addressed in Section D of this chapter (and to some extent here). The third response is addressed in Chapter II on photovoltaic markets.

The Setting for the Investment Decision

In predicting the potential responses of vendors, either to current technology/market conditions or to the initiative, it is reasonable to assume that vendors will make decisions based on their expectations of short and long-term profit potential and of risks associated with investments in cost-reducing photovoltaic production equipment. The determinants of these expectations in the first instance are:

- The degree of confidence that markets will exist of sufficient size and duration to amortize new equipment investments and to earn an adequate profit; and

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[5] Ibid.

- The degree of confidence that production equipment available in the near term will actually produce cost reductions if purchased and used.

It is important to note that the realized size of the market and realized cost reductions are closely interrelated. Obviously, markets for electricity exist. The questions investors are faced with are: (1) What price will photovoltaic systems have to reach before they will be purchased in particular market segments? (2) How large are the sales of photovoltaic systems likely to be in those markets? (3) Can current and near-term production equipment reduce costs of photovoltaic systems (largely array costs) to reach those necessary prices? (4) Given the answers to 1-3, can current and near-term production equipment and necessary plant facilities be purchased at investment cost that will amortize the plant and return a satisfactory profit? (5) Are there any potential (advanced) photovoltaic technologies (or other energy technologies) which may render near-term investments obsolete and unprofitable?

Market Factors

One of the critical issues raised by an August 5, 1977, discussion draft of a similar market pull approach was: "Future photovoltaic markets are not sufficiently well perceived by industry to provide the incentive for desired commercial investment."[6] One factor causing this perception by industry is the sparseness of studies on photovoltaic markets and the preliminary nature of the available studies. The studies are not a sufficient basis for a firm to make a good sales forecast for its own photovoltaic product or for the industry as a whole.

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[6] This comment was taken from slide three of a briefing entitled "Special Topic PV Program Plan Comments," Department of Energy, September 21, 1977.

From the vendor's point of view, an adequate sales forecast is the start of an investment analysis, and its absence means a reasoned decision to invest based on expected revenues and costs cannot be made. Investment in this circumstance would involve the assumption of risk without assurance of adequate reward. The procurement initiative does little to alleviate vendor's uncertainty about commercial markets, and thus fails to address, or addresses only weakly, one of the major impediments to significant private investment in cost-reducing technologies.[7]

Technology Factors

In general, market uncertainty is more of an impediment to investment in new cost-reducing equipment than is technological uncertainty. The JPL SAMICS model (see Section E) and industry

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[7] The discussion below of the investment decision environment employs the term "risk" and "uncertainty." Both terms pertain to a situation in which future outcomes are unknown, but they differ in degree. Risk describes a situation in which a probability distribution may be assigned to the range of possible outcomes. Under certainty, the relative probabilities of different outcomes, and perhaps even the range of outcomes, are unknown. As a practical matter, the difficulty of reaching a correct decision varies inversely with the availability of appropriate information, and uncertainty may be considered an aggravated form of risk.

A decision with respect to the initiative can deal with the related uncertainty with respect to the size of intermediate markets in either of two ways. First, the decisionmaker can attach his own subjective probabilities to various outcomes and use those in an analysis of the worth of the initiative. This process was employed in several quarters within DOE and led to different conclusions (and, in fact, to the venture analysis). A second approach accepts the dispersion in expected market sizes and performs related sensitivity analysis on the conclusions. As reported in Chapter V, the venture analysis examined four intermediate market scenarios (with 14 separate markets) in which intermediate markets are small, moderate, large, and very large. This approach permits identification of the conditions under which the initiative would be desirable.

opinion indicate that an automated factory could produce silicon flat-plate arrays in quantities of 5 MW per year or more at a cost on the order of $2/Wp, depending on the price of silicon and the investment amortization time assumed. Other technologies such as concentrators might result in equal or even lower costs. However, maintenance requirements of concentrators may favor the flat-plate technology for near-term and intermediate markets.

The critical question is not whether a $2/Wp plant can be built, but whether industry will be motivated to make investments in large-scale production facilities. These facilities represent major departures from, rather than gradual evolution of, the small-scale facilities currently used to manufacture arrays. They also represent a major increase in the fixed portion of total production cost and a commitment to a technology that is still advancing. Hence, the technological uncertainty is whether a $2/Wp plant will rapidly become obsolete as photovoltaic technology advances, and thereby produce financial losses.

Risk

Two major uncertainties facing potential investors in photovoltaic production facilities have been identified. These uncertainties increase the risk to a firm in making an investment. As the risk or probability of loss involved increases, there is less of a propensity to undertake the investment for a given reward. The potential for loss is carefully addressed by corporate management before they commit to large capital investments. In evaluating the effectiveness of the procurement initiative in inducing such commitments, the relative risks and rewards to a vendor from alternative government actions must be investigated.

Some insights can be gained by comparing what firms may gain or lose by a decision to invest versus a decision not to invest in new photovoltaic production equipment. The risks incurred by a firm that invests today in new capital equipment for photovoltaic array production would include the following:

- The risk that markets won't materialize or will materialize more slowly than expected. This may lead to lower than desired profits or to losses.

- The risk that an R&D breakthrough in photovoltaic technology will make current capital investments obsolete before they are amortized. Technology breakthroughs are being actively pursued by government and by private companies.

- The risk that, for a given market size, too many competitors will invest in new capital equipment, resulting in sales volumes or selling prices that are too low to realize a profit.

The combined effect of these separate risks is to increase the overall financial exposure and risk of the investing firm.

In return for assuming these risks, what does the investing firm obtain? Basically, the firm obtains a position in short-term markets for photovoltaics (e.g., remote communications), and a chance to establish a position in intermediate-term markets (e.g., outdoor lighting and agricultural water pumping). In general, a position in these markets is desirable only if the firm can make a reasonable profit or if it opens the door to a good market position in large long-term markets (i.e., grid-connected applications). Some companies and observers feel it is unlikely that flat-plate, single crystal silicon technology will penetrate these markets.[8] Whether or not this proves to be the case, the uncertainty itself greatly reduces the motive for heavily investing in present-technology equipment to produce silicon arrays for small-size, short- and intermediate-term markets.

In contrast, what risks are taken by a firm that does not invest in new photovoltaic array production equipment? For the large firm, the only risk is that the firm will be foreclosed from significant sales of photovoltaic systems in the future. In fact, this is not a large risk. Most of the large electronic companies (e.g., Motorola, RCA, Texas Instruments), and small photovoltaic companies backed by large parent corporations (e.g., Solar Power, ARCO-Solar, Mobil Tyco) have the technical, financial, and marketing resources to enter the market rapidly once the prospects are attractive. To these companies, being a "fast second" may be a better strategy than being first and incurring innovators' costs, such as technology acceptance and market development, on which other firms will "free-ride."

For small firms without a large parent corporation, the situation is different. First, the existence of larger firms is a risk to them, in that larger firms may undercut prices or otherwise adversely affect the smaller firm's sales. Second, the small photovoltaic firm may be more dependent on photovoltaic sales as a source of company revenue, and thus find short and intermediate-term markets both attractive and necessary. However, these

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[8] For example, this view was expressed in a May 1, 1978, letter from J. Fred Bucy, President of Texas Instruments, to John M. Deutsch, Director of the Office of Energy Research of DOE. EPRI seems to hold a similar view, given its studies and comments in a letter dated August 29, 1977, from John E. Cummings, EPRI to H. H. Marvin, Director, Division of Solar Energy, ERDA. This concern is also raised in a letter of August 30, 1977, from Arnold Cherdak, MITRE Corp., to H. H. Marvin, Director, Division of Solar Energy, ERDA.

smaller firms have much less risk-bearing potential and may be reluctant to risk their financial solvency via heavy investments in new equipment for markets that are not well defined. The relatively labor-intensive production technology of the current small firms is a rational adjustment to this environment. Further, small firms generally do not have the marketing power to develop reluctant markets, and available evidence indicates intermediate-term markets may not appear spontaneously, but will have to be cultivated and developed.

The procurement initiative will do little to reduce the risk faced by firms considering heavy investment in current-technology photovoltaic production equipment. If the existence of intermediate-term markets cannot be demonstrated, the initiative may be insufficient to stimulate investment. On the other hand, there is little in the photovoltaic procurement initiative to increase the risk of a firm that does not participate. The firm will have the option of entering the photovoltaic market when market uncertainty is reduced, with little loss of strategic market position.

Supporting Analysis

The preceding discussion is supported by an analysis performed by the Jet Propulsion Laboratory and Gnostics Concepts, Inc. on photovoltaic industrialization.[9] They point out that there are three key dimensions of a new investment: (1) Does it require a new technology? (2) Does it require a new product? (3) Does it require new marketing and distribution practices? Firms prefer to deal in an investment climate where the answer to only one of these three questions is affirmative. To obtain large market

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[9] See Appendix K, The Industrialization of Photovoltaic Systems, prepared by the Jet Propulsion Laboratory.

sales, a photovoltaic firm will be faced with affirmative answers to all three questions. If the JPL/Gnostics analysis is correct, the incentive to investment in photovoltaics will be reduced because of the increased complexities and risk of managing a new investment simultaneously involving a new technology, a new product, and new markets. The initiative does little to reduce these risks incurred by a firm accelerating a new product based on a new technology in new markets.

The JPL/Gnostics analysis also highlights the effect of rapid technological change on investment behavior. The effect of rapid technological advance is to delay capital investments and bias those that do take place toward labor-intensive equipment and processes.

To quote from an internal JPL report:

> Finally, the fact that the photovoltaic industry is anticipated to exist in an environment of rapid technological advance has important implications for the capital intensity of the production process adopted by firms. In a regime of rapid technological change it is optimal, from the firm's point of view, to invest less (possibly much less) in capital equipment than in a regime of stable technology. That is, the firm keeps the line flexible to allow adaptation to technological change by incorporating a labor intensive process. This was the experience of the early semiconductor industry and is the experience of current photovoltaic suppliers. Only after the technology stabilized did the semiconductor industry switch to more efficient, highly automated, capital intensive production processes. Furthermore, this is precisely the reaction to anticipated technological change which is socially optimal--it prevents the waste of costly capital equipment.[10]

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[10] "Historical Evidence of Importance to the Industrialization of Flat-Plate Silicon Photovoltaic Systems," LSA Project Task Report, prepared for the Department of Energy by Jet Propulsion Laboratory, April 1978.

Supporting Commentary

The discussion above is based upon commonsense notions of business behavior and on the rational economic firm which trades-off risk and return from various courses of action. While many business and economic studies have verified the importance of the above factors, useful and relevant corroboration is contained in the comments of knowledgeable industry members or observers. The comments are responses to a solicitation by H. H. Marvin for comment on the Photovoltaic Program Plan Restructure, August 5, 1977.

The letter soliciting comments noted:

> The key assumption in undertaking this reorientation (of the Program Plan) is that the market will enter an explosive self-sustaining growth phase at an array price of $1 to $2 per peak watt.[11]

The restructured plan stated:

> The program plan concentrates on load center applications as a vehicle for:
>
> - Providing a demand pull as an incentive for expanded, automated low-cost production capacity.
>
> This strategy places primary emphasis on creating a market demand for photovoltaic systems through a series of highly visible, load center experiments. . .These applications are intended to stimulate potential user involvement in order to provide a growing market and thereby stimulate

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[11] Letter from H. H. Marvin, Director, Division of Solar Energy, ERDA, August 5, 1977.

> industry investment in production capacity and also encourage the development of an industry infrastructure for the delivery and service of photovoltaic systems.
>
> . . .
>
> Federally supported load center applications will cause market volume growth thus pulling through automated (lower cost) production techniques.[12]

The relation of the Program Plan Restructure to the currently proposed initiative, and thus the relevance of the solicited comments to the venture analysis, are obvious. Selected comments on the risks, particularly market risks, perceived by vendors include:

> One way to stimulate the investment of private capital for such (photovoltaic production) facilities would be to demonstrate the existence of a substantial market into which the cells produced at \$2/W could be sold following the establishment of the 20 MW annual production capability in 1980, especially since projected ERDA expenditures shown in the plan taper off. We believe, however, that a market of sufficient size has not yet been described either by the results of our own efforts or by those of other ERDA contractors, and as a result, sufficient private capital will not be forthcoming unless additional markets are uncovered and described.[13]
>
> * * *
>
> In order for industry, large or small, to invest its dollars in capital equipment, they must see a market. . . .A 24 million dollar market, or even twice

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[12] Discussion Draft, restructured Photovoltaic Program Plan distributed for public comment, August 5, 1977. Quotes are from Section 3.2, Program Strategy.

[13] August 26, 1977 letter from H. T. Johnson, General Manager, Westinghouse Corporation, to H. H. Marvin, Director, Division of Solar Energy, ERDA.

> that, still lends itself to a lot of hand fabricated parts and very little automation. At the present level of production and even at the 24 or 50 million dollar level, not much is going to be done other than what we are presently doing. An industry really needs to see a continuing market in excess of 100 million dollars with the prospect of billions of dollars in order to start large-scale capital investment.[14]

* * *

> A 25 to 50 MW market at $3/W is not adequate to justify the capital investment identified in our JPL contract analysis. . . .[15]

* * *

> It seems highly unlikely that present day, relatively small, solar cell manufacturers will invest in such additional production capacity unless a very strong market demand exists beyond their current capacity ("demand-pull"). It might be argued that large semiconductor manufacturers' entry into the market could produce this result, but I don't believe that this will happen until their market research convinces them that a suitable (large) profit can be made. I would think that market research for an as yet nonexistent market is highly uncertain. This would tend to make large companies hesitant to spend significant amounts of capital equipment funds on such a venture. Besides, a manufacturer would not invest a great deal of such funds unless he were sure that advances in technology (Si vs. thin-film) would not render his equipment (and production schedules) obsolete.[16]

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[14] August 31, 1977 letter from Irwin Rubin, General Manager, Sensor Technology, Inc., to H. H. Marvin, Director, Division of Solar Energy, ERDA.

[15] August 19, 1977 letter from Robert McGinnis, Manager of Solar Operations, Motorola, Inc., to H. H. Marvin, Director, Division of Solar Energy, ERDA.

[16] August 26, 1977 letter from Ronald Wichner, Electronics Engineering Dept., Lawrence Livermore Laboratory, to H. H. Marvin, Director, Division of Solar Energy, ERDA.

However, it is extremely questionable if a private market of any extent exists at that ($1 to $2/W array) price. If private industry instead of a federal agency was risking the sums involved (in the restructure of the photovoltaics program plan discussion draft), they would retain economic and market experts to make a market survey in advance.[17]

* * *

. . . we wish to register our opinion that during the next three to five years the real dollar growth of this private sector market will not by itself justify (or supplement to a really significant degree) an expansion of production capacity on the scale or the time table established by ERDA. We accordingly urge that if significant production expansion and cost reduction is desired, that U. S. policy not rely (during the next three to five years in particular) on the private sector, DOD or foreign demand to sustain our industry through any "pauses" in ERDA demand.[18]

* * *

With respect to barriers to small manufacturers in the photovoltaics area; being small manufacturers and capital-limited, they need to have tangible evidence that a market exists and will exist long enough for them to recover their investment and also be profitable.[19]

* * *

We urgently need: grassroots surveys which obtain fresh data from actual users on true life-cycle costs of alternate power sources as they relate to our price

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[17] August 22, 1977 letter from Leonard Liebermann, Professor of Physics, University of California at San Diego, to H. H. Marvin, Director, Division of Solar Energy, ERDA.

[18] July 15, 1977 letter from Gary D. Wrench, President of Spectrolab Inc., to H. H. Marvin, Director, Division of Solar Energy, ERDA.

[19] September 1, 1977 letter from John Heldack and Joseph Feinstein, Varian, to H. H. Marvin, Director, Division of Solar Energy, ERDA.

entry points. To use an analogy, most of the present surveys do little more than tell us that an enormous market exists for large, high-quality color T.V. sets at $50.00 each. No one disputes it, but it is not useful. The Nebraska survey was a good, if qualitative start.[20]

* * *

In 1980--when decisions by industry will have to be made to turn to automated, capital-intensive, new technologies--the total industry sales (annual production times array price) shown in Table 3-3 of the restructured photovoltaics program plan discussion draft, will be essentially made up of government purchases of about $40 million. Yet, according to Maycock and Wakefield (Eleventh IEEE Photovoltaic Specialists Conference, 1975, pp. 252-55), large companies in the United States would be unlikely to invest in production of photovoltaic devices until annual sales of $50 to $100 million can be assured. From the annual revenue aspect then, in 1980, photovoltaics will be in a marginal position to attract investment by large companies.[21]

* * *

We doubt, however, that the $2/peak watt goal with 20 peak megawatts annual production capability can be achieved by 1980. First, it seems unlikely that photovoltaic device manufacturers will install the necessary production equipment without a guarantee of product markets. The government cannot give this guarantee unconditionally, and the ERDA-sponsored market studies have not identified markets as large as the ERDA goals. Furthermore, achieving this production capability would probably require that

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[20] August 24, 1977 letter from Robert O. Johnson, Manager of Marketing, SES, Inc., to H. H. Marvin, Director, Division of Solar Energy, ERDA.

[21] August 29, 1977 letter from G. Mervin Ault, Director of Energy Programs, NASA, to H. H. Marvin, Director, Division of Solar Energy, ERDA.

> production equipment be ordered immediately, even though the choice of technology to use still needs to be made.[22]

In general, the comments underscore the argument of the rational firm outlined above, and point out that there is considerable uncertainty about markets, making sound investment decisions hard to reach. With a high degree of market uncertainty, the potential risks of current investment in cost-reducing photovoltaic production equipment may outweigh the potential rewards in vendors' minds. When one also considers the risks of technological advance making current investments in photovoltaic production capital obsolete, it is difficult to see why a firm would invest heavily in new capital equipment in the near term. The initiative does little to insure an investing firm against these risks and a firm would seem to have little to lose by waiting to see if (and how) technology advances and whether markets develop.

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[22] August 29, 1977 letter from John Cummings, Electric Power Research Institute, to H. H. Marvin, Director, Division of Solar Energy, ERDA.

C. THE RESULTS OF THE PHOTOVOLTAIC SUPPLY WORKSHOP

Another avenue to assessing photovoltaic vendor response is to question members of the industry directly. This approach was taken through a photovoltaic supply workshop. The objectives of the workshop were to obtain (1) expected responses of the photovoltaic industry to the federal initiative, and (2) expected actions of the industry in the presence of continued federal research and development (R&D) without the initiative. The workshop was structured as a "cross-impact analysis" (described below) by the Monsanto Research Corporation (MRC), who conducted the workshop but did not participate directly. Details of the approach and results are contained in Appendix G.

The participants in the workshop and their areas of expertise are shown in Table 12. The participants represented a range of array technologies, including silicon, thin-film, gallium arsenide, cadmium sulfide, and concentrators as well as manufacturers of semiconductor production equipment and silicon materials. This range represents the current state of the supply industry.

The first step of the workshop was to reach consensus on the 30 events most critical to the future development of the photovoltaic industry. The 30 events chosen are shown in Table 13. After the 30 events were chosen, the participants were asked to agree on when the event would most probably occur under three sets of alternative government actions (the base case R&D program, the federal initiative, and a doubling of the R&D program without the initiative). This process was used to estimate the years in which the occurrence of the event is 25% probable, 50% probable, and 75% probable, respectively. The participants showed unusually high agreement (according to MRC) concerning the timing of these events. The span between the 25% and 75% probabilities was

TABLE 12

PARTICIPANTS FOR SERI PHOTOVOLTAIC VENTURE ANALYSIS SUPPLY WORKSHOP

Representative	Title	Company	Expertise
Bob McGinnis	Operations Manager, Solar Energy	Motorola	Large Company Manufacturing Single Crystal Silicon Modules
Ted Blumenstock	Director of Marketing	Solarex	Small Company Manufacturing Single Crystal Silicon Modules
Bob Weinberg	Director, Electronic Business Development	RCA	Potentially Large Supplier; Research Activities in Thin-Film Silicon
A. I. Mlavsky	Exec Vice President, Solar Energy Corporation	Mobil Tyco	Research Activities in Ribbon-Grown Single Crystal Silicon; Oil Company Backing
John Jordan	Consultant to Photon Power and Founder	Photon Power	Cadium Sulfide Solar Cells
Pesho Kotval	Manager, R&D Materials	Union Carbide	Polysilicon Material
Anthony Bonora	Vice President, R&D	Siltec	Equipment for Photovoltaic Cell Manufacture
John Heldack	Corporate Director of Marketing	Varian	Gallium Arsenide/Concentrators; Equipment for Photovoltaic Cell Manufacture

TABLE 13

RESULTS OF THE SUPPLY WORKSHOPS: EFFECTS OF VARIOUS FEDERAL ROLES ON YEAR BY WHICH EVENT IS 50% PROBABLE

Event Number	Event Objectives	Base Case	Federal Initiative[a]	Double[b] Federal R&D
1.	$2/Wp Photovoltaic Module (FOB Plant Price, Constant 1975 Dollars)	1983	+1	+1
2.	$0.50/Wp Photovoltaic Module (FOB Plant Price, Constant 1975 Dollars)	1989	+1	+1
3.	100 MWp/year Photovoltaic U.S. Production at $2 to $3/Wp Sustained Commercial Market (Non-Government)	1982	0	-2
	Federal Roles			
4.	Federal Initiative ($380 Million Federal Purchases over Eight-Year Period)	--	--	--
5.	Base Case Federal Photovoltaic Support Program	--	--	--
6.	Doubling of Federal R&D Support without Federal Initiative	--	--	--
7.	Government-Owned Photovoltaic Capacity, 25 MW/Year Total	*	--	--
8.	25% Investment Tax Credit for Photovoltaic Producers and Near-Term End-Users	1981	0	0
9.	$100 Million/Year Foreign Aid Dedicated to U.S. Photovoltaic Purchases by Developing Countries	1983	0	0

a. Years by which event is accelerated by the initiative
b. Years by which event is accelerated by doubling federal R&D

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* Maximum probability is 25%.

TABLE 13 (Continued)

Event Number	Event Objectives	Base Case	Federal[a] Initiative	Double[b] Federal R&D
30.	Long-Term Federal Photovoltaic Commitment ($0.50 to $1 Billion/ Year for Five to Ten Years)	**	--	--
10.	Photovoltaic Dealer/Installer and Channels of Distribution Infrastructure Established	1986	+2	0
11.	$50 to $100 Million Capital Investment by Photovoltaic Industry	1984	+2.5	+0.5
12.	$0.50 to $1 Billion Capital Investment by Photovoltaic Industry	1992	+6	-1
13.	Corporate R&D Doubled to $100 Million/Year for Photovoltaic	1984	+2	+3
	Competition			
14.	Privately Funded Breakthrough in Photovoltaic Devices with Low Cost (<$0.50/Wp) and High Efficiency at 10 MW	1988	+4	+3
15.	A Cheap, Efficient, Solar Thermal Device for Power Is Developed and Demonstrated (Competing with Intermediate Photovoltaic Market--Off Grid)	1995	0	0
16.	Oil Price Reaches $22/bbl (1975 Dollars)	1984	0	0
17.	One Company Has 40% Share of at least $100 Million Total World Market	1985	+1	+1

**This event was not voted upon because it was reviewed as an alternative to the three federal roles (events 4-6) rather than an addition to them.

TABLE 13 (Continued)

Event Number	Event Objectives	Base Case	Federal[a] Initiative	Double[b] Federal R&D
	Market			
18.	A Favorable Action by U.S. Utilities and PUCs toward Direct Hookup of Photovoltaic System with Existing Power Grid [e.g., Marginal Cost Pricing, Photovoltaic Power from Users, Interconnect to Hybrid (PV + AC Grid) Systems]	1986	+3	0
19.	A Photovoltaic Market Size of 500 MW/Year with a Projected Annual Growth of 20% to 50%	1988	+2	+1
	Political			
20.	Reevaluation of Government Program Which Defines Photovoltaic as a Long-Range Option Only	*	--	--
21.	Solar Coalition Influences Congressional Action	1980	0	0
	Other			
22.	Major Energy Catastrophe (e.g., Second Oil Embargo or Major Nuclear Accident)	1984	0	0
	Technical/Economic			
23.	Low Costs (Corresponding to $0.50/Wp) Achieved for Balance-of-System (BOS): a. Semiconductor Inverters b. Transformers c. Regulators d. Battery ($20/kWh) e. Structure Cost	1987	+1	0

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*Maximum probability assessed to be 38%.

TABLE 13 (Continued)

Event Number	Event Objectives	Base Case	Federal[a] Initiative	Double[b] Federal R&D
24.	Ready Availability of Low-Cost ($10/kg) Solar Grade Polysilicon	1984	+1	0
25.	Licensable Technology for High-Efficiency, Low-Cost Amorphous or Thin-Film Cells is Demonstrated and Shown to Be Profitable in High Volume ($0.50/Wp)	1991	+1	+3
26.	15% Efficient Solar Cells Profitably Produced on Silicon Substrate at Low Cost ($0.50/Wp)	1986	0	+2
27.	Acceptable Probability of 20-Year Photovoltaic System Life Outside Labs	1982	0	0
	<u>Legal/Regulatory</u>			
28.	Deregulation of Some Energy Prices	1984	0	0
29.	Broadly Accepted Standards for Product and Warranty	1982	-.5	-2.5

usually only two to three years. The cumulative probability of the selected events is also shown in Table 13. The events are not listed in order of importance.

Using the probability of occurrence curves for the various events under the base case, the years by which occurrence of an event was 50% probable were selected and used to sort the events in a chronological order. The list of sorted events for the base case is shown in Table 14.

The same analysis was performed using the probability of occurrence assuming curves in the federal initiative to be implemented. The altered chronology is also shown in Table 14. Some of the most conspicuous changes in expectations were:

Accelerated by six years:

- $0.5 to $1 billion private investment (from 1992 to 1986)

Accelerated by three to four years:

- cost breakthrough achieved by private R&D (from 1988 to 1984)
- favorable response to grid hookups by utilities and PUCs (from 1986 to 1983)

Accelerated by two to two and one-half years:

- $50 to $100 million private investment (from 1984 to mid-1981)
- achievement of total market of 500 MWp/year (from 1988 to 1986)
- doubling of corporate R&D to $100 million per year (from 1984 to 1982)
- photovoltaic infrastructure established (from 1986 to 1984)

TABLE 14

RESULTS OF THE SUPPLY WORKSHOP: YEAR BY WHICH OCCURRENCE OF EVENTS KEY TO THE DEVELOPMENT OF PHOTOVOLTAICS IS 50% PROBABLE

Under Base Case Federal Role, Event is 50% Probable by	Key Event	If Initiative is Implemented, Event is 50% Probable by
1980	21 Solar Coalition Influences Congress	1980
1981	8 25% Tax Credit Enacted	1981
1981	20 38% Chance Government Reevaluates to Long-Range Option	*
1982	3 100 MW/Year Market at $2 to $3/Wp Commercial	1982
1982	27 20-Year Photovoltaic Life Accepted	1982
1982	29 Product and Warranty Standards	1982
1983	1 $2/Wp Module Price	1982
1983	9 $100 Million/Year Foreign Aid Program Enacted	1983
1984	11 $50 to $100 Million Capital Investment by Industry	Mid-1981
1984	13 Corporate R&D Doubled to $100 Million/Year	1982
1984	16 Oil Reached $22/bbl	1984
1984	22 Major Energy Catastrophe	1984
1984	24 $10/kg Polysilicon	1983
1984	28 Partial Energy Deregulation	1984
1985	17 One Company Gets 40% of at least a $100 Million/Year Market	1984

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* This event and the initiative were considered mutually exclusive.

TABLE 14 (Continued)

Under Base Case Federal Role, Event is 50% Probable by		Key Event	If Initiative is Implemented, Event is 50% Probable by
1986	10	Photovoltaic Infrastructure Established	1984
1986	18	Utilities/PUC Favorable to Grid Hookup	1983
1986	26	15% Effective Silicon Sheet at $0.50/Wp	1986
Mid-1987	23	Low-Cost Balance-of-System Price Achieved	1986
1988	14	Private Photovoltaic Breakthrough	1984
1988	19	Photovoltaic Market 500 MW/Year 20% to 50% Growth Rate	1986
1989	2	$0.50/Wp Module Price Reached	1988
1991	25	Thin-Film Silicon at $0.50/Wp	1990
1992	12	$0.50 to $1 Billion Capital Investment	1986
1995	15	Solar Thermal System Preferred	1995

Implementation of the federal initiative accelerated the 50% expectation of occurrence of the following events by only one year:

- achievement of $2/Wp modules (to 1982)
- achievement of $0.50/Wp modules (to 1988)
- emergence of one company with at least a 40% share of a market over $100 million per year (to 1984)
- achievement of low-cost photovoltaic balance-of-system costs (to 1986)
- achievement of $10/kg polysilicon material (to 1983)
- achievement of $0.50/Wp thin-film silicon modules (to 1990)

Cross Impact Voting

On May 17 the workshop participants were asked to reach consensus (through a consensor voting machine) on the impacts of each event on every other event listed. For example, participants were told to assume that event 1 had already occurred. Given that occurrence, what impact would it have on events 2 through 30? Impacts were rated on a scale of -8 (almost certainly prevents occurrence of the event) to +8 (is essential to success of the event). The answers were compiled in a cross-impact matrix. The full matrix is presented in Appendix G.

Of the possible federal roles considered, the panel assigned the following relative positive influences on the development of photovoltaics (in decreasing order of importance): long-term federal commitment (event 30), federal initiative (event 4), 25% investment tax credit (event 8), doubling federal R&D without the initiative (event 6), and base case federal role (event 5). The federal reevaluation of photovoltaics as only a long-range option (event 20) was believed to be a critical impediment to the photovoltaic business. The government-owned photovoltaic plant (event 7) was a controversial event. Some believed the plant would succeed and be beneficial to the current industry. Others were certain it would fail and hurt the industry and perception of the viability of photovoltaics. The foreign aid (event 9) mechanism for photovoltaics was not believed to have much influence on photovoltaic industry or market developments. Doubling of corporate R&D (event 13) was judged to have a stronger influence than doubling of federal R&D (event 6).

The solar coalition (event 22) was a strongly positive event, almost equal to that of the federal initiative. While oil at $22/bbl (event 16) and a possible major energy catastrophe (event 21) were strongly positive events, deregulation of some energy prices (event 28) was not. Favorable action by utilities toward grid hookup of photovoltaic systems (event 18) had a moderately strong impact. Low balance-of-systems costs (event 23) were judged not too important relative to the other 29 selected events. A possible competing solar thermal device did not have much influence on future photovoltaic trends. Other strongly positive events were $0.50/Wp module price, $0.50/Wp thin-film or sheet silicon modules, and achievement of a 100 MW/year commercial market.

The 30 events, their probabilities, and the cross-impacts compiled by the workshop participants were analyzed using a computer (proprietary to MRC) program to identify the effects of cross impacts of the events under the three cases: the federal initiative, the base case federal role, and a doubling of federal R&D without the initiative.

For all three federal roles, this analysis indicated that the solar coalition (event 22) and the 25% investment tax credit (event 8) were the most important events (after the particular federal role) in starting and maintaining a successful chain of events for photovoltaics. These two political events were consistently more important than either market events or technical/economic events. This result does not imply that the latter events are not important. It merely indicates that the key events (assuming a given federal role) are the solar coalition and 25% investment tax credit. The primary intuitive reason for this dominance is their early expected occurrences (relative to the other events) coupled with the high cross-impact rates.

Other Observations

A number of other observations, not directly related to the formal cross impact analysis results, are relevant to interpreting the supply industry's input to the study.

First, the participants exhibited a uniformly positive outlook toward photovoltaics. Of the 27 events selected directly by the participants, only three were negative [i.e., solar thermal device (event 15), government reevaluation of photovoltaics as a long-range option only (event 20), and the government-owned photovoltaic plant (event 7)--for those panel members who thought it would fail.] Monsanto Research Corporation stated that, in their experience, positive and negative events usually appear in roughly equal proportions.

Second, during the discussion of the scenario under which the events were chosen, several of the participants pointed out that the photovoltaic market was a world market and not restricted to the United States. In fact, in the discussion of the scenario for the workshop, the phrase "the non-U.S. photovoltaic market is larger than the U.S. market and growing initially faster," was added. The developing countries were mentioned as potential near-term markets for rural electrification and agricultural pumping.

Third, the spread between the 25% and 50% probability of occurrence of most events and the 50% and 75% probabilities was only one year. Events where the occurrence probability was less certain, indicated by a broader curve spread, were: 10 and 12 (uncertain industry responses); 15, 16, 18, and 21 (events outside industry control); and 26 (a technical event on silicon).

Fourth, the participants unanimously endorsed the inclusion of a fourth federal role: A long-term federal photovoltaic commitment ($0.5 to $1.0 billion/year for five to ten years). The cross-impact voting, assuming this event had occurred, was uniformly positive with large votes. However, there was some divergence in the voting. Finally, while the panel exhibited an unusual unanimity on most of the cross-impact votes, there were a number of votes in which the panel divided and were unable to reach a concensus. These divergent votes and the differing viewpoints on each are summarized in Appendix G.

Assessment

The supply workshop provides additional qualitative insights on possible effects of the initiative. However, several caveats should be kept in mind. First, the participants in the supply workshop dealt with key events and responses for the industry, not for their particular firms. Second, it would be naive to assume that the participants did not know that their inputs might affect the outcome of a proposed initiative that would affect them. Even so, we believe the participants were all reasonably candid. Third, during the workshop sessions, limited time was available to discuss the rationale and internal consistency of various responses or predictions. For example, although the workshop members felt the initiative would only advance the $2/Wp price module by one year (1983 to 1982), it was felt that a cost breakthrough would be accelerated by four years (from 1988 to

1984) and that $0.5 to $1 billion private investment would be accelerated by six years (from 1992 to 1986). It is difficult to reconcile these conclusions. In part, the resolution may lie in the greater uncertainty (and generally greater optimism) attached to events in the longer term future. In part, the resolution may lie in the fact that industry is looking for a government commitment and will respond to such a commitment with one of their own--even if the short-term results are minimal.

Despite some inconsistencies, the workshop did provide useful information. First, the initiative was deemed to have little effect in accelerating achievement of a $2/Wp price module or $0.50/Wp price module. Thus, in terms of the explicit objectives of the initiative (i.e., accelerating the near-term availability of low-cost photovoltaic devices), the workshop participants did not feel the initiative would be particularly effective.

Second, the workshop participants felt that key near-term events would be a solar coalition becoming effective in Congress, a 100 MW per year commercial market developing (which they felt the initiative would not accelerate) and a 25% federal tax credit. All three of these factors would have a positive influence on the business environment for photovoltaics.

Third, the workshop participants felt a private R&D breakthrough was likely. As noted above, they felt the initiative would accelerate the occurrence of this breakthrough even though the initiative would not have much effect on reaching the $2/Wp and $0.50/Wp module price goals.

Fourth, by grouping the events into classes, one can observe that the supply workshop participants view political factors (formation of solar coalition, passage of investment tax credit) as most important followed by market events and then technical events.

This grouping indicates some consistency in terms of what causes uncertainty on the part of vendors and potential vendors. In terms of the analysis in Section B on demand pull and vendor response, the workshop results give high priority to a third category of uncertainty or risk facing vendors, namely, that attached to governmental behavior and political activity.

SERI's assessment of the supply workshop is that despite some inconsistencies, it provides useful insights into the likely effectiveness of initiative from an industry perspective. On the whole, we find little evidence from the workshop that the initiative will materially advance achievement of DOE's photovoltaic array price and quantity goals although the participants agreed it will definitely have a favorable impact on many other key events in the development of photovoltaics.

D. A MARKET PERSPECTIVE ON PHOTOVOLTAIC PRICES

Another perspective on the future photovoltaic supply industry, and its response to the initiative is provided by a study done by Gnostic Concepts, Inc. for the venture analysis.[23] The major conclusions of that study are presented here. The study report, Photovoltaic Array and System Prices in 1982 and 1986, is Appendix H to this document.

Industry Growth

The photovoltaic industry will grow very rapidly from 1979 through 1986, though not as rapidly as required by the national photovoltaic program goals. Gnostic Concepts expects industry compound growth over this period of roughly 70% per year. This growth will be supply-limited rather than demand-limited, and thus will lead to a "seller's market" condition. Consequently, there is no incentive for a manufacturer to lower price in an effort to gain sales. From this initial expectation, Gnostic Concepts concludes that neither the program price goals ($0.50/Wp) nor the quantity goals (500 MW/year) will be met in 1986. The quantity goal would require compound growth at roughly 100% per year. (It should be noted, however, that under Gnostic Concepts constrained growth scenario, the 500 MW annual production level is still possible before 1990.)

Price Goals

The Gnostics assessment concludes that program price goals will not be met in 1986 with or without the initiative. The exact

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[23] Gnostic Concepts, Inc. is a private for profit market research firm specializing in the semiconductor and electronics industries.

meaning of this statement and the reasoning behind it needs to be clearly understood.

Note that the statement refers to price and not to cost. Gnostic Concepts is in general agreement that production costs consistent with $0.50/Wp arrays are technically possible. They do not expect this possibility to be realized for several reasons. First because of anticipated rapid growth, most photovoltaic production facilities will be operating past their minimum cost levels. Hence, advanced technologies will not be as efficiently employed as under lower growth situations. As a result, costs of production will be higher. Second, the risk of technological obsolescence will require rapid amortization of investment. Thus, capital-related costs will be higher than would characterize an industry with a stable technology. This effect is discussed more fully in the next section of this chapter. An alternative to rapid amortization under high risk of obsolescence is to postpone investment in capital-intense automated facilities until the technology matures. This issue is discussed in Appendix K. Third, the seller's market environment provides no incentive for a profit-maximizing firm to reduce prices, even when production cost falls.

The Gnostics argument rests on characterization of the market environment and expectation of the economic longevity of automated equipment. The Gnostics argument does not rest on any fundamental barrier to a $0.50/Wp price in a stable market. Given the market conditions anticipated by Gnostics, a demand pull initiative would simply aggravate a supply-constrained market. A delayed initiative, applied when photovoltaic prices are closer to those required for substantial penetration of grid-connected markets, could have positive benefits. Gnostic Concepts does not expect these circumstances to apply before the late 1980s.

Balance-of-System Costs

Balance-of-system costs will retard system price reductions. The dramatic cost reductions expected for photovoltaic modules will not characterize other system components. This is especially true for batteries. The degree to which system prices mirror photovoltaic price reductions will thus depend on the proportion of the system composed of photovoltaics. Grid-connected systems are thus expected to experience more rapid price declines than stand-alone systems, largely because of lower battery requirements.

Suggestions

The Gnostics report suggests that the best timing for an initiative would be in the late 1980s when prices of photovoltaic systems may be approaching an economically viable level in substantial sized (grid-connected) markets. The Gnostics report also suggests that market development demonstrations will be needed in the mid-1980s to answer technical and institutional questions. These demonstrations would facilitate the likelihood and rate of future photovoltaic use in large markets.

Assessment

The Gnostics report provides an independent assessment of the likely effects of the procurement initiative based on their knowledge of the industry and its markets. Their assessment indicates that the initiative will have little effect on accelerating or causing achievement of DOE photovoltaic price and sales goals.

The Gnostics analysis rests crucially on the assumption of a seller's market that will reduce the likelihood of price reduction. This does not mean demand will be large in an absolute sense but only relative to supply. The Gnostics analysis asserts that vendors, seeing a small but growing market will be unwilling to increase production capacity fast enough to catch up with market demand. Both assumptions, seller's market and failure of capacity increases to keep pace with demand, may be questioned. But granting these assumptions and the scenario painted by Gnostics on the basis of their knowledge of the photovoltaics industry, their results are sensible.

E. CAPITAL COSTS AND REVENUE REQUIREMENTS FOR INVESTMENT IN $2/WP PRODUCTION FACILITIES[24]

This section describes the investment, manufacturing, and distribution costs for photovoltaic manufacturing facilities. The technology described here for producing silicon sheet, cells, and modules relies on technology which is either available now or is expected to be available in the near future. The technology for producing high quality polycrystalline silicon material at significantly reduced prices is still at the experimental stage but is being addressed in a number of ways. Marketing and distribution costs are large relative to a $0.50/Wp technology ($0.20 to $0.40/Wp, depending upon the type of customer and the region where the modules were delivered). But these costs are not nearly so large, relative to a $2/Wp technology.

The Investment Required to Implement the $2/Wp Factory

Initial capital investment for a photovoltaic manufacturing plant will vary according to the type of technology selected and the size of the plant. This analysis is based on the manufacturing sequence presented by Donald B. Bickler at the 13th IEEE Photovoltaics Specialists Conference.[25] This sequence is a modified and improved version of the "Strawman Factory" originally presented by JPL at the 8th LSA (Low Cost Silicon Array) Project Integration Meeting. It should be pointed out that there are

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[24] This section of the report was provided by the staff of the Jet Propulsion Laboratory. We particularly wish to thank Mr. Robert Aster.

[25] Gallagher, B. D. and D. B. Bickler, "A Candidate Low-Cost Processing Sequence for Terrestrial Si Solar Cell Panels," Proceedings, 13th Photovoltaic Specialists Conference.

other approaches (flat-plate as well as concentrator) which may be able to achieve the $2/Wp goal.

This technology is based on equipment which either is available now or is expected to be available in the near future. The present factory sequence differs from the original "Strawman" sequence in the area of crystal pullers. The new sequence features pullers which produce very large, single ingots. Continuous melt replenishment of silicon is assumed, thus reducing the cost related to furnace size. Additional modifications were made at several process steps, leading to reduced material and supply costs and other process improvements.

Initial capital investment must be sufficient to meet the following costs: equipment purchase, facility design and construction, interest during construction, startup costs, and working capital costs. The investment tax credit can help to reduce these costs, by a small amount. Table 15 shows the initial investment for three plant sizes (silicon production is not included here).

TABLE 15. INITIAL CAPITAL INVESTMENT IN 1975 DOLLARS

Plant Size	Total Amount	Initial Capital Investment Per Wp Capacity
20 Megawatt	18,400,000	0.92
10 Megawatt	10,200,000	1.02
5 Megawatt	6,100,000	1.22

SAMICS Revenue Requirements for the "$2/Wp" Factory

SAMICS is a costing methodology developed within the LSA Project at JPL. It estimates the operating and financial costs of a manufacturing plant. Financial costs include profits, taxes, one-time costs of starting a new plant, and numerous other capital costs. All these costs are summed and then divided by the expected output of the plant. This establishes a price which would generate the required revenue for this factory.

This required price will vary with different technologies and with different scales of production. It will also vary with different postulated financial scenarios. Two of the most sensitive financial parameters are the time period allowed for amortizing the initial capital investment and the price of high grade polycrystalline silicon.

With this technology, it is possible to obtain a $2/Wp price with initial capital investment amortized in three years. However, silicon prices must be reduced from current levels, and full production at high capacity levels is required. Once the initial capital investment is amortized, this technology can then be competitive (on an operating cost basis) with a $1/Wp technology, but not with a $0.50/Wp technology. Tables 16 through 20 describe the implications of various scales of production, factory utilization rates, amortization periods, and silicon prices.

TABLE 16. REQUIRED MODULE PRICES FOR 20 MEGAWATT PRODUCTION FROM A 20 MEGAWATT CAPACITY (1975 $/Wp)

Amortization Period	Silicon Price (1975 Dollars)			
	10	25	40	55
18 months	2.11	2.42	2.73	3.05
3 years	1.52	1.77	2.02	2.27
lifetime	1.15	1.36	1.57	1.78
minimum price after write-off	0.80	0.97	1.14	1.31

TABLE 17. REQUIRED MODULE PRICES FOR 10 MEGAWATT PRODUCTION FROM A 20 MEGAWATT CAPACITY (1975 $/Wp)

Amortization Period	Silicon Price (1975 Dollars)			
	10	25	40	55
18 months	2.83	3.14	3.45	3.77
3 years	1.93	2.18	2.43	2.68
lifetime	1.39	1.59	1.80	2.01
minimum price after write-off	0.84	1.01	1.18	1.35

TABLE 18. REQUIRED MODULE PRICES FOR 10 MEGAWATT PRODUCTION FROM A 10 MEGAWATT CAPACITY (1975 $/Wp)

Amortization Period	Silicon Price (1975 Dollars)			
	10	25	40	55
18 months	2.27	2.58	2.89	3.21
3 years	1.61	1.86	2.11	2.36
lifetime	1.20	1.41	1.62	1.83
minimum price after write-off	0.82	0.99	1.16	1.33

TABLE 19. REQUIRED MODULE PRICES FOR 5 MEGAWATT PRODUCTION FROM A 10 MEGAWATT CAPACITY (1975 $/Wp)

Amortization Period	Silicon Price (1975 $/Kg)			
	10	25	40	55
18 months	3.15	3.46	3.78	4.09
3 years	2.11	2.36	2.61	2.86
lifetime	1.49	1.70	1.91	2.12
minimum price after write-off	0.86	1.03	1.20	1.37

TABLE 20. REQUIRED MODULE PRICES FOR 5 MEGAWATT PRODUCTION FROM 5 MEGAWATT CAPACITY (1975 $/Wp)

Amortization Period	Silicon Price (1975 $/Kg)			
	10	25	40	55
18 months	2.60	2.91	3.22	3.54
3 years	1.80	2.05	2.30	2.55
lifetime	1.31	1.52	1.73	1.93
minimum price after write-off	0.83	1.00	1.17	1.34

For this particular technology, it is evident that both silicon price and the amortization period are important factors in the computation of a required price. For each $5/Kg change in silicon price, the required module price will change by 10.4¢ (18 month amortization), 8.3¢ (3 year amortization), 7.0¢ (lifetime amortization), or 5.7¢ (minimum price after write-off). Nearly 11 kilograms of silicon are required for each kilowatt of photovoltaics produced. For example, the 20 megawatt plant requires about 214,000 kilograms of silicon.

<u>LSA RD&D in Silicon Materials--Uncertainties and Alternatives</u>

The LSA Project did not choose a preferred process for high grade polycrystalline silicon production. Currently, there are eight candidate processes being pursued. One strong candidate is a silane process that is being developed by Union Carbide. A complete list of candidates includes the following:[26]

1. Battelle Process ($Zn/SiCl_4$)
2. Union Carbide Process (SiH_4)
3. Motorola Process (SiF4/$SiCl_4$)
4. Westinghouse Process ($Na/SiCl_4$)
5. Dow Process (C/SiO_2)
6. SRI Process (Na/SiF_4)
7. AeroChem Process
8. J. C. Schumacher Co. ($SiBr_4$)

These processes are typically being developed in four phases. Briefly, Phase One consists of a theoretical specification of the process. Phase Two is an experimental phase which verifies the technical feasibility of the components of a process. Phase Three is a pilot plant phase which allows design optimization and permits a verification of the expected steady state operation of the full process system. Phase Four would be the construction of full scale commercial units. Economic feasibility is examined at each phase.

At this time it is expected that Battelle and Union Carbide will have the first processes ready for Phase 3. However, the Westinghouse process is potentially capable of producing large quantities of silicon even from Phase 2 experimental apparatus, thus clouding the distinction between Phases 2 and 3 for this process. This process is considered a high risk option, but if it

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[26] Lamar University, Quarterly Technical Progress Report (VI), March, 1977, pages 22,23.

is successful, as much as 500 to 800 metric tons of silicon production capacity would be available from the Westinghouse experimental facility by early 1980. The Westinghouse projection for a large scale production (3,000 metric ton plant) cost is $7.20/kg.

The current plan is to have a 50 metric ton capacity Battelle process pilot plant in operation in June 1981. The Union Carbide process should have a 100 metric ton capacity pilot in operation prior to March 1982. Other processes could enter the pilot plant phase if their results in Phase 2 are encouraging.

Furthermore, there is a ninth alternative. Dow Corning has proposed an advanced Siemans Process. They project that conventional equipment could increase their output by as much as 7.5 times, with a potential silicon cost of $20/kg or less (1975 dollars). This would be a three-year program which is generally considered to have a high probability of success if pursued. This alternative would not be pursued in a long-term (8 to 10 years) program with several alternatives potentially capable of 6 to $10/kg prices. On the other hand, it would be the easiest technology to implement in the near term (3 to 4 years).

Investment Requirements for a 1,000 Metric Ton Silicon Plant

The investment required to implement a low-cost silicon manufacturing plant will vary with the type of technology employed and the size of the plant. This section examines the investment requirement for the proposed Union Carbide plant at 1,000 and 100 metric ton production levels.[27] This is compared with the most

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[27] Union Carbide, Monthly Progress Report, March 1978, pp. 9-13.

recent Lamar data on the proposed Battelle[28] plant at a 1,000 metric ton production level.

These costing models differ with each other and with the SAMICS methodology used earlier in this paper. Therefore, data developed by Union Carbide (U. C.) and by Lamar have been used to estimate investment requirements in a manner which is fairly similar to the SAMICS method used earlier. Specifically, initial capital investment must be sufficient to meet the following costs: equipment purchase, facility design and construction (U. C. and Lamar base their investment requirement figures on these costs); also included are startup costs and working capital. U. C.'s assumptions that working capital is 30% of annual operating expense and startup is 10% of the initial plant cost are used to normalize the comparison between U. C. and Battelle. Table 21 shows the result.

TABLE 21. INITIAL CAPITAL INVESTMENT IN 1975 DOLLARS

		Initial Capital Investment	
Plant		Total Amount	Per Kg Capacity
U.C.	1,000 MT	7,800,000	7.8
U.C.	100 MT	5,400,000	54.0
Battelle	1,000 MT	13,700,000	13.7

Revenue Requirements for Operating the Silicon Manufacturing Plant

SAMICS has not been applied to silicon manufacturing plants at this time. Union Carbide, Battelle, and Lamar University all use somewhat different costing methods. However, this section uses a costing method which normalizes these analyses in a way which is

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[28] Lamar University, Quarterly Technical Progress Report (VI), March 1977, pp. 22-23.

roughly consistent with the SAMICS methodology used earlier in this paper.

The operating costs, such as direct materials, labor, and so forth are taken directly from Union Carbide and Lamar cost analyses. Initial investment in equipment and facilities, startup costs, and working capital are also consistent with these analyses. The financial modeling with respect to depreciation, amortization, profits, taxes, and debt are similar to the method used in SAMICS. Both financial leverage and after-tax profits tend to be somewhat higher for chemical processing firms than for general manufacturing or for electronics manufacturing firms. The numbers used here are 25% debt financing at a 9% interest rate and 75% equity financing at a 25% after-tax rate of return on equity. This leads to an average cost of capital of 19.9%.

Annual revenue requirements and hence the required price will vary with different technologies, different production capacities, and with different amortization periods for the initial capital investment. This paper focuses on the Union Carbide process at 1,000 and 100 metric tons, and the Battelle process at 1,000 metric tons. Table 22 shows the results for several amortization periods.

TABLE 22. SILICON REQUIRED REVENUE PRICES FOR SEVERAL TYPES OF PLANTS (1975 $/kg)

Amortization	Union Carbide		Battelle
Period	100 MT	1,000 MT	1,000 MT
18 months	84	14	24
3 years	52	10	17
15 years	29	6.3	11
minimum price after write-off	16	4.6	8

Technical Uncertainties in the Union Carbide Silicon Process

The Union Carbide silicon production process is one of the strong candidates for becoming the commercial source of high grade polysilicon. It consists of the production of silane (SiH_4) and then the conversion of silane into a semiconductor grade of polycrystalline silicon.

Silane production involves processes which are not new. All process components have been used industrially and are known to be workable. The complete silane production system has not been operated at a full pilot plant scale. It is believed that pilot plant operations will be oriented toward process optimization, with basic feasibility not a serious concern.

Silicon production from silane has been demonstrated experimentally at Union Carbide, but it is not a mature process at this time. There are two approaches which will eventually be tested in the forthcoming Union Carbide pilot plant.

One alternative is to use a free space reactor. This technique produces a very fine silicon powder of semiconductor grade purity. However, powder has problems due to its high ratio of surface to mass. It is difficult to maintain its purity while it is being transferred, and the Union Carbide technique is considered to require further development. There are several ways of consolidating the powder after it leaves the reactor, but a preferred method has not been identified. Union Carbide has an experimental facility for this step of the process which could potentially produce 25 metric tons of silicon from silane. It has been operated successfully in a batch mode, but continuous operation still needs to be verified.

The second alternative that Union Carbide will explore is a fluidized bed approach. Experiments show that this technique can produce a granular material, thus avoiding the powder transfer and consolidation steps. However, this procedure is relatively less mature than the first alternative.

As a summary, all of the process components required by the Union Carbide process have had some level of experimental verification, with the exception of continuous removal of powder from the free space reactor. The full system has not been tested, and the fluidized bed silicon production process has yet to be tested on a large scale.

Marketing and Distribution Costs

Two significant components of the price of photovoltaic modules as received at the site of application are the costs of marketing and distribution. This section gives a very brief summary of the results of a study performed by Theodore Barry and Associates.

Marketing costs are highly dependent upon the character of the customers. Large, sophisticated customers require fewer salesmen with more technical support, while smaller customers take less of a salesman's time per customer, but more per megawatt. Advertising expenses depend on customer type and industry tradition. The marketing cost model developed by TB&A provides a descriptive estimate; there is no attempt to determine an optimal advertising budget.

Distribution costs depend upon the locations of the factory and of the customer, the mode of transportation, and the size of the order. The TB&A distribution cost model determines the optimal mode of transportation (usually rail), whether shipments are direct (from factory to customer) or indirect (factory to regional warehouse to customer), and the optimal size of regional warehouses. Utility-size customers are generally supplied directly, small customers through a regional warehouse, and intermediate customers direct or indirect, depending upon other factors.

The marketing and distribution models developed by TB&A are carefully constructed, with approximately the same level of sophistication as SAMICS. The computations required are straightforward, but extensive. Resources have not yet permitted expressing these models in a computer program, so it is difficult to perform sensitivity studies. However, an elaborate "test case" demand scenario was run through by hand; the resulting estimates should give a good idea of the range of marketing and distribution costs to be expected.

The test case factory was located in Phoenix, Arizona (Region II, Rocky Mountain). There were assumed to be three kinds of customers, as shown in Table 23.

TABLE 23. TEST CASE CUSTOMERS

	Average Order	Average Delivery	Annual Demand	Orders Per Year	Deliveries Per Year
Small Residential Household	10 kW	10 kW	20 MW	20,000	20,000
Medium Commerical Intermediate	0.5 MW	0.5 MW	100 MW	200	200
Large Utility Central Station	50 MW	5 MW	200 MW	4	40

This factory was assumed to have an annual production of 500 MW, with customers of each type in each of seven geographical regions (except there were assumed to be no central station customers in Regions III, IV, or VI), as shown in Table 24. Further details, such as the regional boundaries, can be obtained from TB&A's Phase II Final Report, which is currently in preparation.

TABLE 24. TEST CASE DEMAND DISTRIBUTION

		Customer Demand MWp/Yr			Total Annual
	Region	Small	Medium	Large	Demand
I.	West Coast	50	25	50	125
II.	Rocky Mountain	60	30	50	140
III.	North Central	10	5	0	15
IV.	Great Lakes	10	5	0	15
V.	North Eastern	20	10	50	80
VI.	South Eastern	10	5	0	15
VII.	South Central	40	20	50	110
Total		200	100	200	500

The final delivered price for photovoltaic modules, by region and type of customer, is given in Table 25, expressed in 1975 dollars per peak watt. These prices include an assumed $0.50/Wp price FOB the manufacturer's loading dock.

TABLE 25. DELIVERED PRICE OF $0.50/Wp PV MODULES
(Test Case, 1975 Dollars)

		Customer Type			All
	Region	Small	Medium	Large	Customers
I.	West Coast	0.860	0.813	0.732	0.799
II.	Rocky Mountain	0.841	0.801	0.720	0.789
III.	North Central	0.884	0.838	--	0.869
IV.	Great Lakes	0.914	0.863	--	0.897
V.	North Eastern	0.904	0.860	0.787	0.825
VI.	South Eastern	0.886	0.842	--	0.871
VII.	South Central	0.860	0.818	0.749	0.802
	All Regions	0.864	0.820	0.747	0.808

F. BALANCE-OF-SYSTEM PRICE CONSIDERATIONS

The major elements of a photovoltaic system are photovoltaic arrays, power conditioning and controls, storage (if necessary), structures (including wiring, site preparation, support structure), and installation. Balance-of-system (BOS) prices are defined as all the above except the cost of the photovoltaic array field.

Estimates for the balance-of-system prices have been developed for the elements detailed above. The values used in the analysis were obtained from work performed by recent photovoltaic system design studies,[29] the Gnostic Concepts study for the venture analysis,[30] BDM market and systems descriptions,[31] work by Sandia Laboratories, and by discussions with selected manufacturers and users.

The price estimates attempt to account for system design, location, and size variation. For example, the installation costs for smaller systems are higher on a peak watt basis than for larger systems and probably provide less opportunity for cost reductions than do more complex, less site-specific systems.

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[29] See: (1) General Electric Advanced Energy Programs, Conceptual Design and Systems Analysis of Photovoltaic Systems, ALO-3686-14, March 1977; (2) Westinghouse Electric Corporation, Conceptual Design and Systems Analysis of Photovoltaic Systems, ALO-2744-13, May 1977; and (3) Spectrolab, Inc., Conceptual Design and Systems Analysis of Photovoltaic Systems, ALO-2748-12, April 1977.

[30] See Appendix H.

[31] See Appendix D.

In general, current balance-of-system prices are less than 60% of total system prices. By 1986, however, balance-of-system prices will increase substantially relative to total system prices more so for systems less than 1 kW than for larger systems (see Table 26). In all cases, balance-of-system costs are at least equal to module cost. These values agree with values recently reported by Hein et al.[32]

As shown in Table 26, it is estimated that balance-of-system prices will not substantially decrease in the future, primarily because there are few significant opportunities for price breakthroughs in the technologies involved. Power conditioning is a mature industry. Battery storage devices for photovoltaics make up a very small percentage of the battery industry. Other balance-of-system elements are labor intensive, reasonable prospects for some cost reduction, particularly in very large installations where some degree of automation and learning may be possible on installation.

Details of individual balance-of-system element price projection trends are discussed separately along with the reasons for the trend projection. Where decreases appear possible, the rationale is specified. Similarly, discussions of each analyzed application appear later in this section, with detailed breakdown of balance-of-system elements and prices.

The study could have devoted considerably more resources to refine the quantification of balance-of-system costs. However, the analyses performed show the expected outcome of the procurement initiative to be rather insensitive to the variation of balance-

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[32] G. F. Hein, J. P. Cusick, and W. A. Poley, "Impact of Balance-of-System (BOS) Costs on Photovoltaic Power Systems," Presented at IEEE Photovoltaic Specialists Conference, Washington, D.C., June 1978.

TABLE 26

BALANCE-OF-SYSTEM PRICES

Application	System Size (Peak Watts)	BOS Costs		$/W (Peak)	
		1978	1986	1978	1986
Radio Repeater	200 W	$1,620	$1,070	$ 8.10	$ 5.35
Shallow Well Cathodic Protection	50 W	710	460	14.20	9.20
Deep Well Cathodic Protection	600 W	4,270	2,595	7.12	4.33
Outdoor Lighting	300 W	1,810	1,210	6.03	4.03
Residential	3,400 W	--	$1,405-2,595	0.73-1.08	0.41-0.76
Institutional	51.84 kW	--	$32.4K-63.5K		0.63-1.22
Central Power	10 MW	--	$ 3.8 million		0.38

of-system prices. Variations of 50% and 200% of the base case balance-of-system prices do not have much effect on the costs and benefits of the initiative.

Power Conditioning

The power conditioning subsystem consists of equipment required to condition the output of the photovoltaic array. DC regulators, inverters, and controls are the major components of the power conditioning subsystem.

Small, Isolated DC Systems

Systems servicing DC loads, such as corrosion protection and radio repeaters, require only a voltage regulation function in the power conditioning subsystem to limit battery overcharging. In such systems where minimal control and regulation are required, the power conditioning system is a small fraction of the photovoltaic balance-of-system prices.

Estimates of \$0.50 to \$1/Wp,[33] depending on system size and complexity, were used for small systems (<1 kW) requiring conditioned outputs. This estimate is based on photovoltaic systems currently being sold as replacement units in the market.

The power conditioning industry is a mature one, leaving very little opportunity for innovation. Off-the-shelf components, however, are not readily available at this time. As the photovoltaic market expands, it is expected that industrial electronics firms will enter the market and competition will force the price down. It has been assumed for this analysis that the

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[33] All discussions refer to the photovoltaic array peak watt output.

price of small power conditioning subsystems requiring only DC outputs and storage (<1 kW) will decrease by one-half by 1986.

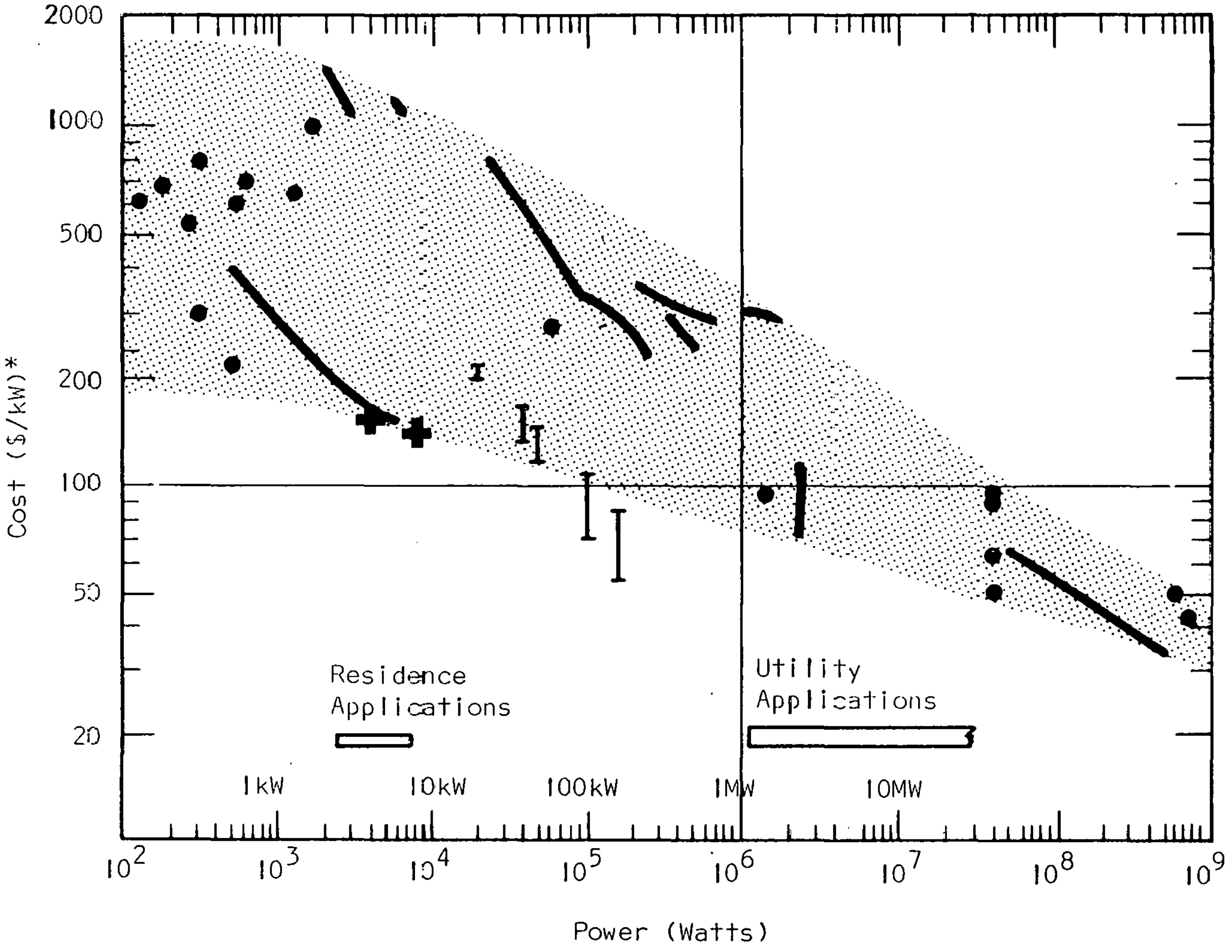
DC/AC Systems

None of the small systems analyzed required DC and AC power, so this section addresses the larger (>1 kW) photovoltaic systems. Systems which require both DC and AC power need inverters as part of the power conditioning subsystem to generate AC wave shapes and frequencies, and are thus more costly. Estimates of $80 to $300/kVA were used in the present analysis, depending on system size and type. These prices represent future prices and are based on data generated as part of the system design studies and discussions with vendors. Figure 3 shows a compilation of vendor data on inverter prices generated by Sandia Laboratories.

Storage

Batteries represent a significant portion of balance-of-system prices, commonly 50% or more. Battery prices are also the most difficult to evaluate and to project.

Lead-acid batteries are the predominant type currently used for photovoltaic systems, because of their low price relative to other types of batteries and other characteristics amenable to photovoltaic systems. The production of lead-acid batteries is a mature and large industry. The lead-acid system has been in use for over a hundred years. In 1977, U.S. manufacturers shipped 54 million batteries, just for automobile application. Three types of lead-acid batteries are currently used in photovoltaic applications: (1) pure lead stationary type; (2) lead-calcium stationary type; and (3) automotive/marine starting, lighting, and ignition (SLI) batteries. Photovoltaic system manufacturers are currently quoting $75/kWh to $150/kWh for battery subsystems, and



Source: Sandia Laboratory

* Represents Inverter Costs only. Addition of controls would add $50-75/kW to the cost.

Figure 3. Inverter Costs Versus Power

these values were used in the study as "present prices" for pure lead and lead-calcium systems, respectively.

Battery prices are not expected to decline from experience effects. In all likelihood, prices will increase due to material and labor cost increases. However, batteries for solar power systems are traditionally oversized to account for uncertainties in solar insolation data and battery end-of-life characteristics. Thus, improved sizing techniques can help offset anticipated price increases. Prices of future lead-calcium systems were assumed to be one-half of current prices because lead-calcium is still an emerging technology. Pure lead systems were assumed to be constant in price for the reasons stated earlier.

Additional work is necessary to fully understand future battery price projections. Advanced battery couples under development, such as sodium-sulfur or zinc-chloride, may reduce prices below $75/kWh but not within the 1986 time frame used in this analysis.

Structures

Structure prices are those related to the structure required to support the photovoltaic array modules, site preparation, foundations, wiring, and any associated shelters required by the subsystems.

At this point, estimates for structural prices are sparse because of the lack of field experience. Estimates used in this analysis are based on figures obtained from photovoltaic system manufacturers and design studies completed in 1977. For smaller systems, $1/Wp was used in the final analysis except for outdoor lighting where $1.50/Wp was used. The $1/Wp appears at present to be a universally quoted number by manufacturers.

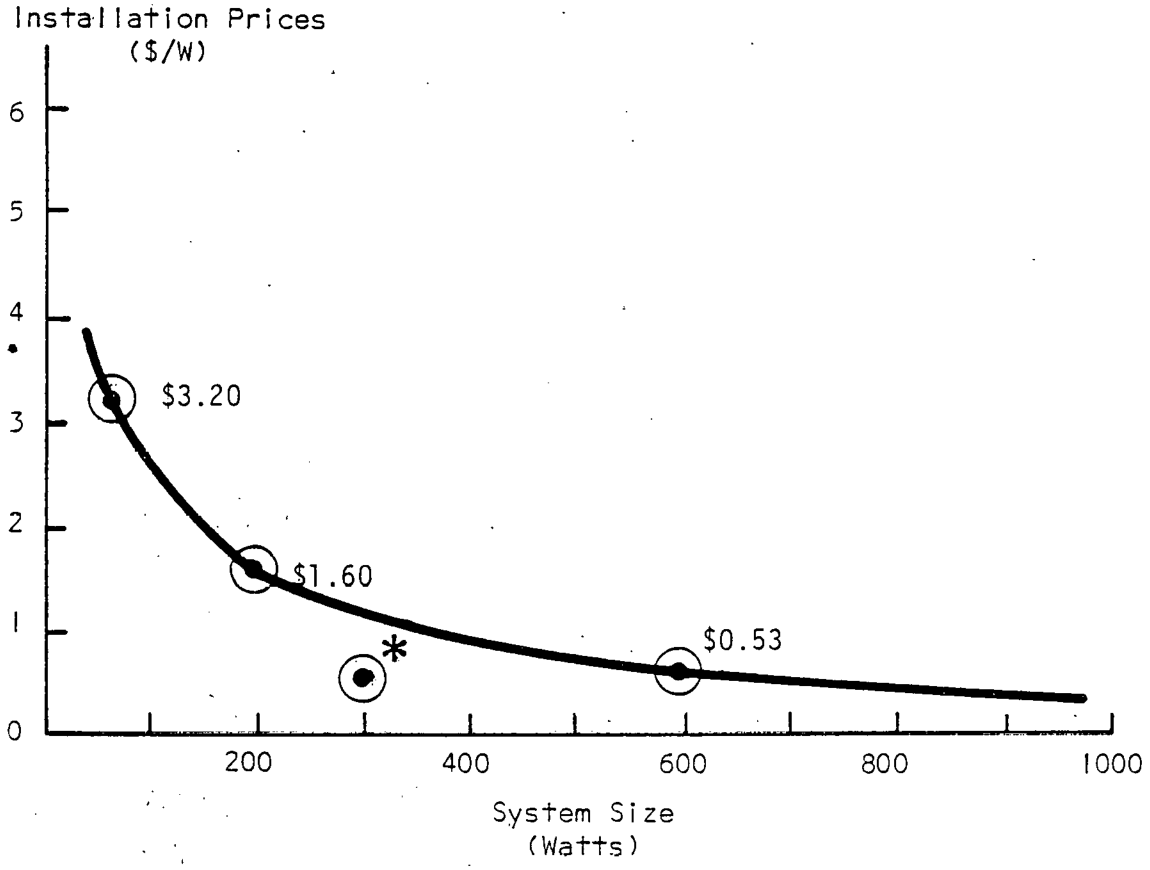
In the interim analysis, it was assumed that structural prices for small systems would reduce by one-third (on a per watt basis) by 1986 because of increased module efficiency. The 1977 analyses used module efficiencies of ~8% for present day modules. Several manufacturers currently offer modules which are ~12% efficient. The final analysis (reported here) assumes the present day availability of these 12% modules. Therefore, structure prices used in the final analysis have been assumed to be flat when projected into the future.

For large residential and central power station applications, estimates for structure are made differently because of the uniqueness of the applications. These are discussed in later sections which address each application.

Installation

Installation prices are defined as those required to actually put a photovoltaic system in place and make it operational. They include the prices of labor, transportation, and any unique installation hardware such as cranes or forklifts.

Estimates of installation prices vary, depending on the type and size of installation, as shown in Figure 4. As noted earlier, small systems are expected to require larger installation costs per watt. The data in Figure 4 are approximately one-half those assumed in the preliminary analysis. The reason for the reduction is twofold: (1) changes in assumption regarding salaries ($20/hr rather than $30/hr) and (2) bottom-up approach to scoping the actual work.



* Local, easy accessable outdoor lighting system.

Figure 4. Variation of Installation Prices with System Size (Expressed in 1978 Dollars)

As an example, consider the 200 W repeater system. Most remote systems require a considerable amount of time to travel to and from the actual site which adds to the price of installation. Furthermore, a two-man team is required for any reasonable sized system because of safety reasons and problems in handling.

Because system locations vary, the prices of transportation of the photovoltaic system from the factory to the site have not been included. Also, it has been assumed that, for the smaller systems studied, no special handling equipment will be required other than truck/jeep/horse transportation (which is assumed to be available already at no additional cost). Large systems will require special handling/installation equipment which is included in system installation prices.

The discontinuity (at ~$1.50/W) in Figure 4 relates to differences perceived for urban vs. remote site locations. Because conventional lighting pole erection normally involves easy access as well as need for specialized equipment, no penalty was assessed to the photovoltaic system installation.

Installation prices are assumed to remain constant in the 1978 to 1986 time frame because learning effects will tend to lower the costs somewhat. However, the anticipated continued decrease in productivity (especially in the field) will tend to increase costs. As a result, the two effects balance each other, resulting in levelized installation prices.

System Descriptions

Several photovoltaic systems were selected for detailed description of balance-of-system prices. The systems vary in location from remote to urban environments, and in size from 50 W to 10 MW. These systems are described in the subsections which follow.

Radio Repeater System

A radio repeater provides a "direct line of sight" type of transmission to maintain radio contact with other units in the area. Common use is in remote areas where it provides communication links between mobile and base stations. Systems vary in size from 50 to 400 Wp. A 200 Wp has been used in this analysis. The operating cycle is continuous, 365 days per year, with transmitting requirements of about 24 Amps. The daily average power requirement is 40 W; the average daily energy demand is 0.96 kWh.

Figure 5 shows a typical setup for such a system. Because of the continuous operational requirement, a battery subsystem, along with associated charge control circuitry, is essential. The ampere-hour meters shown in the figure are optional systems, used mainly for monitoring purposes. The balance-of-system price estimates generated for a radio repeater system of this type (shown in Table 27) were developed using the following logic.

Although most manufacturers are currently marketing modules which typically produce about 8 W/ft^2, there are modules available which produce around 12 W/ft^2 by using rectangular solar cells in a shingled pattern. For the purposes of this analysis, 12 W/ft^2 modules were assumed. The physically smaller array size results in easier handling, shipping, and installation.

Figure 5 shows the typical structure used for small (less than 1,000 W) photovoltaic systems. "C" channels or box channel legs 0.75"-1" are commonly employed to give the proper panel tilt. Panels are bolted to concrete pads, wood poles, or ground anchors. Structure prices include the module structure, concrete, bolts, screws, anchors, etc.

Price estimates for structure are difficult to determine accurately because many organizations add in the costs of engineering and/or profit as part of the structure price. A consistently used number is $1/W for systems of this size. That number was used in this analysis.

In the previous report, the structure price was reduced by one-third for the "Future Price" category. This was done because 8 W/ft^2 modules were assumed in the preliminary analysis with future growth to 12 W/ft^2. In this current analysis, we have assumed 12 W/ft^2 would be available now, with minimal growth. Therefore, little or no reduction in structure price is expected in the future.

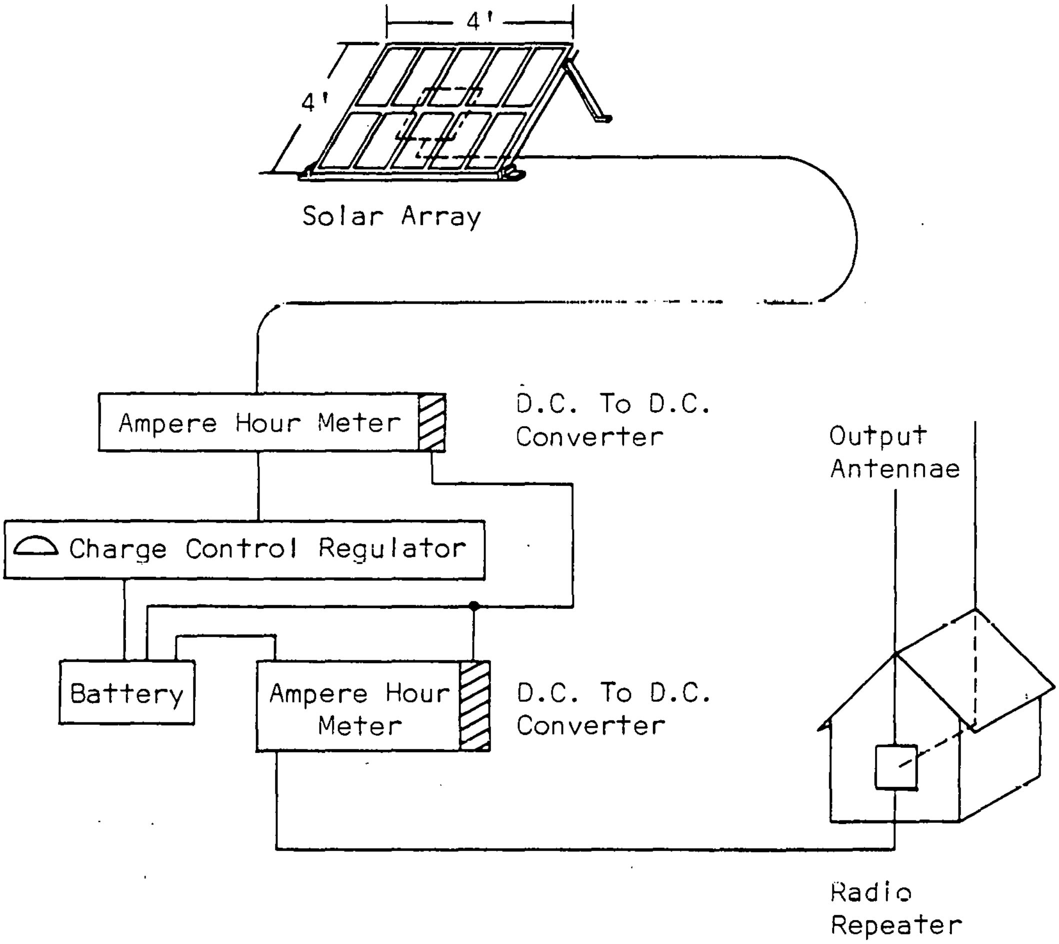


Figure 5. Typical Radio Repeater System (Source: Solarex)

TABLE 27

BALANCE-OF-SYSTEM (BOS) PRICES

(Expressed in 1978 Dollars)

Application:	Radio Repeaters	Location:	Remote
Size:	200 Watts	Battery:	6 kWh
Array Size:[1]	17 ft^2 (4' x 4')		

BOS Element	Present Price	Future Price
Structure	$ 200	$ 200
Power Conditioning	200	100
Installation[2]	320	320
Battery	900[3]	450[4]
	$1,620	$1,070
BOS Prices ($/Wp)	$ 8.10	$ 5.35

NOTES:

[1] Assumes high density (12 W/ft^2) module, areas are approximated.

[2] Two man-days assumed @ $20/hr. Transportation, special equipment not included.

[3] Pb/Ca batteries current quotes, $150/kWh.

[4] Price reduction to $75/kWh.

A battery charge regulator is the only power conditioning normally required in applications of this nature. Current price estimates of $1/W are commonly used. It is generally felt that a shift to mass production and competition will reduce the future prices by one-half.

Radio repeaters are traditionally located in isolated areas. Thus, the prices for installation are significantly higher than for systems with easy access, such as cathodic protection. Figure 6 shows a typical logic network for the installation sequence of a system. The price estimates shown in Table 27 were derived by considering the time associated with installation. It is felt that two man-days is a realistic value. The presence of two men is required for safety reasons, as well as for manipulating equipment. No price reduction is predicted, mainly because of the isolated, one-at-a-time nature of radio repeater systems. Also, field installation productivity is unlikely to improve in the future.

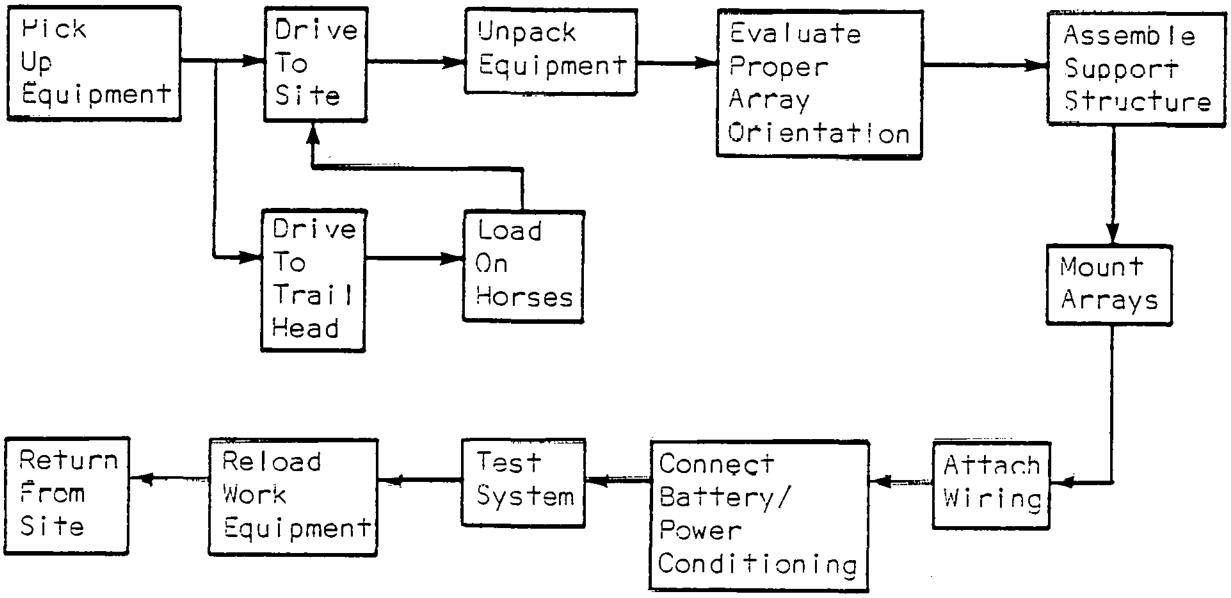


Figure 6. Radio Repeater Site Installation Sequence

Radio repeaters are required to be operational 24 hours/day, 7 days/week. As such, battery performance is an essential component of the system. Lead-calcium batteries, as opposed to the more common pure lead systems, are more often used in these applications because of their better outgassing properties, superior maintenance requirements, and low self-discharge rates.

Current lead-calcium batteries are being sold at $150/kWh, and these prices are used in the "Present Price" analysis. "Future Prices" show a reduction of 50% in battery prices, as noted earlier. Thus, a price of $75/kWh, consistent with current pure lead battery prices, is felt to be possible by the 1986 time frame.

There is considerable variation in load profiles for radio repeaters. As such, no one particular sized battery is optimum. A major problem in sizing batteries is the high continuous drain on the system from the transmitting electronics. Reductions in that drain could significantly reduce battery size. Furthermore, there is little data on system performance, and a consequent tendency to overdesign the systems, especially the battery. However, decreases in battery size from better design and improvements in transmitting electronics will more than likely be offset by increases in battery material prices (i.e., lead).

Shallow Well Cathodic Protection System

The purpose of the cathodic protection system is to prevent corrosion of well casings, pipelines, etc., by imposing a constant current on the device being protected. A typical system might be 50 Wp. The operational cycle is continuous, with an average operating power of 8 W (0.192 kWh/day). Figure 5 would also be representative of a typical cathodic protection system, except for size. The system could be alternatively mounted on a pole, well structure, or pipeline because its smaller size reduces the structure problem. Again, because of the continuous operating requirement, battery performance is essential.

Table 28 shows the cathodic protection balance-of-system prices used in the present analysis. The high density (12 W/ft^2) modules discussed in Appendix D were assumed here for sizing the photovoltaic array. Structure cost of $1/W was assumed, with no future reduction. Power conditioning cost of $1/Wp was assumed, with a reduction to $0.50/Wp because of competition. Because the cathodic protection system is small and likely to be located in accessible areas, estimated installation prices were based on one man-day of labor. No price reduction was allowed because of poor field productivity.

The arguments presented in the previous section are also applicable to batteries in cathodic protection systems (i.e., system overdesign and current battery prices). As can be seen, the battery prices dominate system price.

Deep Well Cathodic Protection System

These systems are the same as defined in the previous section except for size, which relates to the larger size of the systems being protected. Typical operational requirements are 100 W continuous (2.4 kWh/day).

Table 29 shows the estimated balance-of-system prices used in the analysis. Because of the larger size of the system, installation prices were estimated at two man-days. Lead-calcium batteries were assumed in such systems, although some last minute information indicates that buyers of these systems will usually buy the cheaper pure lead batteries and accept the poorer operational/maintenance characteristics. Substituting such batteries would reduce the near-term battery prices to $1,500 (balance-of-system prices to $2,770). Future prices would not be affected appreciably.

TABLE 28

BALANCE-OF-SYSTEM PRICES

(Expressed in 1978 Dollars)

Application: Shallow Well
Cathodic Protection

Size: 50 W

Array Size:[1] 4.2 ft^2 (2' x 2')

Location: Semi-Remote

Battery: 6 kWh

BOS Element	Present Price	Future Price
Structures	$ 50	$ 50
Power Conditioning	50	25
Installation[3]	160	160
Battery	450[2]	225[4]
	$710	$460
BOS Prices ($/Wp)	$14.20	$9.20

NOTES: [1] Assumes 12 W/ft^2 module. Areas are approximate.

[2] Assumes pure Pb battery at $75/kWh.

[3] One man-day assumed because accessibility easier ($20/hr).

[4] System overdesigned.

TABLE 29

BALANCE-OF-SYSTEM PRICES

(Expressed in 1978 Dollars)

Application: Deep Well Cathodic Protection

Size: 600 W

Array Size: 50 ft^2 (4' x 12.5')

Location: Semi-Remote

Battery: 20 kWh

BOS Element	Present Price	Future Price
Structures[4]	$ 600	$ 600
Power Conditioning[1]	350	175
Installation[2]	320	320
Battery[3]	3,000	1,500
	$4,270	$2,595
BOS Prices ($/Wp)	$ 7.12	$ 4.33

NOTES:

[1] Vendor quote.

[2] Two man-days @ $20/hr.

[3] Assume $150/kWh current cost, dropping to $75/kWh.

[4] $1/W assumed.

Residences

A potentially large photovoltaic market is the residential sector. In this application, photovoltaic arrays would be located on the roofs of individual homes, with the home connected to the utility grid. Power needed in excess of the capability of the array would be purchased from the utility; likewise, power produced by the photovoltaic system in excess of household demands would be sold back to the utility (at a different rate in all likelihood). There would be no storage in the residential systems, thus eliminating one of the higher priced balance-of-system elements.

Figure 7 shows a residential concept developed by General Electric which uses photovoltaic shingles as roofing, rather than conventional roofing material.[34] Spectrolab and Westinghouse[35] have also completed design studies for residential systems. The data used for the analysis performed here come mainly from their work. Table 30 shows the BOS prices used in the present study.

Structural prices were assumed to be zero because the photovoltaic modules would utilize existing roof structure as support, negating the need for additional support. The GE analyses project that up to $50/kW credit may be achieved for such systems, but not enough is presently known about such systems to warrant the credit.

Power conditioning for a residence is more complex than for the previous systems because of the need for AC power. Inverters become part of the power conditioning subsystem. An estimated future price of $200/kVA for the inverter plus $75/kVA for controls was used for the analysis. Near-term cost estimates were

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[34] See footnote 29.

[35] Ibid

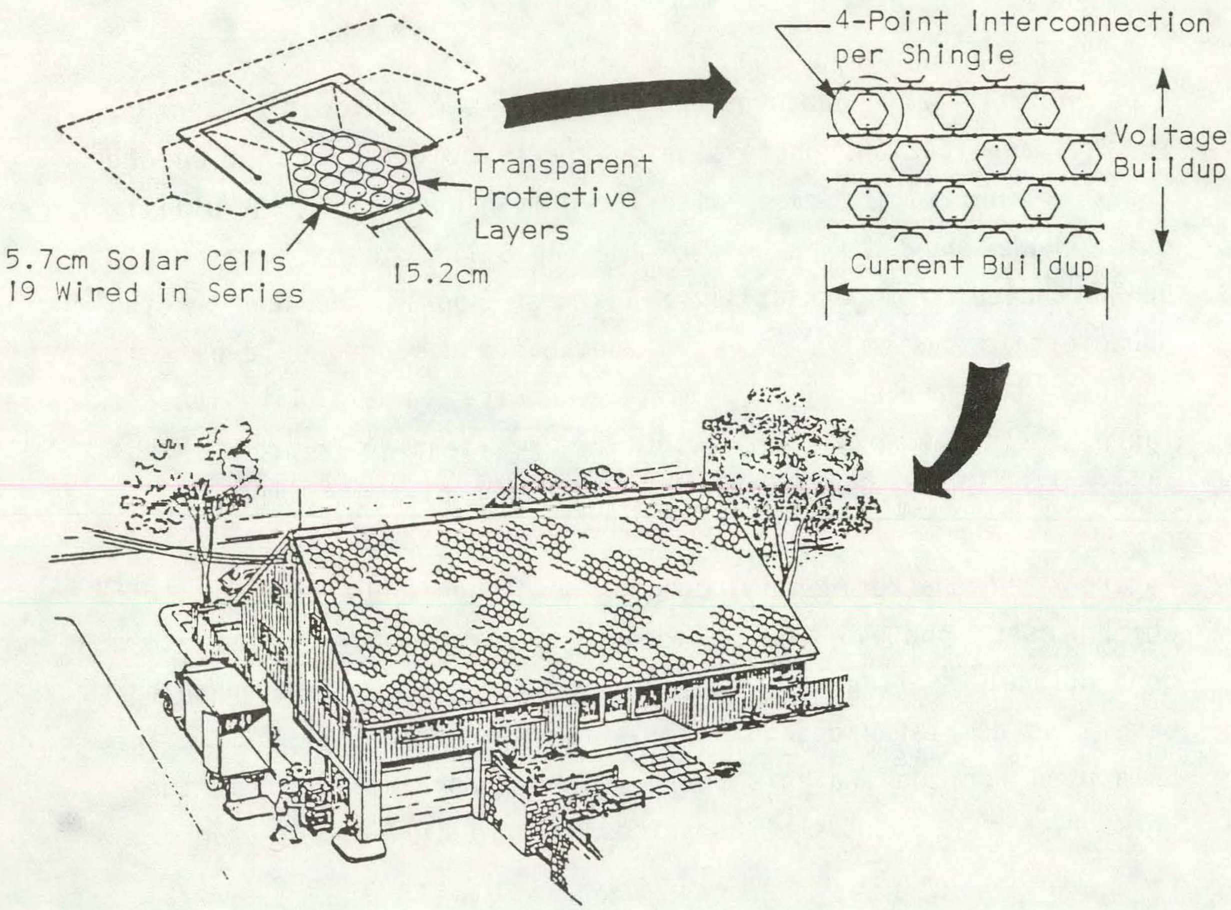

Figure 7. Solar Cell Shingle Roof

Source: Conceptual Design and System Analysis of Photovoltaic Systems, General Electric, op. cit.

TABLE 30

BALANCE-OF-SYSTEM PRICES

(Expressed in 1978 Dollars)

<u>Application</u>: Residence — <u>Location</u>: Residences

<u>Size</u>: 3,400 W — <u>Battery</u>: --

<u>Array Size</u>: Roof Size

BOS Element	Present Price	Future Price
Structures	--	$ 0[2]
Power Conditioning[1]	$2,000	935
Installation	($170-1,360) + $300	($170-1,360) + $300[3]
Battery	--	--
	$2,470 - $3,660	$1,405 - $2,595
BOS Prices ($/Wp)	$0.73 - $1.08	($0.41 - $0.76)

NOTES:

[1] Sandia Labs generated values: $200/kW for inverter plus $75/kW controls (assumes production of 10^4/year).

[2] Assumes MO credit for roofing materials.

[3] Generated from system design studies ($50/kW - $400/kW) plus $300/system. Source: General Electric, op. cit., <u>Conceptual Design and System Analysis of Photovoltaic Systems</u>.

assumed to be twice that due to lack of off-the-shelf equipment. Given sufficient volume, the $275/kVA value used for the future cost may drop to one-half that value in the late 1980s.

One can easily imagine the installation of a photovoltaic "shingle" or modules as simply replacing conventional roofing shingles, with very little cost differential. This differential primarily relates to (a) increased handling concerns, (b) electrical interfacing problems between modules (shingles), and (c) wiring/controls for the overall system. The system studies performed to date indicate estimate costs for a photovoltaic system installation as shown in Table 30. The range in prices are due to differences in the three system studies noted earlier. An average value was used in the analysis described in this report.

Central Power Plant

This application is envisioned to be a large photovoltaic power plant designed for utility interconnection. The size chosen for this anlaysis was 10 MW although sizes up to 200 MW or more can be considered. No battery storage is assumed for the system.

Several analyses have been performed on photovoltaic central power stations.[36] The recent study performed by Bechtel developed fairly detailed costs for a photovoltaic plant which might be installed in the near-term, whereas the studies previously cited[37] developed costs for systems which might be constructed in 1990. The data used in the current analysis come from those reports.

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[36] P. Tsou and W. Stolte, "Effects of Design on Cost of Flat Plate Solar Photovoltaic Arrays for Terrestrial Central Stations Power Applications," Presented at IEEE Photovoltaic Specialists Conference, Washington, D.C., June 1978.

[37] See footnote 29.

Table 31 shows the estimates for the BOS prices used. The Bechtel/JPL data are quoted as "Present Prices" while the design study results are used as "Future Prices." Although the sizes of the plants used in the design studies are larger than those used in this analysis (100 to 200 MW versus 10 MW), no attempt was made to compensate for the size variation. A larger plant will have some "economy of size" advantage; however, the percentage variation will be lost in the accuracy of the reported estimates.

It should be noted that the "Present Price" estimate of $0.65/W is heavily weighted by overhead-type costs such as interest, contingency, engineering, and distributable field costs. It is felt that these are appropriate for inclusion in balance-of-system prices because of the nature of the application.

The assumed reduction in prices appears realistic for the following reasons: (1) Distributable costs, contingency costs, and cost of money[38] estimates may be different for photovoltaic plants than for conventional plants (from which the estimates were made). (2) The major cost elements in the "present prices" were foundations and structures. There is hope of improvement for this type of application based on wind loading requirements and plant location, as well as the use of unconventional materials and innovative engineering. Reductions of two in civil and structural costs, distributable costs, contingency costs, and owner's costs and a reduction in engineering costs by 80% (standardized design) will reduce the "Present Price" by $0.28/W.

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[38] In a photovoltaic plant, there is a potential to incrementally bring a plant on-line, thereby generating revenue while the plant is still under construction.

TABLE 31

BALANCE-OF-SYSTEM PRICES

(Expressed in 1978 Dollars)

Application:	Central Power Plant	Location:	Semi-Rural
Size:	10,000 kW	Battery:	None
Array Size:	8.33×10^{5} ft^{2} (913' X 913')		

BOS Element	Present Cost		Future Price
Structures	--		$\$3 \times 10^{6}$ [1]
Power Conditioning	--	\$0.65/W[3]	\$800,000[2]
Installation	--		Included in Structures
Battery	--		--
	\$ 6.5M		$\$3.8 \times 10^{6}$
BOS Prices (\$/Wp)	\$0.65[4]		\$0.38

NOTES:

[1] Average of Sandia design studies (\$300/kW).

[2] Average of Sandia design studies (\$80/kW).

[3] Bechtel/JPL data--Contract #954848 and Tsou and Stolte, op. cit.

[4] Includes owner's cost, contingency, engineering, distributable field cost (\$0.36/W).

G. SUMMARY

A key requirement for the success of the market pull strategy that underlies the procurement initiative is investment by photovoltaic vendors in capital intensive, labor-saving new production equipment to lower production costs. Accordingly, a key question is "Will vendors make the necessary investments?" From the analyses above, we conclude that, with or without the initiative, vendors are unlikely to make significant investments in new equipment until intermediate markets are more evident and the technology stabilizes.

Vendors are faced with two types of risk or uncertainty which impede investment. The impediments have been described as market uncertainty and technological uncertainty. Dealing first with market uncertainty, there is very little hard evidence on the sales potential for photovoltaic devices in the array price range of \$10/Wp to \$0.50/Wp. There is relative agreement that only at the lower end of this price range will photovoltaics effectively compete with the domestic grid-connected market. Market uncertainty clouds sales forecasts for markets in which electric power has seen only limited use, (e.g., remote foreign village power, many outdoor lighting and cathodic protection applications). Sales forecasting for those applications requires predicting the market success of new products embodying new technology in newly served markets.

The existence and extent of such markets are currently unsubstantiated, yet their realization and penetration are critical to recoup large investments in production equipment. The evidence presented above indicates that vendors and potential vendors do not perceive suitably sized markets in the \$10/Wp to \$2/Wp range.

The procurement initiative per se does little to eliminate commercial market uncertainty, although over the course of the initiative some market data would be obtained. The initiative does provide a temporary government market or government supported market, but it is a poor substitute for a "real" market. In both size and permanence, a government-created market is unlikely to be sufficient to support large commitments of private capital. As long as the market is largely subsidized, there is little private incentive to strive for cost reduction. Hence, the initiative is unlikely to stimulate large-scale investment since each vendor may only receive a small and variable share of the initiative from year to year.

Turning to technological uncertainty, we accept the views of a number of manufacturers and the JPL SAMICS model that a plant with a \$2/Wp required selling price can be built, even though some technical problems remain to be solved. The primary technological uncertainty is the possibility of technological advances in photovoltaics rendering obsolete investments made in the next several years. DOE is actively pursuing R&D and technological advances in photovoltaics, as are a number of independent companies. The supply workshop participants expressed the belief that a price breakthrough from R&D will occur, the only question was when. It is not necessary to assert that a technological breakthrough will in fact occur to impede capital investment. The reasonable possibility of a breakthrough and concerted efforts to achieve it will be sufficient to retard investment until the breakthrough either occurred or appears unlikely to occur.

Quite apart from a dramatic price reduction breakthrough in photovoltaic technology, the specter of DOE achieving its goal of \$0.50/Wp by 1986 may be a deterrent to investment in \$2/Wp production facilities in the next few years. The window to achieve profitability on a 1982 variety \$2/Wp plant will be relatively small if a 1986 variety $0.50/Wp plant becomes a reality.

There is no question that technological advance has been rapid in photovoltaics and that the rapid pace of technical advance is expected to continue. As noted by the JPL study quoted above, the natural response and apparently the historical response to rapid technological change in an industry is a tendency to minimize capital equipment investments and maintain flexible and relatively labor-intensive production processes until the technology stabilizes. This private reaction is socially optimal in that it minimizes the prospect of wasting capital equipment (by making it obsolete) or resources that society can use elsewhere. Again, the procurement initiative does little to minimize the technological uncertainty faced by firms and hence, the risks attached to capital investments. In fact, DOE actively increases those risks through its photovoltaic R&D program.

Hence, we conclude that because of technological uncertainty as well as market uncertainty, the initiative would be unlikely to stimulate sufficient investment in new capital equipment to achieve the cost reductions necessary to make the market pull strategy work.[39]

This conclusion is reaffirmed by the results of the supply workshop. The participants in the workshop believed that the initiative would have very little effect on accelerating the achievement of either a $2/Wp photovoltaic module price or a $0.50/Wp price. The initiative would accelerate the achievement of these goals by approximately one year according to the workshop

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[39] In addition, as noted above, the average firm had very little to lose by "sitting-out" the initiative and waiting to see if adequate markets develop and the technology advances.

participants. The workshop participants indicated that the initiative was unlikely to accelerate the achievement of a sustained 100 MWp/year commercial market at $2/Wp to $3/Wp. Thus, although there was some inconsistency in the supply workshop results, our interpretation is that the supply workshop participants indicated the initiative would have very limited effect over what is likely to occur in the absence of the initiative. We cannot explain why the supply workshop participants believed the initiative would accelerate capital investment by the photovoltaic industry when they believed price and commercial sales would be largely unaffected. In any event, industry investment is a means to an end and not an end in itself. The workshop results suggest that even if investment is encouraged by the initiative, there will be limited output effects of a price and quantity nature. This differs from our assessment that investment will not be encouraged but confirms our conclusions about the relative insensitivity of price and quantity changes as a result of the initiative.

The Gnostics report also tends to confirm the conclusion that the initiative will have little effect in stimulating investment. Because of a rapidly changing technology through the mid-1980s, manufacturers will be reluctant to make significant investments in current production technology. Hence, increases in demand will, in general, be met by marginal additions to existing plant and equipment and capacity will not grow as fast as demand. Hence, a seller's market will exist. The initiative will not encourage much additional investment in production equipment but will aggravate the problem of excess demand. Prices will not fall substantially (because of the seller's market) and investment by manufacturers will not increase significantly as a result of the initiative.

In summary, three different analyses by three different groups have reached the same general conclusion. The initiative is unlikely to stimulate significant investment in additional production equipment and will have little effect in terms of accelerating the achievement of either DOE's price or quantity goals. For this reason, and because a modeling effort (reported in the next two chapters) demonstrates that the costs of the initiative will exceed the benefits even if industry does make the required investments, we have not explicitly modeled vendor response.

IV. INTEGRATING STRUCTURE

A. INTRODUCTION

This chapter describes how the data and information that have been collected on supply and demand factors are synthesized to arrive at an assessment of the likely effects of the photovoltaic procurement initiative. Both the framework for combining the supply and demand information and a model for making the framework operational are described below.

The integrating model is an explicit representation of the interactions between photovoltaic markets and supply under alternative sets of assumptions. It provides a consistent way of assembling and integrating the various assumptions, data, and information that have been obtained on photovoltaic systems supply and demand factors. Secondly, it provides a mechanism for understanding the implications of all the interacting assumptions. By representing the assumptions in a common, explicit framework, much more complex interactions can be considered than are possible intuitively. The integrating model therefore provides a way of examining the relative importance of different assumptions, parameters, and inputs through sensitivity analysis.

Development of the model was an evolutionary process. Initially, all interactions were not represented at the level of detail that was ultimately desirable. However, they were represented in such a way that sensitivity analyses could be performed to determine the most critical parameters. If changing certain variables through their maximum credible range did not have a significant impact on the net benefits of an initiative, then these variables did not have to be considered in great detail. However, if changing variables through their maximum range did result in different initiative recommendations, then more analysis was done in those areas to reduce or deal with the uncertainty surrounding the values the variables could assume. These sensitivity results, along with inputs from DOE, provided an explicit means of efficiently directing the analysis. Important sensitivity analyses and the treatment of uncertainty in certain critical variables are described in the next chapter.

B. THE FRAMEWORK AND INTEGRATING MODEL

Figure 8 sketches the structure developed for integrating information on the supply-demand interactions in photovoltaic markets. As Figure 8 illustrates, it is necessary to combine information on current photovoltaic array prices, balance-of-system prices, and the price of system installation to obtain an estimate of the market price of a photovoltaic system. This combining of components into a system must be done for particular market applications and must incorporate expected changes in costs and prices through time stemming from a variety of factors generally labeled experience. Then, estimates must be made of the size of potential photovoltaic markets and of the price of alternative energy products or technologies that will compete with photovoltaics in those markets. Again, estimates are needed through time and must reflect factors such as changing prices of competing technologies, the price sensitivity of particular markets and consumer responses in each market.

The estimates of the price of photovoltaic systems for a given market application then interact with the estimates of market size, market response, and the price of competing products to yield estimates of the array sales and price in each year. Given these estimates of quantity sold and price plus the price of competing technologies, the gross economic and environmental benefits of the procurement initiative can be calculated for each

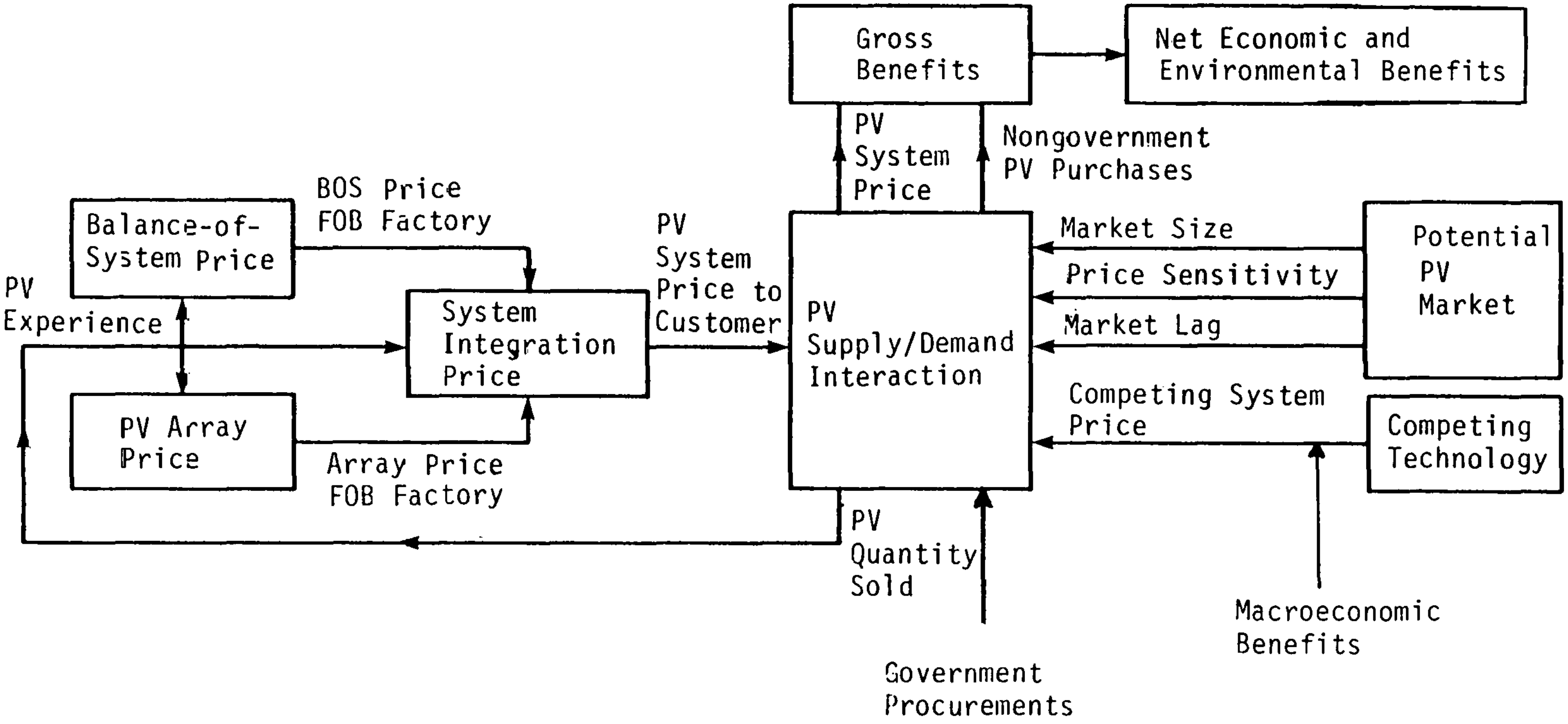

Figure 8. Overview of Integrating Model

market. Appropriate deduction of the costs of the procurement initiative from the gross economic benefits and application of present value discounting then yields the net benefits of the initiative.

The interactions outlined in Figure 8 have been incorporated in a computer model that uses available data and expert judgments on supply and demand input variables to make the price and quantity projections through time.

Before beginning the detailed discussion of the model, it is useful to briefly outline how it will be used in Chapter V. Consider the simplified decision tree shown in Figure 9. It shows some potentially important uncertain events and choice variables. The government can choose to invest funds in research and development or to divert funds into a commercial procurement

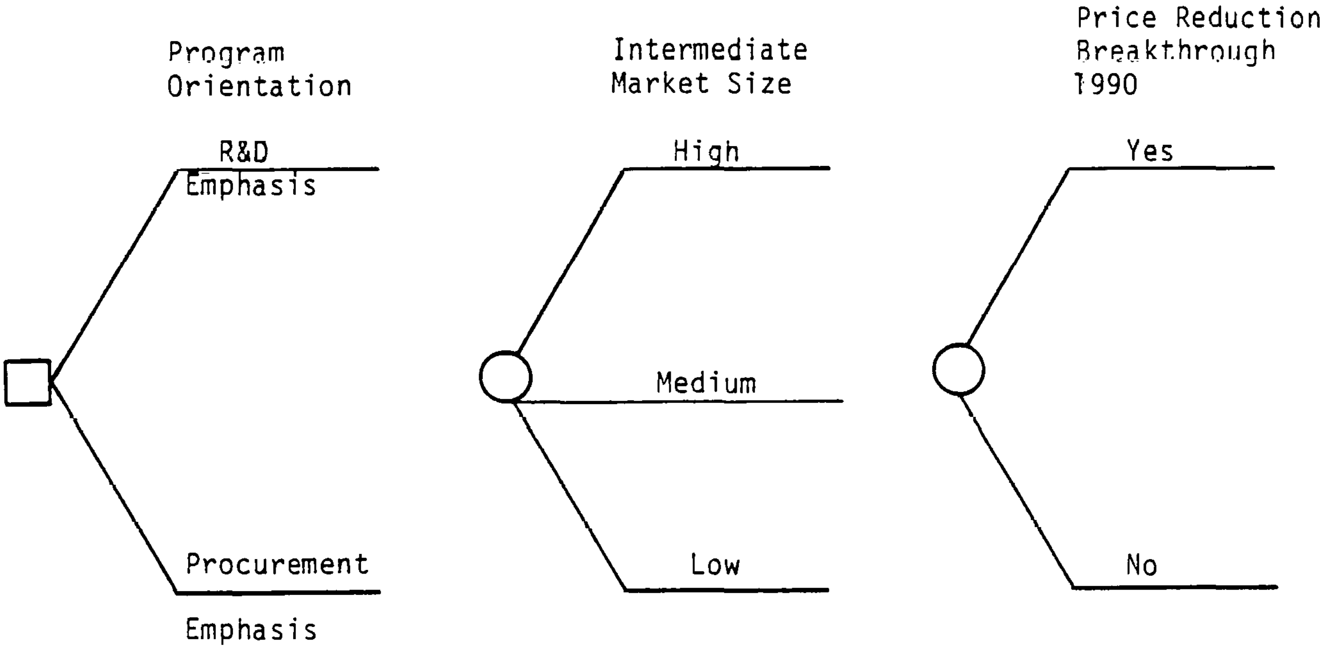

Figure 9. A Simplified Decision Tree

initiative. The intermediate markets such as water pumping and outdoor lighting may be large, moderate, or small in size. The R&D program could lead to a price reduction breakthrough that would enter the market in 1990. For each decision, there are six scenarios defined by the tree. These are shown in Table 32. To evaluate the two decision alternatives it is necessary to determine the effects and net benefits of each of 12 cases. In the absence of a model, it would be impossible to examine the likely effect of changes in more than a few variables.

TABLE 32

SAMPLE DECISION TREE SCENARIOS

Decision	Market Size	R&D Result
R&D Emphasis	Large	Breakthrough
	Large	No Breakthrough
	Moderate	Breakthrough
	Moderate	No Breakthrough
	Small	Breakthrough
	Small	No Breakthrough
Procurement Emphasis	Large	Breakthrough
	Large	No Breakthrough
	Moderate	Breakthrough
	Moderate	No Breakthrough
	Small	Breakthrough
	Small	No Breakthrough

The sections below highlight the key features of the computerized integrating framework. Precise definitions of equations and parameter values are provided in Appendix A of this report. The description is simplified to give the reader an intuitive feel for the model. Chapter V will describe the actual use of the model in the analysis.

C. INTEGRATING MODEL TREATMENT OF PRICE REDUCTION

Future prices for the photovoltaics array, balance-of-system components and the system integration (i.e., installation and mark-ups) are estimated separately in the model. The representation used in the three submodels for estimating these prices has the form of the curve shown in Figure 10. It represents the relationship between cumulative production and all production costs. As cumulative production increases, price decreases toward a minimum price. The minimum price represents the asymptotic limit in price reduction that can be achieved for a particular technology. For example, it might represent the limit achieved in the production of a particular type of array or in the production of a particular combination of balance-of-system components for a specific market application. The rate of decrease toward the minimum price is determined by the experience factor. The experience factor represents the fractional decrease in price from any initial price to the minimum price when the cumulative production doubles. Thus, if price were currently \$15/unit and the minimum price \$1/unit, a 0.8 experience factor would imply that the price would drop to \$12.20[1] when cumulative production doubles. Naturally, a larger experience factor implies a smaller decrease in price. Different experience factors, initial prices, and minimum prices are used for the array, balance-of-system, and systems integration prices. For different types of photovoltaic systems, the parameters describing balance-of-system and systems integration prices are also different.

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[1] \$12.20 = 0.80 x (15.00 - 1.00) + 1.00

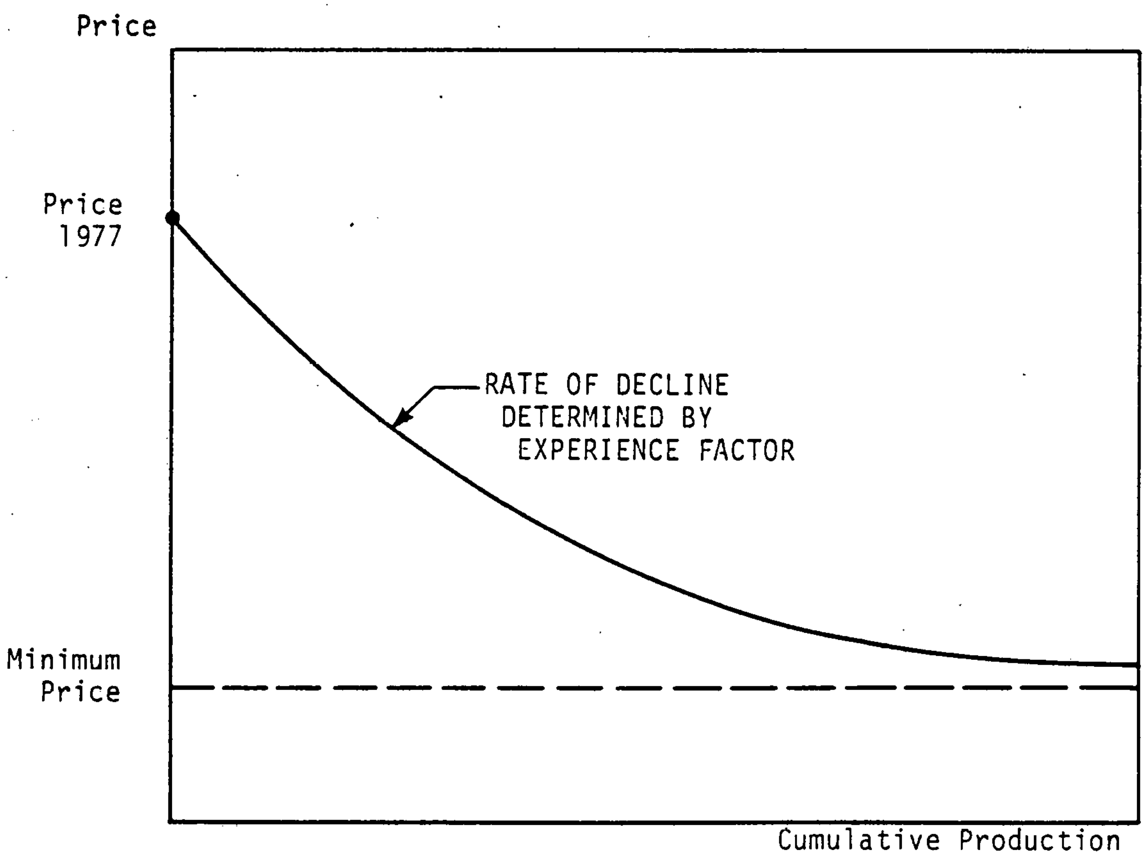

Figure 10. Simplified Price Production Relationship Used as Basis for Integrating Model

Curves such as the one shown in Figure 10 are sometimes called experience curves, although experience curves usually do not have a minimum price. However, to usefully represent the effects of experience on photovoltaic system component prices, a minimum price is necessary. Although opinions may differ on the level of the minimum price, most observers would agree that there is a minimum array price achievable using a particular technology, for example, single-crystal silicon. Without explicitly representing the minimum price, one is forced either to vastly overestimate the long-term price reduction that can be achieved or to underestimate the short-term price reduction that can be obtained. That is, learning based on early investment in new equipment may be relatively large. But given the same technology and production process, that high rate of learning in future years will overestimate long-term cost reduction possibilities.

Fundamental shifts in the underlying production technology, for example, from single-crystal silicon to thin films, is represented by compounding two or more experience curves as is shown in Figure 11.

D. PHOTOVOLTAIC ARRAY PRICE SUBMODEL

Photovoltaic array prices (FOB factory--1975 $/Wp) are assumed to be sensitive to both the absolute level of array production and the rate of growth of production. Prices tend to decrease as cumulative production increases following an experience curve similar to the ones described above. However, if demand rises sharply and industry has to increase production rapidly to meet demand, there is little, if any, immediate price reduction. This is caused by the inefficiency of running second and third shifts and the other extraordinary steps taken to meet demand. These two effects (i.e., volume based cost reduction and supply shortages) interact in determining array prices.

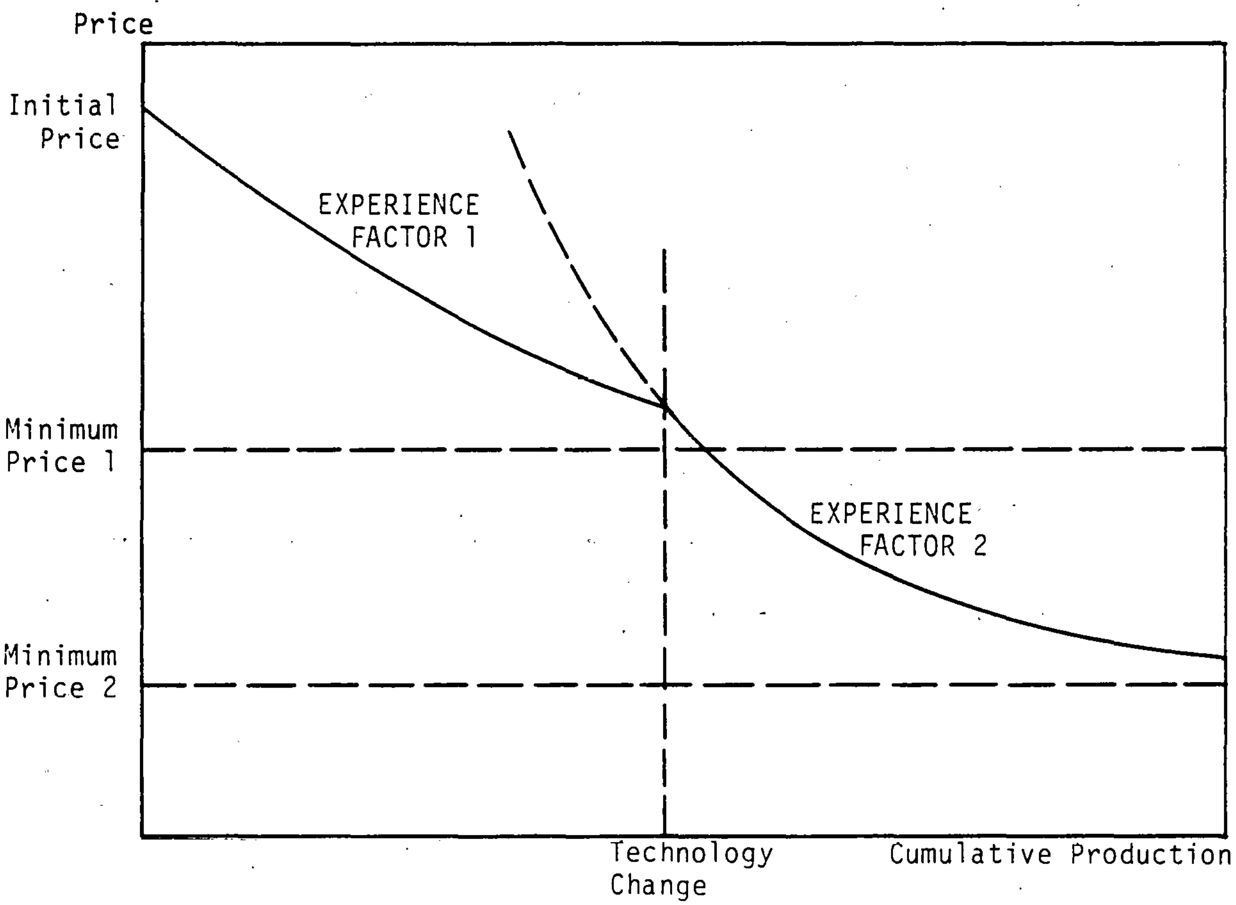

Figure 11. Price Reduction Formulation Used in the Integrating Model

In the model, it is assumed that the supply of arrays will always expand to meet demand at any given market price. However, sharp increases in production to meet demand or overcome supply shortages will result in less price reduction than more moderate expansions in output (i.e., a "sellers' market" will occur).

The impact of disruptions in production can be represented intuitively in terms of the experience disruption factor sketched in Figure 12. The factor represents the fraction of units on which production experience is gained. When array industry growth is small, then experience is gained on 100% of the units produced. When growth is large, the production volumes do not translate into immediate experience. This experience is "stored," and gained at some time in the future when growth is reduced to a more manageable level.

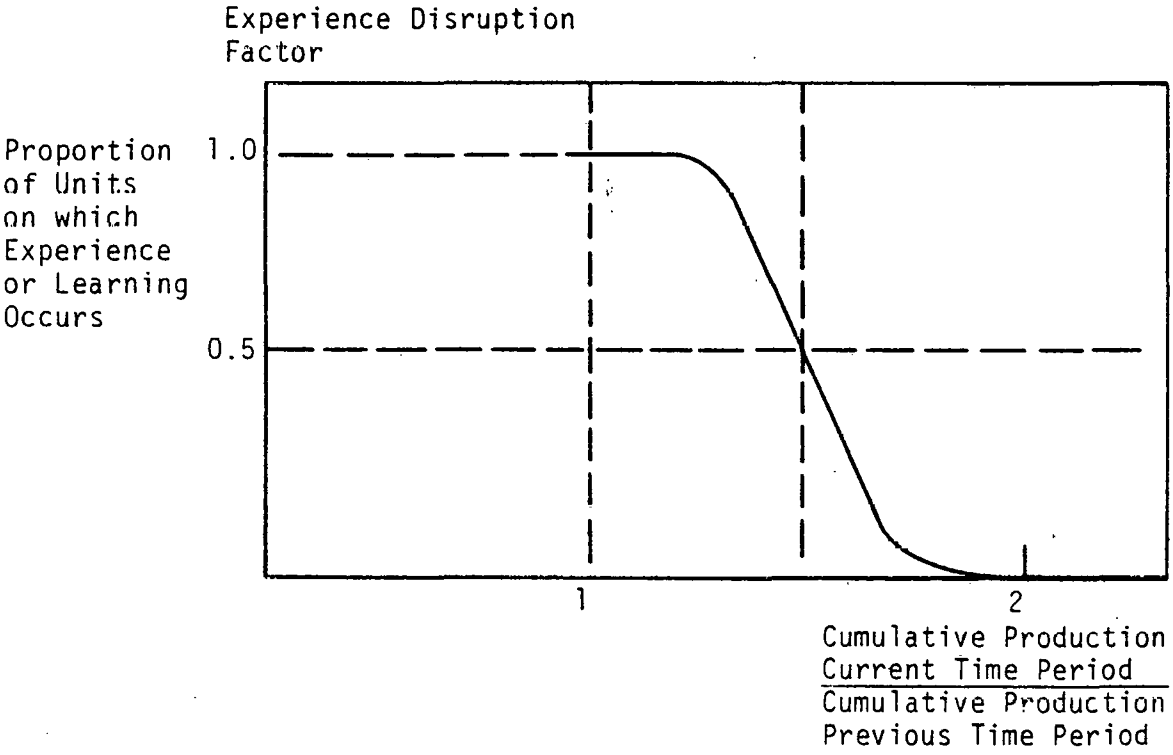

Figure 12. Operational Form of Experience Disruption Submodel

E. BALANCE-OF-SYSTEM PRICE SUBMODEL

In the balance-of-system submodel, the system components in each market, excluding the array, are aggregated. The price of the aggregate balance of system is then represented as a function of cumulative system production.

The relationship between price and cumulative experience is identical to that described in the photovoltaic array price submodel discussion. That is, experience is measured in terms of the cumulative number of units produced. Building a unit in a particular market yields a unit of experience. However, building a unit in one market may also yield some fractional unit of experience in the next market. The size of this fraction (termed cross-market learning) varies according to the similarity of the balance-of-system in the two markets. For example, building a 175 W outdoor lighting system might yield 0.8 units of balance-of-system experience in the market for 250 W outdoor lights. Building the outdoor light might only yield 0.1 unit of experience in the cathodic protection market. The output of this model is the FOB price of the balance-of-system for each market for each time period based on cumulative experience.

The balance-of-system experience curve is an aggregate curve representing all balance-of-system components. The parameters of this aggregated curve are assessed based on estimates of the experience parameters for each of the major balance-of-system components. For example, the initial balance-of-system price is based on estimates of the prices of the major components. Similarly, the minimum balance-of-system price is based on estimates of the minimum price for each component. The experience factor is an estimate of how rapidly the minimum price could be achieved.

F. SYSTEM INTEGRATION PRICE SUBMODEL

The balance-of-system components must be combined with arrays and installed on-site to become a working unit. The system integration price submodel reflects the cost associated with this process. There are two components in the cost of integrating: the cost of doing the integration and the mark-up on the arrays and balance-of-system purchased by the system integrator.

The cost of performing the integration is subject to experience-induced price reduction. The price reduction is represented in a way identical to that used with the balance-of-system. In several, the rate of experience-induced price reduction is less for system integration than for the balance-of-system. The experience for a given market consists of experience at building the given units plus a cross market experience factor.

The mark-up is a percentage that the system integrator applies to the FOB array and balance-of-system prices. The total price of the photovoltaic system to the customer is the sum of the FOB price of the arrays and balance-of-system, the mark-up on these components, and the cost of system integration.

G. MARKET SUBMODEL

As discussed in Chapter II, photovoltaic system markets are represented by specific end uses such as cathodic protection or water pumping. Market size represents potential end use purchases and is determined by the amount of replacement purchases plus new units. Each market grows at its own rate. For example, the communications market grows more rapidly than does the market for cathodic protection of shallow wells. Each market is also characterized by the sensitivity of buyers to changes in price and the speed at which the purchasers will use a new technology. The impact of the price sensitivity of market demand and the delay in acceptance of new technology are described in a later subsection.

H. COMPETING TECHNOLOGY SUBMODEL

The breakeven price that a photovoltaic system must meet to compete with conventional technologies in each market is determined on the basis of the capital and operating costs of the competing technologies and conventional decisionmaking criteria in each market. The decisionmaking criteria may range from a simple payback criterion to a detailed discounted life-cycle costing method. The key point is that the method selected should reflect the criteria used by actual decisionmakers in the specific market. An independent model has been developed to calculate breakeven prices. This model is used to generate and to verify inputs to the competing technology model. Thus, the competing technology submodel either uses estimates of breakeven prices obtained by adapting the estimates provided by BDM and SAI for each market or estimates generated by the independent breakeven model price. These breakeven prices interact with photovoltaic prices to determine the amount of market penetration and sales of photovoltaic systems.

To reflect escalation in the underlying inputs to the competing technology such as labor, materials, and fuel, the competing technology's price is assumed to escalate over time.

I. THE SUPPLY/DEMAND INTERACTION SUBMODEL

This submodel represents the government subsidized sales, the competition between photovoltaics and conventional systems in the markets, and the delays in market acceptance of photovoltaic systems.

The key decision in a government procurement initiative is the number of dollars to allocate to procurements in each subsidized market as a function of time. A variety of subsidy options could be considered. The one currently used assumes that the government subsidizes the difference between the photovoltaic system price and the price of the competing technology or competing source of power. The budget for each market for each year is divided by the subsidy per system to obtain the number of photovoltaic systems in each market that the government initiative subsidizes. The remainder of the market is subject to competition between unsubsidized photovoltaics and the competing technology. The relative prices of the photovoltaics and the competing system determine the percentage of the remaining market captured by each source. This percentage is called the market share. This market share is related to the price ratio as shown in Figure 13. At the two extremes, when one price is much smaller than the other, then the lower cost source sells the vast majority of the units in the marketplace. When the two prices are equal, they sell an equal share.

The shape of the market share curve can be varied by changing the price sensitivity parameter as shown in Figure 14. In less price sensitive markets, a relatively large number of photovoltaic systems might be sold even if the photovoltaic price was somewhat greater than the price of the competing technology. A market would be price sensitive if the buyers are sophisticated purchasers of a relatively homogeneous products such as radio repeaters. A residential market might be less price sensitive because photovoltaic devices may have appeal to the purchaser for reasons quite apart from price considerations.

The market share model represents the quantity of photovoltaic systems that will ultimately be purchased in each market based on the relative economics of the photovoltaic systems versus

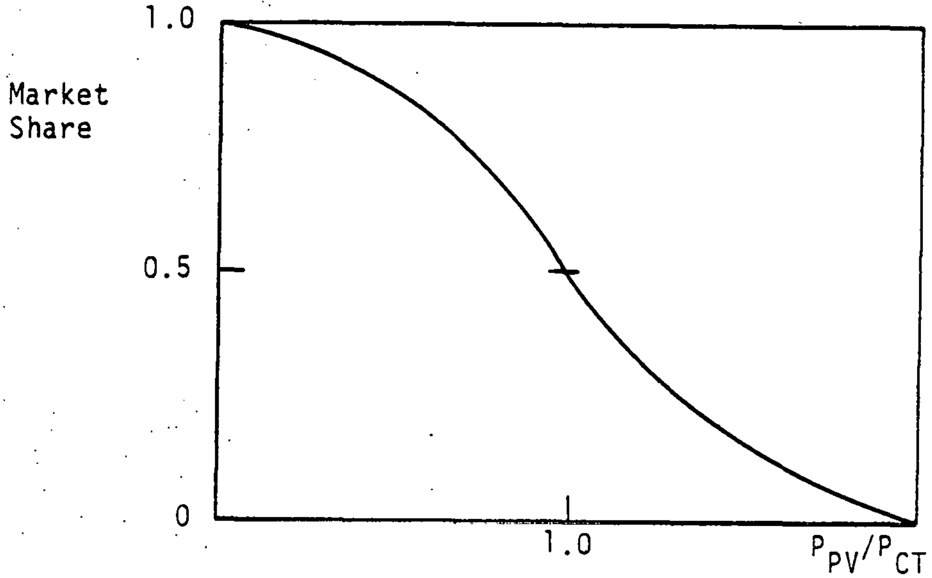

Figure 13. Market Share Function Used in the Integrating Model

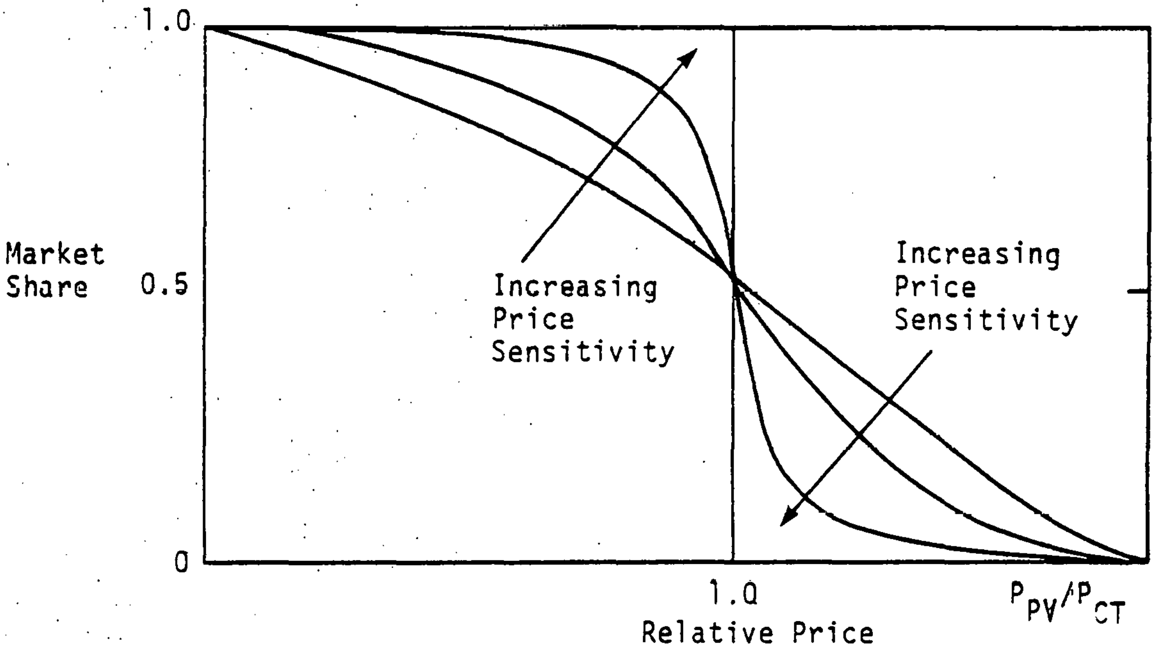

Figure 14. Integrating Model Market Share Curve

conventional systems. However, the actual quantities purchased do not respond immediately to the indicated quantity. There is a lag as consumers adjust to the availability of the new technology and accept it in their applications. Thus, the quantity demanded (sold) responds as shown in Figure 15. The quantity actually purchased approaches the quantity indicated by the market share.

The speed of the adoption of photovoltaic systems can be varied. Figure 16 shows several lag curves. With an increasing lag, it takes longer for the indicated quantity to be reached. The communications industry might have minimal lag when considering the purchase of photovoltaic-powered radio repeaters. On the other hand, there might be more lag in cathodic protection markets, where there is a stronger tradition in conventional methods.

To summarize the supply/demand interaction model, three phenomena are represented:

- government subsidized purchases;
- the market share of solar systems in each market based on the relative economics of photovoltaic systems and competing technologies; and
- the lag in the actual quantities purchased in the nongovernment procurement market.

These phenomena are modeled for each market in each time period.

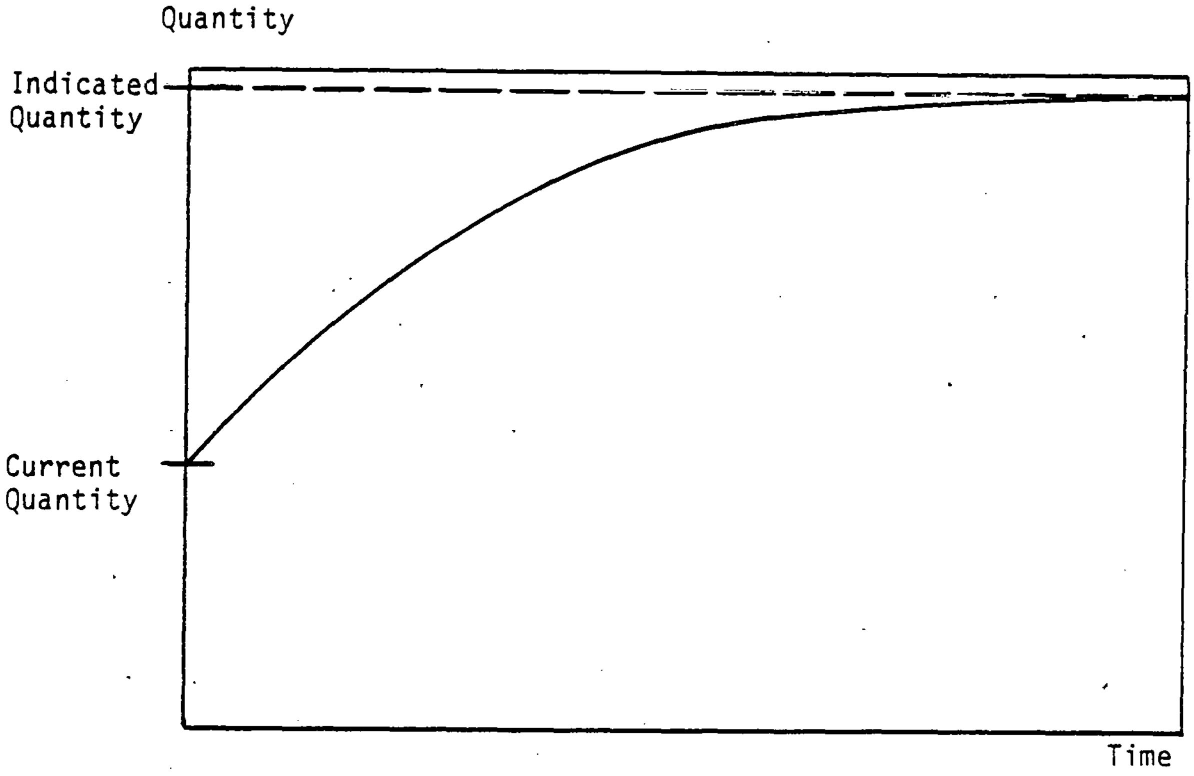

Figure 15. Shape of the Market Response Lag Curve Used in the Integrating Model

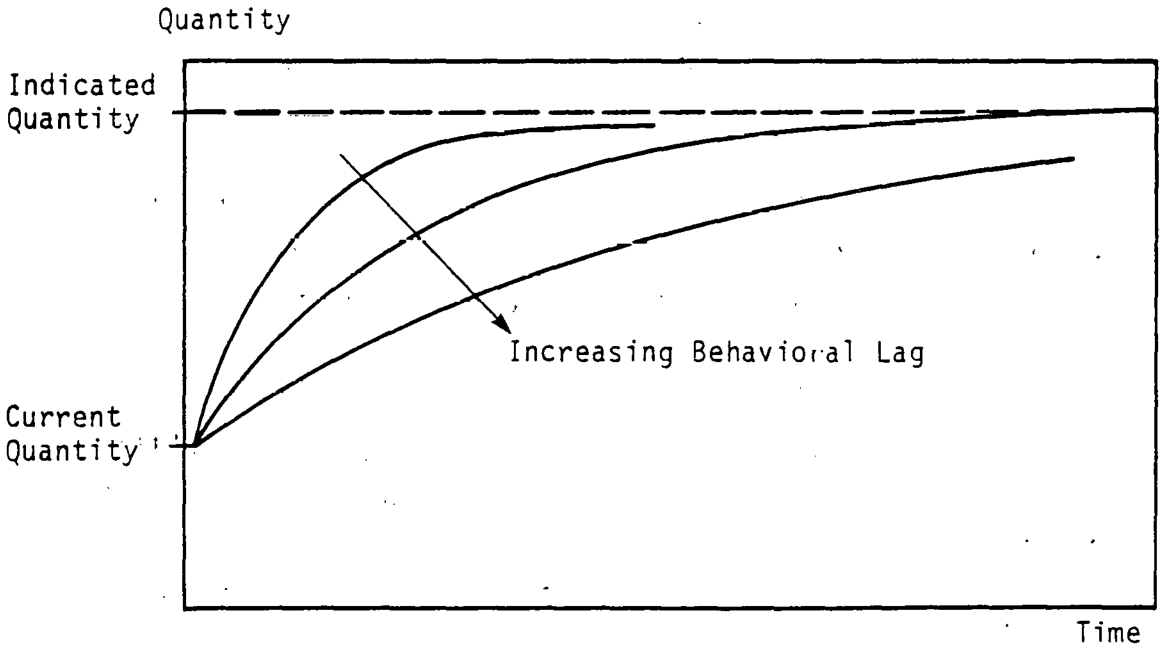

Figure 16. Possible Changes in the Behavioral Lag Curves

J. BENEFITS SUBMODEL

The prices and quantities of photovoltaic systems sold in each time period represent the effect on each market of various assumptions about the government initiative. The model estimates these prices and quantities by market. In addition, these outcomes are evaluated in the benefit model to calculate the net economic effect and the environmental benefit of alternative decisions.

The economic benefits are measured by the change in U.S. consumers' surplus. The change in consumers' surplus is a well-accepted guideline for evaluating the economic impact of a government program. Use of the concept in the current analysis is outlined in Figure 17 which is a sketch of the demand curve typical of each photovoltaic market. The effect of a procurement program is to reduce the price and increase the quantity of the photovoltaic systems. Notice that the sketch used in Figure 17 represents the difference between what consumers were willing to pay for the photovoltaic systems before the initiative minus what they had to pay after the initiative. This difference is the economic benefit of the initiative.

In the integrating model, the change in consumer surplus is calculated using the prices and quantities of photovoltaic devices sold in each market with and without the government program. Each market is assigned a benefit weighting factor. These factors have been set in the analysis to be either zero or one. They represent the percentage of the consumer surplus for that market included in the total gross economic benefits. For example, all domestic markets are weighted equally, and each has a weight of one. Foreign markets might not be given any weight in the national benefit analysis and hence would be weighted zero. Of course, even if the benefit weighting factor is zero, the market must

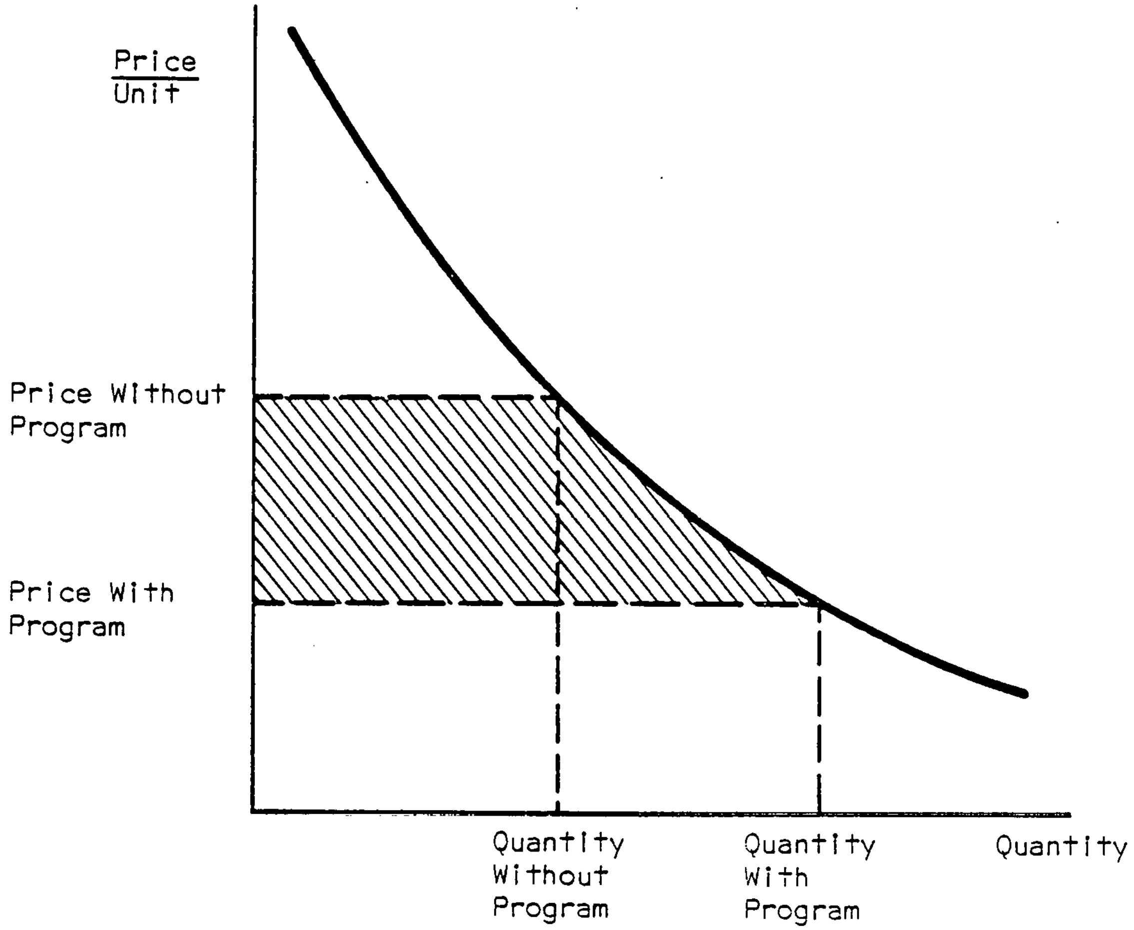

Figure 17. Change in Consumer Surplus in a Typical Photovoltaic Market

still be considered explicitly because of its interactive effects with other markets in terms of adding to cumulative production volume. However, if the foreign aid benefits of entry into non-U.S. markets are evaluated positively, the weight for foreign markets would not be zero. Similarly, if judgments are made that it is more important to emphasize certain markets--domestic or foreign--relatively more than others, they could be given higher weights. Thus, energy saving markets might be weighted more heavily.

The benefits submodel also includes a calculation of the environmental benefits attributable to government programs. Photovoltaic power systems, in general, provide environmental benefits when they replace conventional energy sources that have higher environmental emissions. A government procurement program causes increased environmental benefits to the extent that it accelerates the use of photovoltaics in place of conventional systems.

The environmental benefits are calculated in each year and then discounted and summed to give a discounted present value of benefits. Total environmental benefits are then found by adding the contributions from all markets.

Each of the variables in the environmental benefit calculation is a function of the market application. In finding the change in photovoltaic power that replaces conventional power, one must have both the total power installed with and without the government program and the average lifetime of the particular photovoltaic systems. The environmental benefit per kilowatt hour of solar power also depends on the market. For example, a first order estimate of the environmental benefits of replacing a kilowatt hour of central plant electricity generation might be taken as \$0.001 to \$0.005/kWh.[2] The latter value has been used in the analysis.

Before net benefits of the initiative can be calculated, the program costs must be considered. There are two sources of cost for the program. Administrative costs are the monies spent to

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[2] See, for example, Banager et al., The Economic and Social Costs of Coal and Nuclear Electric Generation, prepared for the National Science Foundation, GPO stock number 038-000-00293-7, March 1976.

manage the procurement and do not result in the purchase of any photovoltaic devices. The second source of costs is the budget used for actual procurement.

The costs and benefits of the market pull initiative occur at various points in time. They are converted into a single value measure by discounting constant dollar amounts at 5%.

The net economic benefits of a government procurement initiative are the discounted economic market benefits minus the discounted administrative and budget costs.

K. SUMMARY

The integrating model provides a consistent and explicit way of comparing data and assumptions about supply factors with data and assumptions about demand factors to produce information about the likely effects of the procurement initiative in terms of array sales and array prices by year, by market, and net benefits.

V. ANALYSES OF THE FEDERAL DECISION

A. INTRODUCTION

This chapter presents the results of the integrating model. Its purpose is to first examine the relative changes in array prices and sales under a variety of scenarios and then to investigate how the federal initiative could alter those scenarios. The variety of scenarios presented represents the uncertainty in current knowledge. The analysis of the initiative under each scenario allows a range of possible net benefits to be derived. The chapter also includes a brief examination of research and development expenditures and alternative procurement strategies, such as government-supported production facilities or a single purchase of arrays at a fixed price by the federal government.

The chapter is organized into five sections. Following the introduction, Section B outlines the baseline assumptions used in the analysis. The next section presents the major results of the integrating model. These results are ordered by their relative impact on the net benefits of the initiative. The examination and comparison of the detailed results in this section are necessary steps to understanding the conclusions that have been drawn. Section D analyzes the role of uncertainty in the results. The section includes a probability tree representing expected results of the initiative and their probability. Section E is an examination of the sensitivity of the results to various assumptions and data used in the analysis.

B. ASSUMPTIONS OF THE ANALYSIS

The assumptions of the analysis fall into three groups. The first group characterizes the response of the photovoltaic industry to market conditions and government actions. The second group characterizes current and potential photovoltaic markets. The third set stipulates the government actions in terms of the dollar outlays in each market.

As emphasized in Chapter IV, the integrating model represents the interactions in the photovoltaic industry. Investment decisions, cost trends, and pricing strategies concerning photovoltaic arrays are represented in the model by a cost reduction equation that relates the annual array price to the cumulative volume of array production. This representation allows the array manufacturing industry response to be characterized by five variables (see Table 33). In addition, assumptions are needed on the extent to which cost reduction from production experience is postponed under conditions of rapid industry expansion; i.e., a "seller's market." Cost reduction in a given year is assumed to drop 50% when industry production in a given year is equal to half of cumulative industry production in past years, and cost reduction is virtually eliminated when industry production in a given year is greater than cumulative past industry production. When the industry "stabilizes" and production in a given year is 25% of cumulative past production (or less), then full cost reduction based on cumulative past production experience is realized. Learning from production during periods of rapid expansion is not lost, but rather delayed.

TABLE 33

INTEGRATING MODEL INPUT ASSUMPTIONS

Part I - Photovoltaic Array Supply Conditions

Array Price in 1977 ($1975/Wp FOB factory)	15.00
Cumulative Production to 1977 (MW)	1.00
Experience Factor (Ratio of New Price Less Asymptotic Price to Initial Price Less Asymptotic Price as Cumulative Production is Doubled)	0.75
Asymptotic Price of Array ($1975/Wp)	0.50

The other components of the industry response are the price of the nonarray system components, the installation costs, and the profits taken throughout the supply-distribution chain. As discussed in Chapter III, the price of the nonarray system components varies with the design of the system and, therefore, on the market application. Price trends in those components are also not uniform across applications. The price of the nonarray system components over time is calculated in the integrating model using the variables shown in Table 34.

The positive effects of experience in building and installing systems for one market on the cost of building and installing systems in another market are also included. The assumed values of these "cross-experience" effects are contained in Appendix B of Volume II.

The second group of assumptions for the analysis describe the markets. Chapter II contains a detailed review of the available information on current, intermediate, and long-term markets. For the integrating model, markets are defined by (1) the potential size of the market in 1978, (2) the growth rate in that potential

TABLE 34

INTEGRATING MODEL INPUT ASSUMPTIONS

Part II - Balance of System Prices and Trends

	Market	Typical System Size (Wp)	Balance-of-System Parameters			System Integration Parameters			
			Reference Price ($/System)	Experience Factor (Decimal Fraction)	Asymptote ($/System)	Reference Price ($/System)	Experience Factor (Decimal Fraction)	Asymptote ($/System)	Markup[a] (%)
1.	U.S. Communications	200	1,300	.80	750	320	1.00	320	20%
2.	U.S. Shallow Well Cathodic	180	1,260	.90	300	320	1.00	320	30%
3.	U.S. Deep Well Cathodic	600	3,950	.90	2,275	320	1.00	320	30%
4.	U.S. Outdoor Lighting	300	1,650	.85	1,050	160	1.00	160	20%
5.	U.S. Government: DOD	3,400	10,125	.95	6,750	0	1.00	0	10%
6.	U.S. Government: Non-DOD	1,600	6,500	.90	3,250	2,000	.90	1,000	20%
7.	U.S. Consumer	40	50	1.00	50	10	1.00	10	50%
8.	Foreign Communications	200	1,300	.80	960	900	1.00	900	40%
9.	Foreign Pumping: Low-Lift	250	305	.80	250	150	1.00	150	40%
10.	Foreign Pumping: Medium-Lift	1,000	2,200	.90	800	2,000	.90	1,200	40%
11.	Foreign Deep Well Cathodic	1,000	4,550	.90	2,000	2,230	.90	1,200	40%
12.	Foreign Remote Power	1,000	4,500	.90	2,000	1,500	.90	660	40%
13.	U.S. Grid: Sunbelt	3,400	2,000	.90	935	1,065	1.00	1,065	20%
14.	U.S. Grid: Non-Sunbelt	3,400	2,000	.90	935	1,065	1.00	1,065	20%

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[a] The percentage markup is applied to the sum of the balance-of-system cost and the cost of the array.

market size, (3) the system price which photovoltaics must attain to be equal to the price of the competing technology or power source in 1978 (termed the breakeven price), (4) the rate of price escalation in competing power sources, (5) a factor reflecting the price sensitivity of the market, (6) a factor representing noncost factors that affect the adoption of new products, and (7) the first year that photovoltaic systems will be available to that market. The most important parameters of those listed are the market size and the breakeven price. Table 35 is repeated from Chapter II. It summarizes these parameters for the 14 markets used in the analysis. The four alternative scenarios of size and price show the uncertainty of current knowledge about photovoltaic markets. Each set of market descriptions is used in the analysis that follows. Therefore, one set has not been chosen as a base case in advance of the sensitivity analyses.

The last set of assumptions for the analysis concerns the timing and distribution of the federal purchases. Chapter I reviewed the planned yearly outlay pattern of the $380 million market-pull initiative. Chapter I also stated that current plans call for the expenditures to focus on grid-connected markets in the late cycles (FY85 to FY86). However, the federal outlays in each year must be specified for each market in order to calculate the net benefits of the initiative. Without direct program guidance, the details of the outlay pattern were specified by the project team. The decisions shown in Table 36 were based on observations of market developments without the initiative. An attempt was made to allocate the initiative funds over the market to have the maximum impact on net benefits. As shown in the table, the outlays in FY79 through FY82 are broadly dispersed over the current and intermediate U.S. markets. From FY82 to FY85, the outlays go predominantly to U.S. government-supported intermediate markets, highway lighting, and DOD applications. Because the initiative was proposed by DOE and plans were made to carry it out under DOE

TABLE 35. INTEGRATING MODEL INPUT ASSUMPTIONS
PART III: MARKET POTENTIALS (1977) AND BREAKEVEN PRICES FOR FOUR MARKET SCENARIOS

	Small Market Scenario		Moderate Market Scenario		Large Market Scenario		Very Large Market Scenario	
MARKETS	System Breakeven Price ($/Wp)	Market Size (MW)	System Breakeven Price ($/Wp)	Market Size MW/yr.)	System Breakeven Price ($Wp)	Market Size (MW/yr.)	System Breakeven Price ($/Wp)	Market Size (MW/yr.)
1. U.S. Communications	20	2.5	20	2.6	20	2.6	26	2.7
2. U.S. Shallow Well Cathodic	35	.5	35	.7	35	.7	35	1.6
3. U.S. Deep Well Cathodic	11	.18	17	1	17	1.5	17	6.5
4. U.S. Outdoor Lighting	1.5	10	2.84	25	2.84	200	4	290
5. U.S. Government: DOD	0	0	4.3	4	4.3	8.5	4.3	86
6. U.S. Government: Non-DOD	6	.6	7	2	7	2	8	6
7. U.S. Consumer	4	1	6	1.8	6	1.8	20	3
8. Foreign Communications	10	1.7	20	2.5	20	4.5	27.5	10
9. Foreign Pumping: Low-Lift	3.5	10	3.5	20	3.5	37.5	4.25	75
10. Foreign Pumping: Medium-Lift	4	5	8	7.5	8	75	9	200
11. Foreign Deep Well Cathodic	15	.1	50	.75	50	.75	50	4.6
12 Foreign Remote Power	4	1	10	4	10	7.5	12	40
13. U.S. Grid: Sunbelt	1.05	390	1.05	390	1.05	390	1.05	390
14. U.S. Grid: Non-Sunbelt	.63	2145	.63	2145	.63	2145	.63	2145

TABLE 36

INTEGRATING MODEL INPUT ASSUMPTIONS

Part IV - Federal Initiative Budget Data

(Government Outlays in Millions of Nominal Dollars)

Market	Fiscal Year 79	80	81	82	83	84	85	86
1. U.S. Communication	5	5						
2. U.S. Cathodic Protection-Shallow Wells	0	0						
3. U.S. Cathodic Protection-Deep Wells	5	5						
4. U.S. Outdoor Lighting		10	30	40	40	30	25	10
5. U.S. Government: DOD				10	10	10	5	
6. U.S. Government: Non-DOD	5	10	10	5				
7. U.S. Consumer Market	5	10	10	5				
8-12. Foreign Markets								
13. U.S. Grid Sunbelt					5	10	10	15
14. U.S. Grid Non-sunbelt	—	—	—	—	5	10	10	15
TOTAL BUDGET	20	40	50	60	60	60	50	40

auspices, no federal initiative funds are spent in foreign markets. Grid applications are subsidized in FY83 through FY86.

In addition to the initiative outlays, a total of \$12 million in administrative costs is added to the program. These costs are distributed over the eight-year initiative in proportion to the yearly direct federal outlay. A 5% real discount rate is used to calculate all benefits and costs of the program.[1]

Finally, the impact of the Federal Photovoltaic Utilization Program (FPUP) is incorporated into the integrating model by adding an appropriate number of array sales to the total annual array production in 1979 to 1981. These additional sales are considered as part of the base case strategy and not part of the incremental benefits of the initiative. Appendix B in Volume II contains details of all the input assumptions of the integrating model.

C. RESULTS FROM THE INTEGRATING MODEL

The effects of uncertainty in the near-term and intermediate markets dominate the results of the integrating model. Accordingly, a set of four cases representing different assumptions for these markets will be presented instead of a single nominal case.

First, a variety of impacts of the procurement initiative primarily manifested in the near-term and intermediate markets is examined. Next, the impacts of the procurement initiative on grid competitive applications are examined in more detail in

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[1] Appendix B of Volume II presents a summary of the analysis using a 10% real discount rate.

combination with alternate assumptions about array price reduction breakthroughs associated with advanced photovoltaic technologies. The results of the integrating model are then combined into the analysis of the federal decision on the procurement initiative.

Impacts in Near-Term and Intermediate Markets

Large Near-Term and Intermediate Market Scenario

The results of the "large market scenario" are summarized in Table 37.[2] The table is an abbreviated form of the output from the computerized integrating model. It shows total array sales in peak megawatts and array prices in dollars per peak array watt with and without the initiative and sales in peak megawatts by market in each of four years. The change in gross consumer surplus benefits for each market (expressed in millions of dollars discounted to 1977) resulting from the initiative is given in the right-hand column. Summary totals of the gross benefits of the initiative over the base case for the domestic markets (markets 1-7, 13, and 14)[3] and foreign markets (8-12) are given, plus environmental benefits, and program costs. The net domestic benefits, which are gross domestic consumer benefits plus environmental benefits less program cost, are shown at the bottom of the table.

Table 37 shows total array sales without the initiative to be approximately 7 MW in 1982, increasing to 54 MW in 1986, and 720 MW in 1996. With the initiative, array sales are increased

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[2] The market input assumptions of the large market scenario are shown in column 3 of Table 35.

[3] Throughout this section, the markets will be referred to by the number corresponding to the tables as well as by verbal descriptors.

TABLE 37. RESULTS OF THE INTEGRATING MODEL LARGE INTERMEDIATE MARKETS SCENARIO[a]

TOTAL ARRAY PRODUCTION AND PRICES	1978	1982	1986	1996	
Array Prices ($1975/Wp)	13.60[b] (13.60)[c]	8.10 (5.50)	3.40 (2.60)	.40 (.40)	
Total Array Sales (MW/Yr)	1.1 (1.1)	6.6 (18.8)	53.9 (80.9)	721 (738)	
ANNUAL SALES BY MARKET (MW/YR)					Discounted Gross Benefits ($10^6)
1. U.S. Communications	.6 (.6)	2.3 (2.2)	3.9 (3.9)	6.6 (6.6)	18.4
2. U.S. Shallow Well Cathodic	.3 (.3)	.6 (.6)	.7 (.7)	.8 (.8)	4.7
3. U.S. Deep Well Cathodic	.03 (.03)	.4 (.5)	1.2 (1.2)	1.7 (1.7)	5.4
4. U.S. Outdoor Lighting	0 (0)	.8 (5.)	6.4 (10.1)	77.5 (78.5)	32.7
5. U.S. Government: DOD	0 (0)	.1 (2.2)	1.4 (1.7)	9.4 (9.5)	5.1
6. U.S. Government: Non-DOD	0 (0)	.01 (1.3)	.5 (.8)	2.5 (2.6)	2.2
7. U.S. Consumer	.03 (.03)	.1 (1.1)	.9 (1.2)	4.1 (4.1)	4.2
8. Foreign Communications	.1 (.1)	1.2 (1.5)	4.1 (4.4)	9.7 (9.7)	19.4
9. Foreign Pumping: Low-Lift	0 (0)	.1 (.3)	2.7 (5.0)	58.0 (58.7)	18.0
10. Foreign Pumping: Medium-Lift	0 (0)	.7 (3.4)	28.0 (40.0)	97.2 (98.2)	133.7
11. Foreign Deep Well Cathodic	0 (0)	.2 (.2)	.7 (.7)	1.4 (1.4)	3.3
12. Foreign Remote Power	0 (0)	.2 (.6)	3.6 (4.6)	9.8 (9.9)	16.6
13. U.S. Grid: Sunbelt	0 (0)	0 (0)	.02 (3.7)	261.3 (267.5)	7.9
14. U.S. Grid: Non-Sunbelt	0 (0)	0 (0)	0 (3.0)	180.8 (188.6)	6.0

SUMMARY OF RESULTS (Expressed as Present Values of 1977 $10^6)

Gross Domestic Consumer Benefits	86.5
Gross Foreign Consumer Benefits	190.9
Environmental Benefits	7.6
Program Cost	224.8
Net Domestic Benefits	-130.7

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[a] Also assumes a 2% real electricity growth rate and a price reduction breakthrough from R&D occuring in 1990. All other assumptions are explained in Section B of this chapter.

[b] Indicates Results without the Initiative.

[c] Indicates Results with the Initiative.

nearly threefold to about 19 MW in 1982, and by 50% to 81 MW in 1986. Sales in 1996 (following an array price reduction breakthrough) are slightly higher than without the initiative, 738 MW. Array prices in 1982 are $5.50/Wp with the initiative and $8.10/Wp without it. In 1986, arrays prices are $2.60/Wp with the initiative and $3.40/Wp without it.

Without the initiative, the foreign intermediate-lift pumping market (10) accounts for more than half of the 1986 market; other foreign markets provide another 11 MW so that the total of the five foreign markets is 39 MW or about 75% of total 1986 array sales. About half of the domestic sales are highway and street lighting (4), and about half of the remaining U.S. market is communications (1). Under the initiative, most of the increased domestic sales occur in outdoor lighting (4) and the foreign pumping markets (9,10,12). If the grid-connected markets being subsidized under the initiative are excluded, foreign sales account for about 75% of sales in 1986 under the initiative.

Benefits from the procurement are concentrated in the near-term and intermediate markets. The largest category of domestic consumer benefit ($32.7 million, or about 40%) comes from outdoor lighting (4); communications (1) is next with $18.4 million (or about 21%); the grid connected markets account for only about $13.9 million or 16% of the $86.5 million gross domestic consumer benefits. Environmental benefits are small accounting for another $8 million; but when the present value of program costs of $244.8 million is added, the net domestic benefit is -$130.7 million. Benefits in foreign markets total $190.9 million, with $133.7 million of this in the medium lift pumping market (10).

Under this large market scenario, the weighting of foreign versus domestic benefits has a critical impact on the evaluation of the federal initiative. If foreign market benefits are given no credit, the net benefit of the initiative is -$130.7 million. If foreign benefits are weighted fully, the world benefits of the initiative outweigh the U.S. costs by about $30 million. If foreign benefits are weighted at 50% of domestic benefits (50 cents on the dollar), the result is to offset about three-fourths of the loss for a net benefit of -$35.3 million.

Small Near-Term and Intermediate Market Scenario

The next market scenario considered corresponds to a very limited set of domestic and foreign markets for photovoltaics in the array price range of $2 to $10/Wp. Outdoor lighting, primarily streets and highways, and pumping applications are assumed to be small in this case, with breakeven prices approaching those for grid-connected applications. The communications and cathodic protection markets are smaller in size and more difficult to penetrate than in the previous case because of assumed lower breakeven prices. The numerical assumptions of this market case are shown in column 1 of Table 35.

Table 38 summarizes the results of the integrating model using the assumptions for the "small market scenario." The annual array sales in the absence of the initiative are quite low: 2.8 MW in 1982 and 5.2 MW in 1986. Even with initiative sales included, annual sales are still small: 7.0 MW in 1982 and 12.2 MW in 1986. At this level of sales, it may be possible for a few manufacturers to install automated production facilities; in the absence of the initiative, the photovoltaic sales by 1986 would not support an investment in even one 10 MW/year plant.

Array and system prices decline slowly under this market scenario, but the initiative has some impact on achieving price reductions (from a commercial market price of $8.00/Wp without the initiative in 1982 to $5.70/Wp with the initiative).

TABLE 38. RESULTS OF THE INTEGRATING MODEL SMALL INTERMEDIATE MARKETS SCENARIO[a]

TOTAL ARRAY PRODUCTION AND PRICES	1978	1982	1986	1996	
Array Prices (\$1975/Wp)	13.50[b] (13.50)[c]	8.00 (5.70)	4.20 (3.20)	.80 (.80)	
Total Array Sales (MW/Yr)	.8 (.8)	2.8 (7.0)	5.2 (12.2)	99.0 (109.9)	
ANNUAL SALES BY MARKET (MW/YR)					Discounted Gross Benefits ($\$10^6$)
1. U.S. Communications	.6 (.6)	2.2 (2.1)	3.7 (3.8)	6.3 (6.3)	24.6
2. U.S. Shallow Well Cathodic	.2 (.2)	.4 (.4)	.5 (.5)	.6 (.6)	4.6
3. U.S. Deep Well Cathodic	0 (0)	.01 (.01)	.1 (.1)	.2 (.2)	.5
4. U.S. Outdoor Lighting	0 (0)	.01 (3.1)	.04 (.9)	.5 (.5)	.4
5. U.S. Government: DOD	0 (0)	0 (0)	0 (0)	0 (0)	0
6. U.S. Government Non-DOD	0 (0)	0 (.7)	.04 (.1)	.6 (.7)	.5
7. U.S. Consumer	0 (0)	.02 (.7)	.1 (.2)	1.5 (1.5)	1.3
8. Foreign Communications	0 (0)	.02 (.04)	.2 (.3)	2.1 (2.2)	2.0
9. Foreign Pumping: Low-Lift	0 (0)	.02 (.1)	.4 (1.0)	13.0 (13.3)	6.0
10. Foreign Pumping: Medium-Lift	0 (0)	0 (0)	.02 (.07)	3.3 (3.4)	1.0
11. Foreign Deep Well Cathodic	0 (0)	.01 (.02)	.1 (.1)	.2 (.2)	.6
12. Foreign Remote Power	0 (0)	0 (0)	0 (.01)	.3 (.3)	.1
13. U.S. Grid: Sunbelt	0 (0)	0 (0)	.01 (2.8)	54.8 (62.4)	10.8
14. U.S. Grid: Non Sunbelt	0 (0)	0 (0)	0 (2.4)	15.7 (18.4)	7.8

SUMMARY OF RESULTS (Expressed as Present Values of 1977 $\$10^6$)

Gross Domestic Consumer Benefits	50.5
Gross Foreign Consumer Benefits	9.7
Environmental Benefits	5.3
Program Cost	224.8
Net Domestic Benefits	-169.0

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[a] Also assumes a 2% real electricity growth rate and a price reduction breakthrough from R&D occurring in 1990. All other assumptions are in Section B of this chapter.

[b] Indicates Results without the Initiative

[c] Indicates Results with the Initiative.

The dominant market without the initiative is domestic communication (1). However, in the 1990s, following the development of new technology and array prices approaching one dollar, a low-lift irrigation market in foreign countries (9) and grid-connected applications (13,14) develop as well. With the initiative, the U.S. outdoor lighting market and U.S. grid-connected markets are significantly larger in 1986 than without the initiative. By 1996, the markets are about the same size with or without the initiative, except in grid applications (13,14), where sales are 78 MW instead of 70 MW.

In this "small market scenario," half of the gross domestic consumer benefit comes in the communications market (1) and about one-third from the residential grid-connected applications (13,14). The gross benefits in foreign markets total $9.7 million. In this case, benefits are far less than program costs, regardless of how foreign consumer benefits are weighted. If foreign benefits are ignored, the net benefit from the initiative is -$169.0 million. If foreign benefits are weighted at 50%, the net benefit is increased only slightly, to -$164.2 million.

Moderate Near-Term and Intermediate Market Scenario

The "moderate market scenario" contains market size and breakeven price estimates between the extremes of the large market scenario and the small market scenario. Under this scenario, modest potential intermediate markets of the order of 70 megawatts of annual array sales can be developed at array prices above $2/Wp. The details of this market scenario are shown in column 2 of Table 35.

Table 39 summarizes the results of this scenario. The initiative results in total array sales being increased by 9 MW in 1982 and by 12 MW in 1986. The reduction in array price in 1986 is $0.80.

TABLE 39. RESULTS OF THE INTEGRATING MODEL MODERATE INTERMEDIATE MARKETS SCENARIO[a]

TOTAL ARRAY PRODUCTION AND PRICES	1978	1982	1986	1996	
Array Prices ($1975/Wp)	13.60[b]	7.90	3.50	.60	
	(13.60)[c]	(5.30)	(2.70)	(.60)	
Total Array Sales (MW/Yr)	1.0	4.6	17.2	293.2	
	(1.0)	(13.6)	(29.3)	(309.1)	
ANNUAL SALES BY MARKET (MW/YR)					**Discounted Gross Benefits ($10⁶)**
1. U.S. Communications	.6	2.4	3.9	6.7	20.5
	(.6)	(2.2)	(3.9)	(6.6)	
2. U.S. Shallow Well Cathodic	.3	.6	.7	.8	5.1
	(.3)	(.6)	(.7)	(.8)	
3. U.S. Deep Well Cathodic	.02	.3	.8	1.2	4.1
	(.02)	(.3)	(.8)	(1.2)	
4. U.S. Outdoor Lighting	0	.1	.8	8.5	5.0
	(0)	(3.9)	(2.4)	(8.6)	
5. U.S. Government: DOD	0	.03	.7	4.3	2.4
	(0)	(2.2)	(.5)	(4.3)	
6. U.S. Government: Non-DOD	0	.01	.5	2.5	2.7
	(0)	(1.4)	(.8)	(2.5)	
7. U.S. Consumer	.03	.1	.8	4.0	4.8
	(.03)	(1.1)	(1.2)	(4.0)	
8. Foreign Communications	.1	.8	2.3	5.4	12.5
	(.1)	(.9)	(2.5)	(5.4)	
9. Foreign Pumping: Low-Lift	0	.1	1.4	29.1	11.2
	(0)	(.2)	(2.8)	(29.6)	
10. Foreign Pumping: Medium-Lift	0	.1	2.8	9.6	16.4
	(0)	(.4)	(4.2)	(9.8)	
11. Foreign Deep Well Cathodic	0	.2	.7	1.4	3.8
	(0)	(.2)	(.7)	(1.4)	
12. Foreign Remote Power	0	.1	1.9	5.2	10.7
	(0)	(.4)	(2.5)	(5.2)	
13. U.S. Grid: Sunbelt	0	0	.02	151.3	9.7
	(0)	(0)	(3.5)	(160.3)	
14. U.S. Grid: Non-Sunbelt	0	0	0	63.5	7.1
	(0)	(0)	(2.9)	(69.4)	

SUMMARY OF RESULTS (Expressed as Present Values of 1977 $10⁶)

Gross Domestic Consumer Benefits	61.4
Gross Foreign Consumer Benefits	54.7
Environmental Benefits	6.4
Program Cost	224.8
Net Domestic Benefits	-156.9

---

[a] Also assumes a 2% real electricity growth rate and a price reduction breakthrough from R&D in 1990. Other assumptions in Section B of this chapter.

[b] Indicates Results without the Initiative.

[c] Indicates Results with the Initiative.

The initiative has very little effect on market size in 1996. However, grid-connected applications are expanded slightly. The total gross domestic benefit derived from the initiative is $61.4 million. In the small markets scenario, that gross benefit was $50.5 million. In the large markets case, the total gross benefits of the initiative were $86.5 million. Foreign market benefits total $54.7 million, with about half of this total coming from the pumping markets (9,10). The net domestic benefit under this scenario is -$156.9 million. If foreign benefits are included at 50% of their total value, the present value of the net benefit from the initiative would be -$129.6 million.

Very Large Near-Term and Intermediate Market Scenario

The very large market case represents the most optimistic forecasts of market sizes that are available. This case contains substantially larger near-term and intermediate markets than the large market scenario discussed above. The results of the integrating model with these assumptions of market size are given in Table 40. Annual array sales in 1986 are 258 MW without the initiative and 290 MW with the initiative. Although the initiative has a significant impact on sales in this case, the total is still below the DOE program goal of 500 MW/yr by 1986. The array sales in 1982 with the initiative (56 MW) exceed the DOE program goal of 20 MW. However, the 20 MW goal is reached even without the initiative in this very large market case. Even under this very large intermediate market case, very few grid-connected photovoltaic applications have been installed by 1986 except through directly subsidized purchases under the initiative.

In this very large intermediate market case, there are substantial consumer benefits in the intermediate markets from accelerating the array price reductions. Consumer benefits from the grid-connected markets (13, 14) are very small ($7 million), while DOD

TABLE 40. RESULTS OF THE INTEGRATING MODEL VERY LARGE INTERMEDIATE MARKETS SCENARIO[a]

TOTAL ARRAY PRODUCTION AND PRICES	1978	1982	1986	1996	
Array Prices ($1975/Wp)	14.90[b] (14.90)[c]	6.90 (5.60)	2.40 (2.10)	.30 (.30)	
Total Array Sales (MW/Yr)	3.6 (3.6)	36.1 (56.5)	258.0 (290.2)	1496.3 (1505.8)	
ANNUAL SALES BY MARKET (MW/YR)					Discounted Gross Benefits ($\$10^{6}$)
1. U.S. Communications	1.3 (1.3)	3.1 (3.1)	4.2 (4.2)	6.8 (6.8)	3.1
2. U.S. Shallow Well Cathodic	.6 (.6)	1.3 (1.3)	1.6 (1.6)	1.9 (1.9)	1.6
3. U.S. Deep Well Cathodic	.1 (.1)	2.1 (2.1)	5.3 (5.3)	7.5 (7.5)	7.3
4. U.S. Outdoor Lighting	0 (0)	4.4 (9.7)	32.8 (38.9)	224.9 (225.6)	40.2
5. U.S. Government: DOD	0 (0)	1.0 (3.9)	21.1 (23.9)	98.2 (98.5)	20.8
6. U.S. Government: Non-DOD	0 (0)	.2 (2.3)	3.1 (3.4)	7.8 (7.9)	3.3
7. U.S. Consumer	.9 (.9)	2.6 (2.4)	4.4 (4.4)	7.6 (7.6)	5.7
8. Foreign Communications	.9 (.9)	6.1 (6.0)	11.6 (11.6)	21.9 (21.9)	13.4
9. Foreign Pumping: Low-Lift	0 (0)	.6 (1.1)	18.8 (22.8)	126.8 (127.3)	22.8
10. Foreign Pumping: Medium-Lift	0 (0)	8.5 (16.7)	121.9 (131.3)	263.8 (264.4)	156.7
11. Foreign Deep Well Cathodic	0 (0)	1.2 (1.2)	4.2 (4.2)	8.3 (8.3)	7.0
12. Foreign Remote Power	0 (0)	4.9 (6.9)	29.0 (30.3)	53.0 (53.1)	41.6
13. U.S. Grid: Sunbelt	0 (0)	0 (0)	.1 (4.7)	330.6 (333.1)	4.2
14. U.S. Grid: Non-Sunbelt	0 (0)	0 (0)	.02 (3.7)	337.0 (341.8)	3.1

SUMMARY OF RESULTS (Expressed as Present Values of 1977 $\$10^{6}$)

Gross Domestic Consumer Benefits	39.2
Gross Foreign Consumer Benefits	241.6
Environmental Benefits	6.8
Program Costs	224.8
Net Domestic Benefits	-128.9

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[a] Also assumes a 2% real escalation rate of electricity and a price reduction breakthrough in 1990.

[b] Indicates Results without the Initiative.

[c] Indicates Results with the Initiative.

and U.S. outdoor lighting markets (4, 5) yield benefits totaling about $24 million. U.S. communication and cathodic protection markets (1, 2, 3) yield benefits of $12 million. Foreign consumer benefits for this case are $242 million, roughly three times the domestic gross benefits of $89 million. The net benefits of the initiative in this case are -$128.9 million without any contribution from foreign markets and -$8.1 million if foreign benefits are weighted at 50% of their consumer surplus value. The initiative yields a positive net benefit in this very large market case if foreign market benefits are weighted at 53% of their value (53 cents on the dollar) or more.

Comparison of the Four Market Cases

The four market cases discussed above reflect a spectrum of assumptions on the size of near-term and intermediate photovoltaic applications that might generate a market pull to reduce the price of photovoltaic arrays and, hence, increase market penetration. Table 41 compares array sales and array price in these four cases. The difference in level of sales extends over a factor of 100 from the small market case to the very large market case. The difference in array price is much less pronounced; and, in fact, the moderate, large, and very large market cases yield essentially the same results for array prices throughout the 1980s. The similarity in results is partially due to the assumptions that array price reductions normally attributed to production experience will be delayed under very rapid capacity expansion. In all three of these cases, the industry is expanding rapidly enough so that this constraint on rapid price reduction is significant. A sensitivity analysis case was run on the large market case with this price reduction constraint ignored. Ignoring the constraint is equivalent to assuming that no matter how rapidly demand and sales expand the industry can expand production to meet that demand in an orderly manner and will still

TABLE 41

COMPARISON OF MARKET CASES

Part I: Array Sales, Prices, and Total P.V. Array Industry Revenues

Market Scenario Case	Government Procurement Initiative in Effect?	Array Prices ($1975/Wp)		Array Sales (MW/Yr)		Total Revenue to P.V. Array Industry ($1975 x 10^6)	
		1982	1986	1982	1986	1982	1986
Small	No	8.00	4.20	2.8	5.2	22.4	21.8
	Yes	5.70	3.20	7.0	12.2	39.9	39.0
Moderate	No	7.90	3.50	4.6	17.2	36.3	60.2
	Yes	5.30	2.70	13.6	29.3	72.1	79.1
Large	No	8.10	3.40	6.6	53.9	53.5	183.3
	Yes	5.50	2.60	18.8	80.9	103.4	210.3
Very Large	No	6.90	2.40	36.1	258.0	249.1	619.2
	Yes	5.60	2.10	56.5	290.2	316.4	609.4
Sensitivity Case							
Large Market Scenario with Limits Removed on Array Price Reduction with Cumulative Production Experience	No	4.34	2.06	21.0	95.3		
	Yes	3.53	1.79	44.0	119.7		

take advantage of all avenues available to reduce price. With the constraint removed, array prices were decreased and sales increased; but the net benefits from the initiative were not significantly affected (i.e., the results changed by less than $19 million).

The limitations on capacity expansion and the speed with which reductions in array prices occur will be significant in determining the rate at which photovoltaics can expand into near-term and intermediate markets. The large and very large market cases shown in this chapter correspond to "seller's market" situations with very rapid expansion of production capacity. However, these situations differ from the seller's market scenario outlined in the assessment by Gnostic Concepts Inc. (Appendix H, Volume III) because the integrating model results assume that the industry will continue to lower prices with increased production and not take advantage of the opportunity to reap additional profits.

Table 41 also compares the market scenarios by calculating the total revenue received by the photovoltaic array manufacturing industry. In the small market scenario industry revenues do not exceed $40 million per year and remain constant through the 1980s. This situation would not be favorable to industry investment in production facilities. In the moderate market scenario, industry revenues range from $40 million to $80 million per year. In this scenario, the market pull initiative pulls array prices down far enough to keep industry annual revenue constant at about $75 million per year during the 1980s. Without the initiative, array prices decline slower and annual revenue increases from $36 million in 1982 to $60 million. In the large market scenario, total industry revenues look much more attractive. Without the initiative, revenues more than triple between 1982 and 1986 (from $54 million per year to $183 million per year). The initiative produces higher revenues in 1982 (about twice as large as without the initiative) and the revenues double by 1986 to $210 million/yr.

The very large market scenario yields photovoltaic array production industry revenues of $250 million to $600 million per year. The initiative results in higher revenues in 1982 but in 1986 the situation is reversed. Both the large and very large scenario revenues emphasize that it is possible for the photovoltaic industry to be prosperous even when the net benefits of the initiative are negative. In fact, in these scenarios it is the healthy photovoltaics industry that is causing the initiative to have very little impact over an R&D program without the initiative.

The four market scenarios can also be compared by the benefits of the initiative under each case. Table 42 presents that comparison. The gross benefits to current or near-term U.S. markets (i.e., communications and cathodic protection) do not change significantly under most of the market scenarios. The largest changes in gross U.S. benefits occur in the intermediate markets such as lighting, government, and consumer applications. In the grid-connected markets, gross benefits decline with larger estimates of near-term and intermediate market sizes. This decline occurs because larger intermediate markets create a "demand-pull" situation for photovoltaics even without the initiative. This demand pull allows a small penetration into the grid markets without the initiative. The incremental impact of the initiative on the grid markets is small and becomes less important as the intermediate market size estimates are increased.

The larger market scenarios result in larger benefits of the initiative in foreign intermediate markets. Benefits from sales in foreign markets might be regarded as including some export

TABLE 42

COMPARISON OF MARKET CASES

Part II: Benefits of the Initiative[a]

Market Scenario:	Gross Domestic Benefits in: Communications and Cathodic Protection Markets	Gross Domestic Benefits in: Lighting, Government, and Consumer Markets	Gross Domestic Benefits in: Grid-Connected Markets	Gross Foreign Benefit	Net Benefit from Initiative Weighting Foreign Benefits at: 0%	10%	50%	90%	100%
Small	30	2	19	10	-169	-168	-164	-160	-159
Moderate	30	15	17	55	-157	-151	-130	-108	-102
Large	29	44	14	191	-131	-112	-36	+41	+60
Very Large	12	70	7	242	-128	-104	-7	+90	+114

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[a] Benefits are discounted at a 5% real rate throughout the analyses in this chapter.

benefit to industry and balance-of-payment benefits to the United States and helping to accomplish U.S. foreign policy goals in aiding developing countries. Weighting these benefits at about 50% of their dollar amount in the case of very large intermediate markets would cause the initiative to have a total positive net benefit. However, in other cases the benefits from intermediate markets are not sufficient to offset the large program cost. The last five columns of the table display alternative weights for foreign markets consumer surplus.

Impact of the Initiative on Grid-Connected Applications

The results above indicate that the initiative is not successful in accomplishing an early penetration of grid-connected photovoltaics through a demand pull, regardless of whether the intermediate markets are small or very large. Under the nominal assumptions, significant grid-connected market applications require breakeven systems prices of the order of $1/Wp at today's electricity prices. The additional array price reduction generated from the initiative has little effect in reaching this goal.

What changes in assumptions would lead to a major penetration of the grid-connected markets by photovoltaics in the mid- to late-1980s? The price pattern of grid electricity delivered to residential consumers can have an impact. If electricity prices (measured in constant dollars) were to increase by 50% to 100% between now and 1990, the requirements for array price, balance-of-system, and system integration price reduction would be eased considerably. Accordingly, this issue was investigated by examining a series of cases on the integrating model in which the breakeven system price for grid competitive applications was assumed to rise more rapidly. The nominal assumption of 2% annual escalation in real electricity prices was first changed to 4%. An extreme case at a 6% rate of increase was also examined. This latter case represents a doubling of electricity prices by 1990 and a tripling over the next 20 years (Table 43).

TABLE 43

THE IMPACT OF ALTERNATIVE ANNUAL ESCALATION RATES ON RELATIVE ELECTRICITY PRICES IN SELECTED YEARS

Annual Rate of Increase in Competing System for Residential Application (Delivered Grid Electricity)	Relative Electricity Prices (1978 = 1.0)			
	1978	1986	1990	1996
2%	1.0	1.17	1.27	1.43
4%	1.0	1.37	1.60	2.03
6%	1.0	1.59	2.01	2.85

Table 44 summarizes the results for these sensitivity analyses.[4] Array sales and array prices for 1986 and 1996 are given with and without the initiative, and benefits from the initiative in grid markets and total domestic benefits are shown in the right-hand columns.

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[4] The detailed results corresponding to this table and all the tables of this chapter are in Appendix C, Volume II.

TABLE 44. RESULTS OF THE INTEGRATING MODEL UNDER VARIOUS ELECTRICITY ESCALATION RATES AND MARKET SIZES (With a Price Reduction Breakthrough Assumed to Enter the Market in 1990)

ASSUMED REAL GRID ELECTRICITY PRICE GROWTH (ANNUAL RATE)	ASSUMED MARKET SIZE (NEAR AND INTERMEDIATE)	PROCUREMENT INITIATIVE?	ARRAY SALES IN GRID MARKETS (MW/YR.)		ARRAY PRICES ($1975/Wp)		GROSS BENEFITS OF THE INITIATIVE IN GRID MARKETS ($ MILLION)	NET DOMESTIC BENEFITS OF THE INITIATIVE ($ MILLION)
			1986	1996	1986	1996		
2%	Small	No	.01	70	4.20	.80		
		Yes	5.2	81	3.20	.80	18.6	-169
	Moderate	No	.02	215	3.50	.60		
		Yes	6.4	230	2.70	.60	16.8	-157
	Large	No	.02	442	3.40	.40		
		Yes	6.7	456	2.60	.40	13.9	-131
	Very Large	No	.12	668	2.40	.30		
		Yes	8.4	675	2.10	.30	7.3	-129
4%	Small	No	.04	898	4.20	.50		
		Yes	15.7	964	3.20	.50	49.5	-131
	Moderate	No	.07	1336	3.50	.40		
		Yes	7.2	1375	2.70	.40	38.9	-129
	Large	No	0.1	1773	3.30	.40		
		Yes	7.5	1797	2.60	.40	29.5	-111
	Very Large	No	.5	2127	2.40	.30		
		Yes	9.8	2136	2.10	.30	13.9	-120
6%	Small	No	.1	2459	4.20	.40		
		Yes	6.5	2503	3.20	.40	78.3	-98
	Moderate	No	.2	2682	3.50	.40		
		Yes	8.7	2709	2.70	.40	63.5	-101
	Large	No	0.3	2877	3.40	.30		
		Yes	9.1	2897	2.60	.30	53.8	-82
	Very Large	No	1.5	3034	2.40	.30		
		Yes	13.1	3041	2.10	.30	24.4	-107

The cases displayed in the table show that even under a 6% electricity growth rate there is little penetration of the residential grid-connected market by 1986. In 1996, the penetration of the grid market is about 70 MWp to 700 MWp under the 2% growth rate, depending on the size of the intermediate market and therefore the array price achieved. The initiative makes little difference in the size of this market. Under the 6% electricity growth assumption, the 1996 grid market is 2 to 3 GWp/year; but again we see that the initiative makes relatively little difference in terms of level of sales or price. The 4% growth rate leads to 1996 array sales of 900 MW to 2,000 MW. This situation gives the most significant indication of how larger intermediate markets accelerate the development of grid applications by lowering array price into the grid-competitive range. The initiative has some effect in accelerating the price reduction process in the case of the small market size. As the market size estimates increase, the acceleration effect of the initiative becomes smaller.

In light of these results, the obvious next question is: Why does the initiative not have a larger effect in accelerating grid market development? First, under the 6% growth case, the penetration of grid markets does not occur until the late 1980s. Second, due to the results of the supply workshop, we have assumed some type of photovoltaic array price reduction breakthrough will occur in the late 1980s and enter the market in 1990. Experience gained through the initiative has relatively little impact in accelerating the development of a new generation of photovoltaic technology in the 1990s.

One could hypothesize the less probable situation in which no price reduction breakthrough occurs before the end of the modeled time horizon. Under this scenario, any penetration of grid markets under high real electricity price increases must come from the near-term technologies that would be supported under the initiative. Table 45 corresponds to Table 44, except that no price reduction breakthrough is assumed to occur until after the time horizon of the model (2006). Under this set of conditions, the initiative can make a large difference in benefits if the 6% growth rate case is assumed to be probable. If both the small market size case and the 6% electricity growth rate are assumed, the benefits from the initiative are $1.05 million. The effect of the initiative in this situation is to assure development of a photovoltaics industry that can have a major impact in grid applications in the 1990s. In other cases, the development of larger intermediate markets assures the viability of the industry and achieves significant price reduction even if the initiative is not instituted. Therefore, the marginal benefits of the initiative are reduced.

The Value of Array Price Reduction Breakthroughs

In a future where electricity prices escalate rapidly, the value of R&D breakthroughs to a lower cost photovoltaic technology also increase. The integrating model does not include a representation of how the size of near-term and intermediate markets and the presence or absence of the procurement initiative may affect the chances of achieving such an array price reduction breakthrough. However, the model can be used to determine what such a breakthrough would be worth. Table 46 shows the worth of an array price reduction breakthrough under the same sets of assumptions used to evaluate the initiative. Except in the small market scenario coupled with the case of 2% real electricity growth, in which the commercialization of photovoltaics is very limited, the benefits of the breakthrough range from $2 billion to $10 billion.

TABLE 45. RESULTS OF THE INTEGRATING MODEL UNDER VARIOUS REAL ELECTRICITY ESCLATION RATES AND MARKETS (Without a Price Reduction Array Breakthrough)

ASSUMED REAL ELECTRICITY PRICE GROWTH (ANNUAL RATE)	ASSUMED MARKET SIZE (NEAR AND INTERMEDIATE)	PROCUREMENT INITIATIVE?	ARRAY SALES IN GRID MARKETS (MW/YR.)		ARRAY PRICES ($1975/Wp)		GROSS BENEFITS OF THE INITIATIVE IN GRID MARKETS ($ MILLION)	NET DOMESTIC BENEFITS OF THE INITIATIVE ($ MILLION)
			1986	1996	1986	1996		
2%	Small	No	.01	.8	4.20	2.50		
		Yes	5.2	1.7	3.20	2.20	7.3	-166
	Moderate	No	.02	5.4	3.50	1.70		
		Yes	6.40	8.60	2.70	1.60	12.8	-144
	Large	No	.02	26	3.40	1.20		
		Yes	6.70	32	2.60	1.10	14.9	-107
	Very Large	No	.1	84	2.40	.90		
		Yes	8.4	89	2.10	.90	8.2	-112
4%	Small	No	.04	10	4.20	2.40		
		Yes	5.7	24	3.20	2.10	263.0	+106
	Moderate	No	.07	72	3.50	1.60		
		Yes	7.2	108	2.70	1.50	169.1	+28
	Large	No	.1	247	3.40	1.10		
		Yes	7.5	288	2.60	1.10	103.5	-6
	Very Large	No	.5	526	2.40	.90		
		Yes	9.8	744	2.10	.90	36.4	-78
6%	Small	No	.1	165	4.20	2.10		
		Yes	6.5	336	3.20	1.70	1153.8	+1054
	Moderate	No	.2	575	3.50	1.40		
		Yes	8.3	805	2.70	1.20	599.9	+501
	Large	No	.3	1189	3.40	1.00		
		Yes	9.1	1347	2.60	1.00	308.3	+226
	Very Large	No	1.5	1840	2.40	.80		
		Yes	13.1	1878	2.10	.80	87.4	-18

TABLE 46. THE VALUE OF AN ARRAY PRICE REDUCTION BREAKTHROUGH IN PHOTOVOLTAICS

GRID ELECTRICITY PRICE GROWTH (ANNAUL RATE)	MARKET SCENARIO	PRICE REDUCTION BREAKTHROUGH IN 1990?	ARRAY SALES IN GRID MARKETS (MW/YR.)		ARRAY PRICES ($1975/Wp)		GROSS BENEFITS OF A PRICE REDUCTION BREAKTHROUGH IN GRID MARKETS ($ MILLION)	NET DOMESTIC BENEFIT OF A PRICE REDUCTION BREAKTHROUGH ($ MILLION)
			1986	1996	1986	1996		
2%	Small	No	.01	.8	4.20	2.50		
		Yes	.01	3.1	4.20	1.80	126	174
	Moderate	No	.02	5.4	3.50	1.70		
		Yes	.02	148	3.50	.70	1473	1734
	Large	No	.02	26	3.40	1.20		
		Yes	.02	453	3.40	.40	2015	2680
	Very Large	No	---	---	---	---		
		Yes	---	---	---	---	---[a]	---[a]
4%	Small	No	.04	10	4.20	2.40		
		Yes	.04	54	4.20	1.60	2851	3012
	Moderate	No	.07	72	3.50	1.60		
		Yes	.07	1084	3.50	.50	5884	6401
	Large	No	.09	247	3.40	1.10		
		Yes	.09	1790	3.40	.40	2804	7046
	Very Large	No	---	---	---	---		
		Yes	---	---	---	---	---[a]	---[a]
6%	Small	No	.1	165	4.20	2.10		
		Yes	.1	1003	4.20	.90	6563	6852
	Moderate	No	.2	575	3.50	1.40		
		Yes	.2	2540	3.50	.40	8833	9372
	Large	No	.3	1189	3.40	1.00		
		Yes	.3	2873	3.40	.30	8751	9557
	Very Large	No	---	---	---	---		
		Yes	---	---	---	---	---[a]	---[a]

[a] Runs of the integrating model for the very large market cases were not made; the benefits would be in excess of those for the large market case.

As mentioned earlier, most of the cases presented assume a price reduction breakthrough occurs in 1990. In the case where no price breakthrough occurs within the time horizon of the model, the intermediate market is small, and electricity prices escalate at 6% per year, the initiative achieves a high value--$1 billion in discounted domestic net benefits. Suppose a breakthrough to a new photovoltaic technology is assumed to occur later than 1990. A sensitivity case was examined with a breakthrough assumed to occur in time for massive entry of the new technology into the market in 1996. The domestic net benefit from the initiative in this case is $48 million, which is above the value of -$98 million for the nominal assumption of entry of the new technology into the market in 1990 and far below the value of $1.0 billion for the initiative in the case of no R&D breakthrough. Table 47 shows that the timing of the breakthrough is important to the value of the initiative but not as important as the fact that one occurs in the time period where grid-competitive markets are developing. When a new technology becomes available, the impact of the initiative in gaining early experience on near-term technology is of much less consequence. Under all except the small market case, this experience is obtained through nonsubsidized intermediate applications. The initiative only accelerates this experience slightly. Under the small market case, the experience is of great value assuming (1) that photovoltaics are urgently needed by the 1990s (the 6% electricity price growth assumption) and (2) no better photovoltaic technology comes along in the next 10 years (i.e., no breakthrough is assumed). The industry indicates that this combination of events is unlikely, but not impossible.

TABLE 47

SENSITIVITY OF INTEGRATING MODEL RESULTS TO PRICE REDUCTION BREAKTHROUGH[a]

	Breakthrough in 1990	Breakthrough in 1996	No Breakthrough before 2006
Net Benefit from the Initiative ($ millions)	-98	+48	+1,054
Value of the R&D Breakthrough (Increase in Consumer Benefit) Compared to No Breakthrough Case ($ millions)	6,852	--	--

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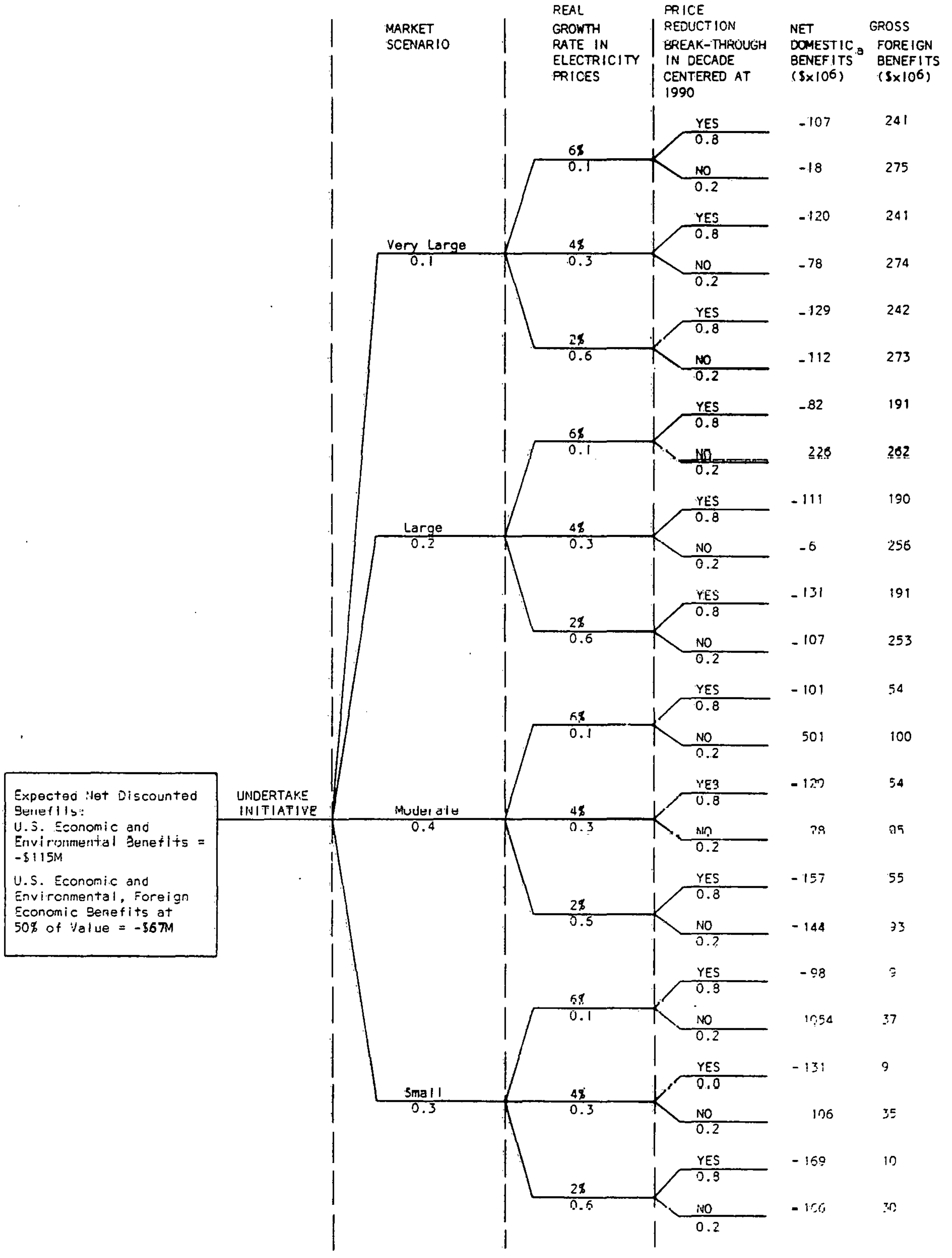
[a] Results shown assume small intermediate market scenario and high real electricity price growth (6%).

D. ANALYSIS UNDER UNCERTAINTY

The cases that have been presented in Section C can be displayed in the form of a "tree" of alternative scenarios, which is shown in Figure 18. The first stage of the tree is the size of the near and intermediate markets; the second stage is the escalation rate in the real price of grid electricity, and the third stage concerns the possibility of an array price breakthrough with the representative year for the breakthrough taken as 1990. The numbers at the end of each branch of the tree represent net



[a] Net Domestic Benefits = Present Value of Gross Domestic Benefits Minus the Present Value of the Initiative's Costs

Figure 18. Analytical Results of Alternative Scenarios Using a 5% Real Discount Rate

domestic benefits (i.e., gross domestic benefits minus program costs, in $ millions) and gross benefits in foreign markets ($ millions).

If probabilities are assigned to each branch, a probability associated with each of the scenarios in the tree can be calculated. Table 48 shows an illustrative set of probabilities based on an assessment of all the information obtained in the venture analysis. The conclusions of the analysis are not particularly sensitive to changes in these values.[5] Their main purpose is to illustrate that only under very unlikely sets of circumstances does the analysis show net positive benefits for the initiative.

TABLE 48

PROBABILITY ASSESSMENTS FOR TREE CALCULATION

1. <u>Market Cases</u>

Case:	Very Large	Large	Moderate	Small
Probability:	0.1	0.2	0.4	0.3

2. <u>Escalation Rate in Real Electricity Prices</u>

Case:	2%	4%	6%
Probability:	.6	.3	.1

3. <u>Array Price Reduction Breakthrough in Photovoltaics?</u>

Case:	Yes (by 1990)	No
Probability:	.8	.2

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[5] In fact, most of the project team believed that the 10% probability of 6% electricity prices increases for 15 to 20 years was high and that the 20% probability of no PV breakthrough before 2006 was also high.

If only domestic benefits are included, the probability distribution on net benefit is presented in Figure 19. There is only a 5% chance of positive benefits--these cases represent a 6% real electricity price growth and no array price reduction breakthrough. The mean or expected value of this distribution is -$115 million. In other words, the discounted expected gross domestic benefits are only about half the discounted program costs.

If foreign benefits are included at 50 cents on the dollar, the probability distribution of net benefit is represented as Figure 20. The probability of positive net benefits is now about 15%. The incremental benefits have come from benefits to foreign markets under the very large market case. There is a 85% chance of negative net benefits from the initiative. The mean or expected value of this probability distribution is -$67 million.

Resolving uncertainty as to which market case applies may be possible over the next few years with an expanded program of market studies and system tests and applications directed at the near-term and intermediate markets.

The other case motivating the initiative is a small market, high escalation in electricity price, and no price breakthrough. This case is unlikely, but costly if it occurs. The benefits of the initiative are best conceived as insurance if this unlikely set of circumstances should prevail. However, there is no need for an immediate commitment to the initiative. If after several years further information indicates that near-term and intermediate photovoltaic markets are very small and electricity prices may escalate to double or triple their current levels, it may be appropriate to investigate in more detail how near-term photovoltaic technologies can be developed as a backstop in case

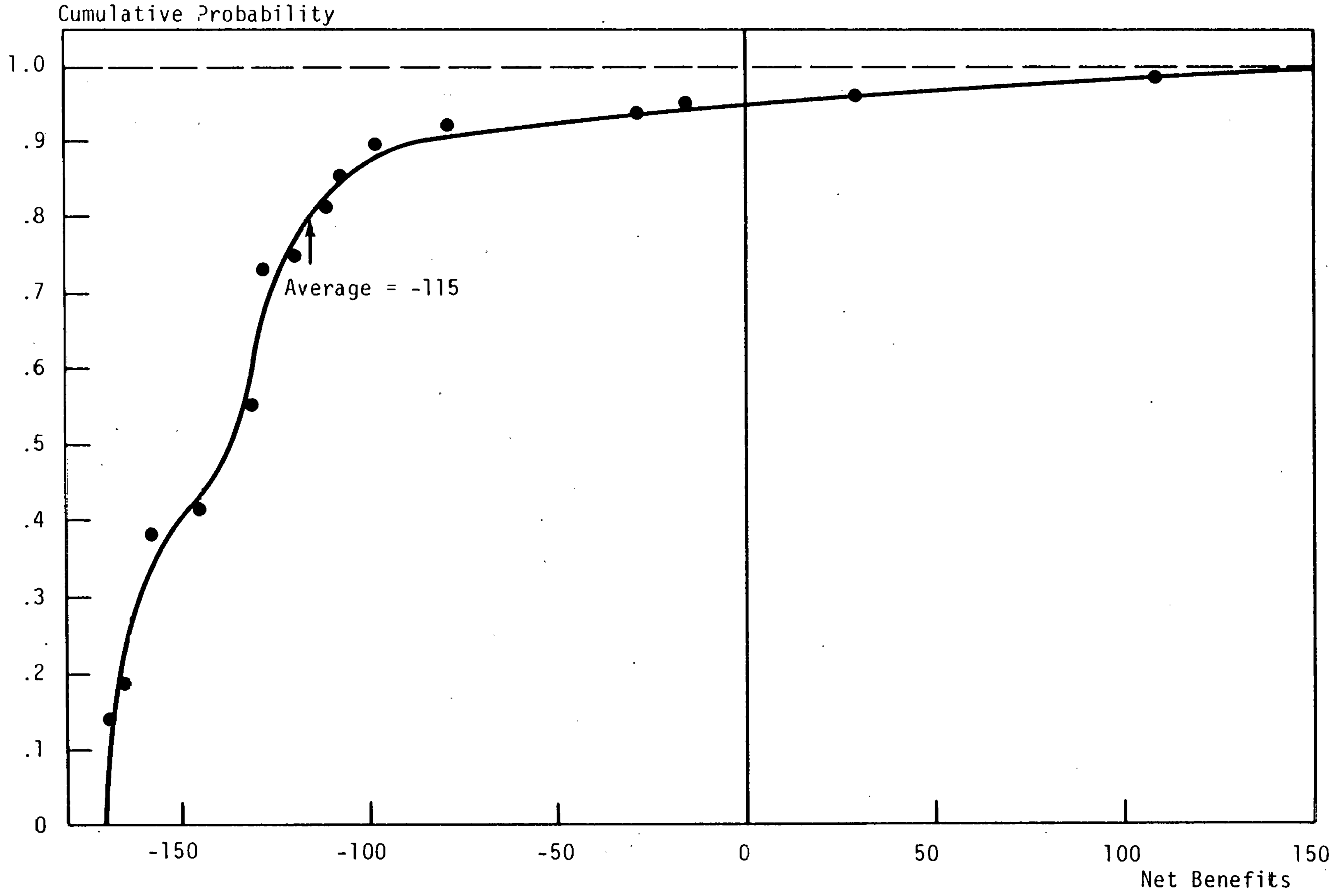

Figure 19. Cumulative Probability Distribution on Net Benefits (Economic and Environmental Benefits --U.S. Only) Discounted at 5%

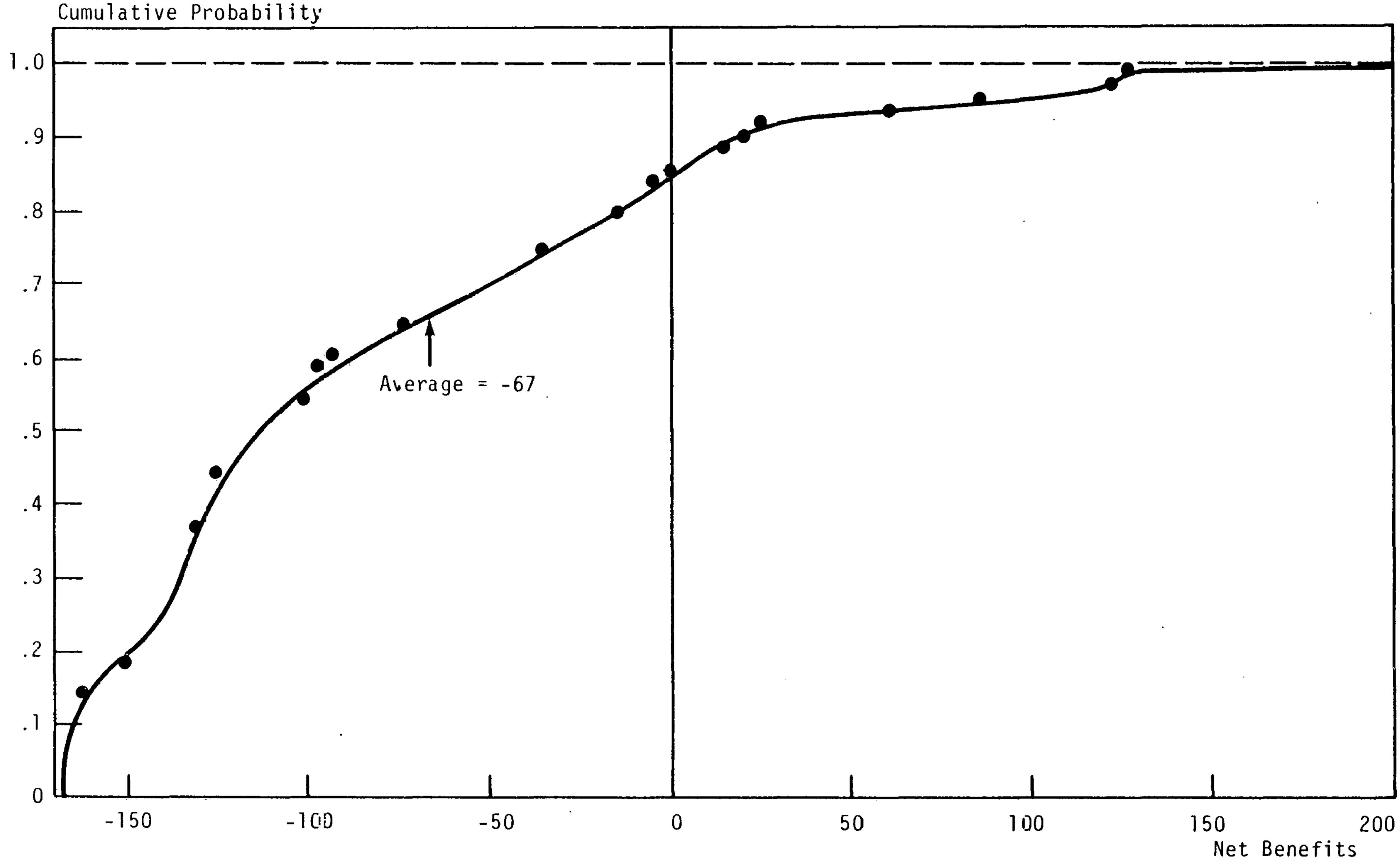

Figure 20. Cumulative Probability Distribution on Net Benefits of the Federal Initiative (U.S. Economic and Environmental Benefits and Foreign Economic Benefits at $0.50/$1.00) Discounted at 5%

the cheaper arrays expected from advanced technologies should fail to arrive from R&D breakthroughs.

E. SENSITIVITY TO DATA AND ASSUMPTIONS IN THE ANALYSIS

The analysis presented in this chapter is complex. As discussed in Chapter IV, a relatively detailed integrating model was developed and exercised over a wide variety of cases. Five successive rounds of analysis were carried out; at each stage both the model and data set were carefully examined and refined and extensive sensitivity analysis carried out to gain insight as to which elements of data and assumptions were driving the conclusions of the model. In the preceding two sections, we have presented the analysis as it has evolved from this process, highlighting the crucial uncertainties and their impact on the benefits of the procurement initiative. In this section, we review the insights regarding data and assumptions that are less sensitive in determining the overall conclusions of the venture analysis. In most instances, these insights are drawn from sensitivity runs on the integrating model, summarized in Appendix C, Volume II.

Supply Issues

There has been much discussion of array price reduction, balance-of-system experience, and cost-of-system installation and markup as these determine the cost of photovoltaic systems over time in various market applications. The huge market uncertainties make these issues of secondary importance because their impact will be to change the breakeven price at which various markets can be penetrated. The near-term and intermediate markets are uncertain in size and breakeven price. These uncertainties are resolvable only with market studies, system tests and applications, and, ultimately, market experience. The uncertainty of the near-term and intermediate markets has been reflected in the analysis by carrying through four market scenarios. If array prices decline more rapidly, these markets would develop more rapidly than we have assumed; but the qualitative character of the results for the four cases would remain essentially the same. Similarly, balance-of-system, systems integration, and markup can have the effect of accelerating a retarding market development somewhat; but the effect on the benefits of the multi-cycle procurement initiative is slight. Sensitivity runs confirm this insight.

Penetration into grid-competitive applications such as residential use depends critically on the economics of the competing energy source, assumed to be grid electricity. If real electricity prices remain at or near today's levels, very low array prices, balance-of-system costs, system integration, and markups are required to achieve any significant penetration into grid application. Thus, sensitivity to any of these factors taken by itself is low. If lower costs occurred in all cost factors, we would obtain penetrations into the grid market similar to those achieved under the 4% and 6% electricity price growth cases.

Research and development breakthroughs can be regarded as discontinuous changes in array prices that come from new knowledge and processes rather than the cumulative experience of large-scale production. As we have shown, price reduction breakthroughs reduce the net benefits of the initiative, but may lead to earlier penetration into the grid-connected market and, therefore, to very high benefits for federal policies leading to a price breakthrough. Such policies have not been analyzed in detail within the venture analysis, but the sensitivity analysis on the integrating model indicates a very high value for such breakthroughs in contrast to that for the initiative.

The decline in array price is assumed to come from steady evolutionary progress as larger volumes of production experience are obtained. Rapid expansion of the industry has been assumed to delay price reductions, but the price reduction commensurate with cumulative experience is achieved after industry growth drops to a more moderate level. Thus, in the case of large markets, price reduction and market sales growth are slowed somewhat. Sensitivity analysis of this assumption indicates that this disruption has little effect on the benefits of the initiative.

Market Issues

The dominant issues of the venture analysis are uncertainty in market size and breakeven price. The market growth rate and the growth rate in price of competing technologies are important because they affect market size and breakeven price in future years. The four market cases and three cases for escalation in grid electricity prices have been chosen so that these uncertainties are well represented. The system price breakeven point for grid electricity in residential applications is a complex calculation. A critical assumption of that calculation is the rate at which the utility will buy electricity back from the residence (termed the buyback rate). If 100% buyback is assumed, the breakeven price for grid applications increases about 30%. This is similar in its impact on grid penetration in 1990 as increasing electricity price escalation from 2% to 4% or 4% to 6%. The implications of utility buyback on the worth of a photovoltaic system is discussed further in Chapter II.

The price sensitivity and lag parameters in the market share model have relatively small effects on the benefits from the initiative. Making the grid-connected market less price sensitive would bring in more grid-connected applications earlier, and this increases the benefits of the initiative by the order of $20 million.

Similarly, making some of the intermediate markets more price sensitive would reduce initiative benefits. Increasing the lag in market penetration tends to favor the initiative slightly since the initiative procurements are assumed to establish market penetration directly without a lagged effect.

Initiative Definition

The analysis took as its point of departure a set of budget allocations over time. However, the exact budget allocations to specific markets were not specified. In addition to the nominal procurement pattern described in Section B above, alternatives were investigated in which a much larger fraction of the money was spent in grid competitive applications and in which a significant share was spent in foreign markets. These alternatives did not provide benefits as large as the nominal procurement pattern, even if benefits in foreign markets were considered with the same weight as domestic benefits. However, only a few alternatives were investigated.

Federal Decision Criteria

Sensitivity to the discount rate was carried out for selected cases. The discount rate appears to be very insensitive for cases in which the benefits accrue largely in the intermediate markets. This sensitivity occurs primarily because costs and benefits occur in similar time patterns. The complete analyses outlined in this chapter were conducted first with a 10% discount rate and then with a 5% rate for inclusion in the report. Using the probabilities outlined in Table 48, the expected net benefits of the initiative using a 10% discount rate are -$87 million. When the discount rate is 5%, the expected net benefit of the initiative is -$115 million.[6] This result occurs because the lower discount rate increases the value of the grid competitive market benefits under both the initiative and base case situations. Second, the lower discount rate increases the present value of program costs as well as the program benefits.

F. ALTERNATIVE FEDERAL ACTIONS

Federal Guaranteed Buys at Low Array Prices

The analytical methods used in this venture analysis can also be used to evaluate other federal alternatives for accelerating the development of photovoltaics. Where the alternatives differ considerably from the procurement initiative, it may be necessary to modify the model and probabilistic analysis to fit the characteristics of the new alternative. Nonetheless, many of the ideas that have been developed here may apply.

We shall examine briefly the proposal that the federal government guarantees to buy up to 20 MW at a maximum price of $2/Wp. At least one manufacturer has asserted that they could meet this price and production goal and would be willing to deliver this quantity of production to the government provided the government agreed not to resell it on the open market and provided they could be assured a supply of polysilicon at a price low enough to support the $2/Wp array price.

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[6] The decision trees using both the 10% and 5% discount rate are displayed at the back of Appendix C, Volume II.

Analysis of this proposal is predicated on several assumptions:

1. With the procurement, an array price of $2/Wp will be established in the private market beginning in 1983.
2. Without the procurement, array price declines will follow the experience curve set forth in the nominal (noninitiative) case.
3. A moderate market size and a 2% electricity price growth rate were used as the illustrative scenario to run this case.

The results summarized in Table 49 indicate potential gross domestic consumer benefits of $150 million if an array price breakthrough in 1990 is assumed. Without an R&D breakthrough, benefits are much larger, $650 million. Foreign benefits, if counted at 50 cents on the dollar, would increase these results to $232 million and $880 million, respectively. If a DOE program cost of $40 million is assumed, these benefits would appear to make the program advantageous. However, this comparison must be viewed with caution for two reasons. First, the 20 MW of arrays should have value for tests and applications that should offset much or even all of the $40 million cost. Second, the $40 million program cost only covers the cost of the arrays. Designing, purchasing, and installing these arrays into working systems could cost $40 million to $80 million more. It should be recalled that the federal government is currently planning to spend approximately $100 million on the Federal Photovoltaic Utilization Program (FPUP).

TABLE 49

POTENTIAL BENEFITS OF FEDERAL GUARANTEED PURCHASE AT $2/Wp ARRAY PRICE

Case	Array Price ($/Wp)		Array Sales (MW/Yr)		Gross Benefit Using 10% Discount Rate	
	1986	1996	1986	1996	Domestic	Foreign
Moderate Market, 2% Growth Rate in Grid Electricity Price, Array Price Breakthrough in 1990, No Initiative	3.50	0.40	17	493		
Same with Procurement Leading to $2 Array Cost in 1982, Price Breakthrough in 1990	1.50	0.40	34	528	149	165
Moderate Market, 2% Growth Rate in Grid Electricity Price, No Price Breakthrough in 1990	3.50	1.70	17	69		
Same with Procurement Leading to $2 Array Cost in 1982, No Price Breakthrough in 1990	1.50	0.90	34	152	657	448

Analysis of this case should be regarded with some caution. More extensive investigation is needed before concluding that the 20 MW procurement at $2 is a desirable federal action. Nonetheless, these preliminary calculations show it could be more promising than the multi-cycle procurement designed around a demand-pull philosophy.

VI. OBSERVATIONS, CONCLUSIONS, AND RECOMMENDATIONS

A. OBSERVATIONS ON KEY ISSUES

One of the key elements of the venture analysis methodology has been the use of multiple parallel approaches to key aspects of the project. The approaches used were: the integrating model, the photovoltaic industry cross-impact workshop, the market/demand workshop, and the Gnostic Concepts, Inc., assessment. Table 50 presents the key issues of the venture analysis and responses to these issues from the four approaches. The approaches did not always directly address each issue. Often issues were addressed only indirectly. When an issue was addressed by all four approaches, there was usually some disagreement. However, the differences usually represent differences of degree rather than directly opposing views.

B. SETTING FOR MAJOR CONCLUSIONS

To place the major conclusions of the venture analysis in the proper perspective, it is important to summarize the findings concerning the future potential of photovoltaics as an energy source, the current status of the photovoltaic industry, and the content of the national photovoltaic plan. These findings are not major conclusions of the analysis but rather provide a context in which the major conclusions should be interpreted.

Discussions with the research community, photovoltaic suppliers, and potential buyers, as well as the analytical results of the venture analysis,show that photovoltaics has the potential to be a significant source of electrical energy for the United States. There is disagreement, however, concerning how large this potential contribution could be and when it can be realized.

TABLE 50

OBSERVATIONS ON KEY ISSUES OF THE VENTURE ANALYSIS

KEY ISSUES	INTEGRATING MODEL RESULTS	SUPPLY WORKSHOP RESULTS	MARKETS WORKSHOP RESULTS	GNOSTIC CONCEPTS, INC., ASSESSMENT RESULTS
1. Will the initiative help in meeting the $2/Wp array price goal in 1982?	Not much; the initiative has its largest impact in the early 1980s. However, in every case the $2/Wp array price goal is still not met. The uncertainty of the near and intermediate market sizes is a much more significant factor in determining prices than the impact of the initiative.	Yes; it is 50% probable that that $2/Wp goal is reached in 1982 with the initiative and 1983 without.	Not directly addressed; however those offering opinions suggested that the initiative would not significantly accelerate developments in their markets (i.e., communications, cathodic protection, and agricultural pumping).	No; the initiative will have no impact on meeting the 1982 price goal. They predict $2.08/Wp for concentrators and $3.31/Wp for flat-plate silicon modules in 1982 with or without the initiative.
2. Will the initiative help in meeting the $.50/Wp array price goal in 1986?	Very little; price reductions due to the initiative are far too small to achieve this goal. Prices remain well over $.50/Wp in 1986 except when a technology breakthrough is assumed.	Not much; the goal of $.50/Wp has a 50% probability of occurring in 1988 with the initiative and in 1989 without.	Not directly addressed; see comment on issue #1.	No; the initiative will have no effect. In 1986, array prices are predicted to be $.97/Wp for concentrator arrays and $1.31/Wp for flat-plate silicon arrays with or without the initiative.
3. Will the initiative help in meeting the 500 MW/yr. goal in 1986?	Not much; the initiative usually results in the production of 10-50 additional MW/yr. in 1986. However, even the largest market scenarios yield only 200 MW/yr. by 1986. The uncertainty in intermediate market sizes and electricity prices again outweigh the impact of the initiative.	Yes; the initiative is expected to increase the probability of a 500 MW sustainable market to 50% in 1986 from about 25% in 1986 under the base case only.	Probably not; market sizes in U.S. communications, cathodic protection and agricultural pumping were not believed to have this potential. Earliest penetration of utility markets will be in the 1990s.	Probably not; the maximum attainable production is estimated to be approximately 80 MW in 1986.

TABLE 50

OBSERVATIONS ON KEY ISSUES OF THE VENTURE ANALYSIS

KEY ISSUES	INTEGRATING MODEL RESULTS	SUPPLY WORKSHOP RESULTS	MARKETS WORKSHOP RESULTS	GNOSTIC CONCEPTS, INC., ASSESSMENT RESULTS
4. Is the initiative a more effective policy option than increased R&D without the initiative?	No; sensitivity analysis indicates that if R&D outlays lead to a low-cost technology breakthroughs, the benefits would significantly outweigh those of the initiative under almost all probable scenarios.	In some respects; the initiative would allow a small (100 MW) industry to be reached sooner, an infrastructure to develop sooner; earlier industry production investment, and quicker reduction in nonarray system components. Increased R&D would stimulate private R&D, hasten the development of thin-film and high-efficiency solar cells. Some demonstrations to obtain information are necessary.	Not directly addressed; some tests and applications were thought to be needed for pumping and grid-connected applications.	Probably not; although this questions was not directly addressed in the Gnostic's Assessment, it is implied that an R&D increase would at least be as effective as the initiative in meeting program goals. Also, a procurement delayed to the late 1980s would also be more effective. However, some small demonstrations to obtain information are necessary.
5. Does the initiative have an impact on penetrating large grid-connected U.S. markets?	No: the initiative's major impact in all likely scenarios is on intermediate and foreign markets. Breakeven prices in grid-connected markets are too low to be affected by the initiative, unless real electricity prices triple in the next 15-20 years.	Uncertain; the initiative does some to increase the probability of reaching $.50/Wp or the development of thin-film technologies. However, the initiative may stimulate favorable actions by utilities and PUCs sooner.	No; utilities felt a large multi-cycle demonstration at this time was not appropriate. A limited number of controlled experiments would be more useful.	No; as it is not proposed. However, lower cost demonstrations in the early 1980s and grid-connected tests on a larger scale in the late-1980s would have a positive impact on these markets.
6. Do the economic benefits of the initiative warrant the costs?	No; the initiative results in an expected net loss based on current market and supply information.	The industry felt that the economic benefits to them would be positive but those benefits were not measured. They felt they would not bear the costs directly and therefore favored the initiative.	Not directly addressed; the general attitude was that the initiative would not produce many useful results.	No; the initiative has little positive effect on either price or quantity goals and could have a negative effect on the industry if a "seller's market" occurs between 1982 and 1986.

TABLE 50

OBSERVATIONS ON KEY ISSUES OF THE VENTURE ANALYSIS

KEY ISSUES	INTEGRATING MODEL RESULTS	SUPPLY WORKSHOP RESULTS	MARKETS WORKSHOP RESULTS	GNOSTIC CONCEPTS, INC., ASSESSMENT RESULTS
7. Are there benefits to the initiative other than those captured by consumer surplus calculations?	Yes; although domestic economic benefits are the primary measure used in the model, environmental and foreign benefits are estimated and do result from the initiative.	Yes; any increased government involvement represents a needed federal commitment to photovoltaics. Informational benefits of tests and applications cannot be replaced with R&D or market studies only. An initiative could also help utility attitudes toward photovoltaics become more positive and encourage the establishment of a photovoltaic infrastructure.	Yes; informational benefits would result from procurements in the pumping and grid-connected markets. Questions of the appropriate funding level of these procurements were raised.	Yes; reorganization of the initiative to demonstrate grid-connected applications in the late 1980s would be valuable. The informational benefits of a small demonstration starting in the mid-1980s are very valuable.
8. Are there disbenefits to the initiative other than those captured by consumer surplus caculations?	Not addressed; vendor response analysis indicated that if investment is stimulated by the initiative, this investment could be in soon to be obsolete production equipment. Also, private sector resources could shift away from R&D to production investments.	No major disbenefits were suggested.	Yes; a few participants stated that the initiative could demonstrate that photovoltaics is not cost-competitive. As a result, market interest in photovoltaics could be reduced.	Probably not; delays in price reduction that could result from added demand by the initiative in an already capacity constrained industry are considered in the model.

The current photovoltaic industry is characterized by high prices for its product and nongovernment sales in small remote markets, primarily communications and cathodic protection. For small purchases (50-100 Wp), current commercial module prices typically range from $24/Wp to $10/Wp (FOB factory, 1975 dollars). The current high prices of photovoltaic arrays and photovoltaic power systems are the key obstacle that must be overcome before widespread use of photovoltaics will occur.

The current national photovoltaic program attempts to reduce the current high prices of photovoltaics through three parallel approaches. First, research is conducted on new photovoltaic technologies (such as thin films and advanced material devices) with the potential for very low costs. Second, continued development of current photovoltaic technologies (e.g., single crystal silicon, both flat plates and concentrators) is undertaken to achieve cost reductions through improvements in array design and production techniques. The third element is a market pull strategy aimed at stimulating markets and private sector investment in cost-reducing production facilities.

As stated previously, the main question addressed by the venture analysis concerns the effectiveness of the market pull strategy in achieving the price reductions necessary to penetrate large energy markets. The first three conclusions deal specifically with the market pull initiative. The remainder deal with alternatives to the market pull strategy.

C. MAJOR CONCLUSIONS

The Market Pull Initiative is Not An Effective Mechanism to Achieve the Required Photovoltaic System Price Reductions

The photovoltaic industry currently faces highly uncertain intermediate markets for its product. There are serious questions concerning the number and type of sales that will occur as array prices drop from their current levels to about \$1/Wp to \$0.50/Wp.

The market pull initiative is designed to pull photovoltaic system prices from their present levels to the range of \$1/Wp to \$0.50/Wp by stimulating a large demand for photovoltaics at relatively high prices. The stimulated demand will then presumably induce the industry to make production investments that will achieve lower costs. Lower costs and competition among suppliers should result in lower prices which will then stimulate additional demand and lead to further investment. These reinforcing events are assumed to continue until grid-connected markets become feasible, and photovoltaics begin to displace conventional energy supplies.

Market studies undertaken for DOE have identified a large number of potential intermediate photovoltaic markets. The ranges of market size estimates and competitive photovoltaic price estimates contained in existing studies are very large. Discussions with representatives of potential intermediate markets during the market demand workshop and other meetings reinforced the uncertainty in the intermediate markets.

Another indication of the uncertainty surrounding these intermediate markets is the actions and statements of the industry. The general enthusiasm of the industry for the initiative as reflected in the supply workshop indicates that it perceives an investment in production equipment to currently be a high risk. The industry generally believes that government purchases in the 1980s would help reduce that risk. Finally, at least one potentially large photovoltaic supplier has explicitly stated that intermediate photovoltaic markets do not exist. In a recent letter to DOE, the president of Texas Instruments Incorporated stated:

> . . . Our work also suggests, at least in the U.S., that the demand for electrical energy as a function of price is discontinuous. Only a few scattered applications are available at array prices of $1 to $15 per watt. . . In the case of photovoltaic devices, the lack of demand above $1 per peak watt is not conducive to the step-by-step process improvements such as have been made in the manufacture of integrated circuits.[1]

Because of this uncertainty, the effectiveness of the initiative was analyzed under a range of possible market scenarios. If the intermediate markets are large (i.e., 250 MWp/yr or larger at system prices above $1/Wp), the integrating model showed the photovoltaic industry would grow rapidly even without the added stimulus of the market pull initiative. The incremental benefits of the initiative under large market scenarios did not offset the initiative's cost. If the intermediate markets are actually small or do not materialize (i.e., annual markets of less than 40 MWp at system prices above $1/Wp), then the market pull initiative will probably have little impact on "pulling" photovoltaic prices into the range needed to penetrate large energy saving markets. Only under a very restrictive set of circumstances did the procurement initiative significantly accelerate the penetration of grid-connected markets. These circumstances simultaneously require: a very small intermediate market; a rapid rate of escalation of

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[1] Letter of May 1, 1978, from J. Fred Bucy, President, Texas Instruments, Inc., to Dr. John Deutsch, Director, Office of Energy Research, Department of Energy.

electricity prices,(nearly a threefold real increase by 1990); and no array price breakthroughs resulting from photovoltaic research and development. The large benefits of the initiative under these circumstances occur because the photovoltaic price reductions caused by the initiative enable today's photovoltaic technology to make energy contributions earlier than in the base case.

The size of the U.S. outdoor lighting market and the foreign pumping market could make them significant for the development of the photovoltaic industry. There have been no U.S. supported system tests or experiments in either of these markets. U.S. photovoltaic suppliers will have to compete with foreign suppliers in international markets.

The Impact of the Initiative on Grid Competitive Markets is Probably Small

Under most scenarios, the market pull initiative has very little effect on the penetration of photovoltaics into U.S. grid-connected markets. The initiative is ineffective because it does not reduce photovoltaic prices to the range needed to penetrate those markets. Most studies, including this venture analysis, indicate that photovoltaic system prices without storage must reach \$0.50 to \$1/Wp before they are grid competitive in the United States, barring a sharp escalation in electricity prices.[2]

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[2] The first photovoltaic systems installed in the grid will probably not have on-site storage. Rather, they will use the grid as a substitute for storage (i.e., the system will sell excess electricity to the grid when it is not needed on site and buy grid electricity when the photovoltaic system does not supply the total demand). Storage costs will be a significant portion of the balance of the system. If the grid systems considered in this analysis included storage, the allowable price of the array would be lower than those indicated.

This conclusion does not imply that the initiative is necessarily the lowest cost means of insuring that photovoltaics are available to the grid market. For example, a price reduction breakthrough resulting from R&D may bring the industry into a competitive position for serving grid markets at a lower cost than achievable from production experience in intermediate markets using existing technologies.

The Value of the Market Pull Initiative Depends on the Goals of the Department of Energy

An explicit goal of the Department of Energy in the area of photovoltaics is the displacement of conventional energy sources, especially imported fuels. Under most scenarios examined by the venture analysis, the energy displacement benefits of the initiative do not justify the program's cost. The net loss is due primarily to the nature of the U.S. markets that the initiative will be able to stimulate. Most current photovoltaic applications either use very little energy (e.g., remote communications) or, until penetrated by photovoltaics, used no energy at all (e.g., new applications of cathodic protection).

The initiative can also be judged by its effect on sustaining the photovoltaic industry through a discontinuity in market demand between current prices and the $0.50 to $1/Wp system prices necessary to penetrate energy saving markets. The initiative is of value in achieving this goal only if near-term and intermediate markets are very small. If large intermediate markets develop, these nonsubsidized markets alone should accelerate the development of a larger photovoltaic industry. Under this latter situation, the marginal benefits of the initiative do not outweigh its cost. In fact, the program could be detrimental to the industry because it would add more demand to an industry that is already expanding very rapidly.

Other criteria for judging the initiative are how it benefits foreign markets, its impact on U.S. exports of photovoltaic systems, or the indirect benefits of foreign sales on U.S. intermediate markets. The indirect benefits of foreign sales on U.S. intermediate markets are expected to be small. If some fraction of gross benefits to other nations (measured as consumer surplus) is added to the U.S. benefit calculation, the initiative could become more attractive, especially if intermediate foreign markets prove to be very large. Most of the intermediate photovoltaic markets may be overseas. Therefore, most of the benefits from reducing prices would be accrued overseas.

The Benefits of a Price Reduction Breakthrough Outweigh the Benefits of the Market Pull Initiative

An array price reduction breakthrough in photovoltaics would have a major impact on achieving the DOE program goals and in displacing conventional energy sources. Therefore, federal funding of photovoltaic research and technology development to achieve this breakthrough has the potential to yield benefits in excess of the cost of these research and development programs. The breakthrough needed to yield these benefits is a discrete change in array price, not in technology. Thus, the achievement of low-cost arrays is just as important whether the basic devices are single crystal silicon or thin film.

The results of the integrating model indicate that under almost all scenarios, the benefits of a price reduction breakthrough range from several hundred million to several billion dollars. The integrating model also indicated that the timing of the breakthrough is not as important as the fact that one occurs in the time period when grid-competitive markets are developing (i.e., in the 1990s).

A Series of Field Tests and Experiments Explicitly Directed Toward Ascertaining Performance and Market Information is Necessary

Only very limited information is currently available on the potential size of intermediate markets and the performance required by potential purchasers in each market. There is also very little information on the performance of alternative photovoltaic designs in these applications. The need to address the performance uncertainties is also important in U.S. grid-connected markets. Discussions with utilities during the market workshop highlighted the need for performance data over a period of 10 to 20 years.

D. RECOMMENDATIONS

Currently available information does not support an affirmative decision on the market pull decision. Therefore, the project team recommends that the initiative not be implemented until and unless the conditions necessary for its success arise.

The project team also recommends that research and development on both silicon and competing photovoltaic technologies be accelerated. A series of moderately funded field tests and experiments should also be continued, with the explicit objective of obtaining market and performance information rather than the encouragement of private sector investment and price reduction through market pull. These tests should include grid-connected applications of sufficient size to obtain realistic information on the interaction between the photovoltaic systems and the grid servicing these systems.

The project team recommends that these experiments be augmented by an intensive set of market studies designed to reduce the market uncertainty that photovoltaic vendors face. These studies should include a major investigation of international markets for photovoltaics. Reducing this uncertainty by demonstrating that markets exist in the system price range above $1/Wp will encourage investment and production by vendors and insure that a healthy industry exists to service the energy savings markets in the future. If markets are proven not to exist in this price range, then a more serious problem requiring further changes in the national photovoltaic program may have to be addressed.

The venture analysis primarily investigated one strategy to accelerate the commercial development of photovoltaics. The potential of photovoltaics as a U.S. energy resource underlines the need for further investigation of alternative government strategies. For example, end-use incentives, incentives to stimulate foreign sales, alternative federal array or system purchase programs, or incentives to stimulate investment by the photovoltaic industry should be investigated. The results of the venture analysis suggest that no critical decisions concerning the commercialization of photovoltaics have to be made immediately. Therefore, it is recommended that the available time be used to identify effective policies for accelerating the commercial development of photovoltaics.

The recommendations outlined above are consistent with the photovoltaic research, development, and demonstration bill (HR 12874) recently approved by the U.S. House of Representatives. The purpose of the bill is:

> To provide for an accelerated program of research, development, and demonstration of solar photovoltaic energy technologies leading to early competitive

> applicability of such technologies to be carried out by the Department of Energy . . .[3]

The bill represents a ten year federal commitment to photovoltaics. While the bill does set forth some specific program requirements, considerable flexibility is provided in structuring the priorities of the federal photovoltaic program. The bill charges the Department of Energy with the responsibility to conduct the program planning necessary to most effectively achieve the objectives of the bill.

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[3] HR 12874, 95th Congress, 2nd Session, May 25, 1978, p. 1.

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