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PHOTOVOLTAIC MARKETS: A REVIEW AND ASSESSMENT

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ABSTRACT

This paper reviews available information on potential markets for photovoltaic power systems. A set of key parameters which affect the rate of photovoltaic market penetration is used to develop a simple analytical structure that characterizes potential markets. Completed studies on photovoltaic markets were reviewed to describe potential markets using this structure. Selected markets were then examined in greater detail in a market demand workshop attended by potential purchasers in these markets. Available information, while sufficient to provide a rudimentary indication of how markets might develop, does not allow the construction of any single market scenario in which a high level of confidence can be placed. Throughout this paper, major uncertainties in the available information on photovoltaic markets are highlighted.

I. INTRODUCTION

This paper summarizes existing information on the size and characteristics of potential near-term, intermediate, and long-term markets for photovoltaic power systems (1). The paper is organized into two major sections. Section 2 describes what information has to be obtained to characterize photovoltaic markets. Section 3 provides a summary of the market data collected to date. Section 3 is further divided into near-term, intermediate, and long-term market categories. Throughout, 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.

2. CHARACTERIZATION OF MARKET RESPONSE

A set of five key parameters which affect the rate of photovoltaic penetration into current and future markets is used to characterize the market response to photovoltaic systems.

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. 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.

Photovoltaic Power System Description: A detailed design of the photovoltaic power system and estimation of its costs constitute 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. 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. In many markets, there is a wide range of system sizes and types. Thus, market

descriptions must serve as generalizations of market characteristics. 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. 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 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 price at which the photovoltaic system is equal to the competitive system is termed the breakeven price.* 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.

*The following example illustrates how the photovoltaic break-even 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 established 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 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. Breakeven system price =

$$\frac{\$14,650}{600\ \text{Wp}} = \$24.42/\text{Wp}.$$

This price is the allowable $/Wp 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.

3. 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. Near-term markets are defined as those in which sales are currently being made. 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 (into the range of $2/Wp) 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. Long-term markets are defined as those applications which could be penetrated with only major reductions in photovoltaic system prices, such as residential or central utility power applications.

The summary of market data draws on two sources of information. The first is publicly available market studies. The second source is a workshop with representatives of key current and potential markets conducted by SERI. Emphasis is placed on the size of potential markets for photovoltaics and on the prices at which photovoltaics become competitive. Estimates of the size of the potential market and breakeven prices from various sources are often conflicting. The discussion below compares and contrasts these sources and then summarizes major uncertainties for each market category.

3.1 Near-Term Markets

The published sources of market data on near-term markets are the previous work by the BDM Corporation (2), InterTechnology Solar Corporation (3), and Aerospace Corporation (4). An initial screening of potential near-term markets resulted in the selection of approximately 17 markets for further consideration. Table 1 summarizes the available data on potential near-term markets. As shown in Table 1, 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 U.S. 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.

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

TABLE 1

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 SAI[2]	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]	227[7]		26[6]	28		3.4	1.1		4	1.7	
ICP Pipelines-U.S.	27	3-7[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		

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.

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. 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 world-wide 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 these markets will only emerge after more detailed market research and market experience.

3.2 Intermediate Markets

As in the case of near-term markets, the primary source of information on intermediate photovoltaic markets is work by the BDM Corporation (2). However, data on only a few intermediate markets were contained in this work. Information on several intermediate markets presented here represents a very rough description of these markets and cannot be substantiated by detailed market research. Table 2 summarizes available data on potentially significant 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. 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.

Similarly, other federal applications could be either a very small market or a significant market.

A variety of potential U.S. consumer markets is contained in Table 2. 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.

Currently available descriptions of foreign intermediate markets are also highly uncertain. Table 2 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.

Descriptions of intermediate markets for photovoltaics both in the United States and foreign countries are speculative at this time. The market workshop session on agricultural applications and the market studies suggest that an intermediate agricultural market in the United States does not exist. A variety of possible U.S. 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-$10/Wp range.

3.3. Long-Term Markets

Several studies have examined the allowable costs for photovoltaic power systems in major energy consuming markets. In the SERI Photovoltaic Venture Analysis, the MIT Energy Laboratory analyzed the economics of photovoltaics on a regional basis in three different settings: single family residences; institutional buildings; and central utilities.

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.

TABLE 2

SUMMARY OF INTERMEDIATE 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)
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

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.

The MIT results are expressed as breakeven system prices which represent the net present value over a 20-year period (in 1975 dollars) of a photovoltaic system installed in 1978 divided by the peak power rating of the photovoltaic array. The results are based on hourly simulations of photovoltaic systems with 3.2 kW of peak array capacity and no storage.

In the residential sector, results ranged from a high breakeven system price of $1.25/Wp in Phoenix (southwest region) under a 100% buyback rate to under $.50/Wp in Texas for all buyback rates. At 0% buyback, the breakeven system price in Phoenix is reduced to approximately $.90/Wp. The 50% buyback in Phoenix results in a breakeven price of approximately $1.10/Wp. In the northeast region, represented by Boston, results ranged from $.55/Wp at 0% buyback to approximately $.70/Wp at 100% buyback. Breakeven prices for the southern region (Miami) ranged from $.60-.85/Wp and in the north-central region (Omaha) from $.40-.70/Wp. It is obvious that the potential size of the residential market is large. However, photovoltaic system prices will need to be drastically reduced for photovoltaics to compete in this market.

Analyses of the institutional and central utility sectors conducted by MIT yielded similar results. However, breakeven system prices in both of these sectors were expected to be somewhat lower than in the residential sector. This is especially true in the central utility sector where photovoltaic systems would have to cost approximately $.50/Wp to be economically competitive. Other studies also suggest that major reductions in photovoltaic system prices will be needed for photovoltaics to compete in energy markets.

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