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PHOTOVOLTAIC POWER SYSTEMS: REVIEW OF CURRENT MARKET STUDIES: METHODOLOGY FOR LONG TERM DEMAND PROJECTION

by

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The paper which follows has been prepared for two purposes; first, in response to a number of requests from individuals both within and outside of the Photovoltaic community for information on the potential near term, mid-term and particularly long-term markets for photovoltaics and second to present the preliminary work of the Photovoltaics project at the Energy Laboratory in projecting equilibrium demand curves for a specific emerging energy technology. The material presented represents an interpretive summary meant primarily to guide those who would seek additional information concerning Photovoltaic development propects. The information on Photovoltaic markets is that available to the author as of spring 1978. M.I.T. Energy Laboratory through its research efforts is rapidly expanding the understanding of long-term markets. Such groups as the BDM Corporation continue to do the same for near and intermediate markets guaranteeing that this summary will be out-dated before it is out of the typewriter. Even with these caveats, however, there is considerable potential usefulness in this paper if only to offer the framework for a continuing update. In the near future such updates will also be provided by at least the following current study efforts.

- SERI Venture Analysis looking at the Photovoltaic Program Plan and, in particular, the market pull component
- American Physical Society study directed by Professor Henry Ehrenreich of Harvard which is focused on the technology development side. Requested by Frank Press' office, The White House.
- Market/benefit study being carried out by staff members in DOE Policy Evaluation with a large support contract to Booz-Allen-Hamilton

there are at least two other evaluative studies underway which are less well organized than the three listed above. To date there are no available reports from this set.

At the present time the recommended companion piece to this paper is "Photovoltaic Power Systems: A Tour Through the Alternatives" by Henry Kelly of the Office of Technology Assessment.[1] The Kelly article offers an excellent discussion of the state of development of the Photovoltaic Technology but is less strong on market potential though he does include a brief discussion and summary of a number of the near and mid-term market studies completed to date.

Projection of markets for any product is more of an art than a science under the best of circumstances. The very nature of the photovoltaic technology makes projection of its market even more uncertain. There is a set of three generic market areas for photovoltaic power systems. The first markets are cost effective today in applications which are remote and for which the alternative energy source is exceptionally costly. There is another set of applications for photovoltaics which fall into the range between $1 and $8 per peak watt (module) which would apply to applications lying away from traditional electrical grids, such as agricultural pumping and rural electrification in developing nations. These applications appear to have a large potential market but the technical questions, i.e., the real testing of any such system, has yet to be done. The final market for photovoltaic power systems is the one at which the US DOE photovoltaic

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1 Henry Kelly, "Photovoltaic Power Systems: A Tour Through the Alternatives" Science, Vol. 199, February 10, 1978, pp. 634-643.

program is aimed; that of replacement of fossil energy in the United States energy economy. This final objective requires exceedingly low priced hardware from a low of under 10¢ to a high of slightly over $1 per peak watt.

Each of the three demand categories listed above is important to the program and to the "industry". The first two must be seen as a means to an end from the point of view of the Federal program though these two may represent significant sales potential from the point of view of many of the industrial firms involved. Table 1 summarizes estimates of major applications for photovoltaic power systems in the present market. Table 1a., presents an estimate of the sources of intermediate demand for photovoltaic power systems. Both tables have been estimated by the BDM Corporation A concern expressed by many regarding the intermediate markets projected here is the heavy dependence upon lighting applications which appear asyncronous to the technology itself. As an example of the difficulties of intermediate market projections, a second study was carried out in parallel to that of BDM by the ITC Corporation. The results of the ITC study were not comparable to those of BDM for a number of methodological reasons. It is significant to note, however, that the two did not, in general, agree upon the applications likely to be significant during the intermediate range nor did they agree upon the size of the market within that range.

As stated above, it is our contention that, though more difficult, estimation of the long-term demand for photovoltaics is far more important than estimation of the short or intermediate term demand. If market projections are an "art", the projection of long-term markets is a "black art". The material which follows is a summary of work carried out by the Energy Laboratory both for our Department of Energy (DOE) contract

TABLE 1

MAJOR APPLICATIONS IN THE PRESENT MARKET

Application	1975 PV Sales (Units)	Typical Array Size (kWp)	1976 Array Sales (kWp)	1977 Total Annual Market (Units)	Growth Rate (Annual)	Fraction Available To Solar	1977 PV Market Potential (kWp)	1977 Break-even Array Price ($/Wp)
Mircowave Repeaters-U.S.	40	.600	24	1,150	.15	.5	350	18
Radio Repeaters-U.S.	150	.200	30	47,000	.15	.25	2,400	18
Telemetry-U.S.	800	.016	13	3,000	.05	1.	48	190
Cathodic Protection of Oil and Gas Wells (<300ft)	750	.050	36	50,000[1]	.04	.5	1,300	65
Cathodic Protection of Oil and Gas wells (>3,000 ft)	8[2]	.600[2]	0	60,000[1]	.04	.5	18,000	15
Cathodic Protection of Pipelines	60[3]	.400	24	11,300[1]	0 (?)	1.	4,500	22

SOURCE: BDM Corporation for SERI VENTURE ANALYSIS STUDY, APRIL 1978

TABLE 1a

MAJOR INTERMEDIATE MARKETS FOR PHOTOVOLTAICS

Application	Conventional Power Source	1976 Annual Sales/Instal-lations (1,000s)	Annual Sales Growth Rate	Fraction Available to Solar	Average Array Size (kWp)	1986 Break-even Price ($/$W_p$)	Factors Making Photo-voltaics an Attractive Alternative
175 W Hg Street and Highway Lighting[1]	Underground Power Lines	500	.04	.06	.25 to .49	.75 to 2.30	$4-15/Foot Cost of Installing underground line
250 W Na (or 450W Hg) Street and Highway Lighting[1]	Underground Power Lines	175	.04	.06	.35 to .7	1.30 to 3.60	Energy Conserving Lighting
175 W Hg Outdoor Lighting (Pole Mounted)[1,2]	Underground Power Lines	840	.04	.65	.11 to .22	.75 to 2.60	$4/Foot Cost of Installing Underground Line in Parking Lots
175 W Hg Outdoor Lighting (Pole Mounted)[1,3]	Underground Power Lines	360	.04	.65	.26 to .52	-.50 to .12	
1 Hp (Av.) Water Pumping Units--U.S.	GED Generator	60	.05	1	1	6.20	High O&M Costs of Small Generators
1 Hp (Av.) Water Pumping Units	Utility Power	480	.05	1	1	-1.20	Average Installation cost of $300
Power for Construction Tools, Lighting, etc.[4]	1.5-5 kW GED Generators	74	.02	.1	1.6 to 5	-.5	High O&M Costs of Small Generators
Recreational Vehicles[4]	2.5-4 kW GED Generators	92	.02	.1	.25 to 3.5	--	Quiet Operation High O&M Costs of Generator

[1]Lighting applications disaggregated by geographic region; array size based on use of energy conserving lighting
[2]Commercial/service lights operating 6 hours or power per night
[3]Commercial/service lights operating dusk to dawn
[4]Data disaggregated by generator size

SOURCE: BDM Corporation for SERI VENTURE ANALYSIS STUDY, APRIL 1978 as well as for a short run study we are doing in support of The Solar Energy Research Institute (SERI). This material summarizes a number of the problems associated with the projection of long-term demand for a technology such as photovoltaics and then presents a set of preliminary results from that analysis.

The uncertainties associated with the projection of long-term market size are significant determinants of its accuracy. These uncertain areas require additional information in order to project with increasing accuracy the eventual long-term photovoltaic power system penetration into the United States energy economy. The four areas of uncertainty are prices, exogenous events in the world energy economy, remainder of systems costs, and long-term utility reaction. These four go together to determine the quantities of photovoltaic power systems demanded.

Prices: The eventual value of power from a photovoltaic power system will be determined by a series of factors both within the control of the technology development process as well as exogenous to it. Prices, here, are a function of specific uncertainties. These uncertainties include technology development, manufacturing capability, quantity of energy input, environment and environmental regulation, institutional regulation, and marketing success. Throughout the process of technology change, development, and commercialization, the reduction in uncertainty directly affects the long-term projection of photovoltaic power systems price. The primary government role is aimed at price reduction in photovoltaic power systems as well as reduction in system performance uncertainties.

Exogenous variables: The success of any new power system will depend largely on events exogenous to its own development. The most significant of these will be the future price of alternative forms of energy. It is significant to recognize that systems such as photovoltaics will be competing with both currently defined energy systems, such as grid-connected electricity generated through fossil fuel or nuclear plants; with technologies currently under development such as breeder reactors, coal gasification, windmills, OTEC, etc.; as well as with technologies not yet seen. Analysis of the likely competitive position of one technology within this range requires the development of scenarios of likely events which include changes in conventional energy prices as well as success of currently considered energy alternatives. These scenarios are required in order to choose likely sets of events from a nearly infinite menu of possible events.

There are, in addition, a set of exogenous variables which determine, in part, the acceptance of a new technology such as photovoltaics. These involve the physical characteristics of the technology and/or competitive nature of other technological developments. The significance of this fact is that photovoltaic power systems compete for roof space in specific applications with solar heating and cooling systems (SHAC). Photovoltaic power systems, because they will be economic far later than heating and cooling, may have less access to the retrofit market available to the earlier solar technologies. On the other hand, they may be complementary to SHAC systems if configured in a hybrid mode. A second physical constraint is that photovoltaic technologies, roof-mounted in an application such as a home, must be south-facing.

This implies a sloping roof to the south with maximum exposure of walls and windows to the north, directly contradictory to the current architectural designs for energy-efficient homes which include south-facing windows and walls, and minimizing north-facing walls. The third area of concern is in the increased energy efficiency projected to occur in electrical use in the home and in other applications. The impact of this increase in energy efficiency could be to minimize the amount of photovoltaic equipment required to accomplish a given task. This also, however, reduces the eventual size of the market.

Remainder of systems costs: As prices of photovoltaic power systems drop, the proportion of non-module costs to total system costs become more significant. Requirements for power-conditioning equipment, for support-structure and wiring, for installation, and for operation and maintenance, become major determinants to the price at which photovoltaic power systems, as opposed to modules, can enter the market. On the margin these costs, on which the photovoltaic program has little if any effect, determine the eventual competitiveness of the system.

Long-term utility reaction: Electric energy in the United States is in large part provided large, regulated electric utilities. These utilities provide power to most users today and will in all likelihood continue to do so. The willingness of utilities to provide backup power for dispersed electric generation systems such as photovoltaics will determine to a large extent the acceptance and economics of such dispersed systems. As a result, a significant uncertainty in any long-term analysis involving electric power generation or requiring electric power backup, is highly dependent upon the willingness of utilities or of public utility commissions to address on economic grounds (through the rate structure) the development of such systems. The inclusion of dispersed electric generation systems within a grid may be to the economic advantage of the utility due to load management benefits. Further careful and detailed analysis is required to investigate this assertion, or the conditions under which it may hold. In any scenario, however, the long-term electric rates set by public utility commissions will determine the attractiveness of any dispersed generation or storage system to the nonutility owners of such a system.

The projection of long-term markets for Photovoltaic power systems is a three stage process. The first is the projection of the cost-competitiveness for any given application for photovoltaics. The second is the construction of a demand potential curve for the technology at a range of prices. The third is the estimation of the rate of penetration into the electrical energy market that would occur at any given price and over time. It is beyond the scope of this paper to review all of the potential methodologies available to accomplish each of the three stages listed above. It is significant, however, to note that a detailed discussion of area 1, cost of photovoltaic power systems to the owner, may be found in Carpenter and Tabors, "A Uniform Economic Valuation Methodology for Solar Photovoltaic Applications Competing in the Utility Environment."[2] Analysis of available methodologies for stage 3 above are the subject of the SERI workshop report, "The Market Penetration of Solar Energy: A SPURR Model Review Workshop's Summary."[3] Evaluation and estimation of demand curves for technologies

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2 Carpenter and Tabors, " A Uniform Economic Valuation Methodology for Solar Photovoltaic Applications Competing in the Utility Environment", MIT Energy Laboratory Technical Report, April 1978.

3 Schiffel, Costello et al,"The Market Penetration of Solar Energy A SPURR Model Review Workshop Report", (Golden, Colorado: SERI) December 1977.

such as Photovoltaics competing with a utility grid requires an innovation in methodology. One such methodology is discussed later in this paper, that developed at the MIT Energy Laboratory by Tatum, Carpenter, Taylor and Finger.

Previous Studies of Long-Term Photovoltaic Markets

There are four primary sources for long-term photovoltaic penetration analysis results for the United States, and one source which attempts to summarize both the short- and long-term photovoltaic markets for the United States.[4]

These four studies vary considerably in their results and in their approach to projection of long-term markets. The first two studies, those by General Electric Space Division and Westinghouse Research Division, were carried out in the early stages of the development of the photovoltaics program. They relied heavily upon descriptive techniques such as Fisher-Pry logistic curves for estimation of likely penetration into the markets studies. The efforts of such early analyses tended to indicate potential for large photovoltaic penetration into, in particular, residential markets, with lesser emphasis on applications such as shopping centers, and final inroads into the central utility market. The General Electric study was segmented into an estimation of

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4 General Electric Advanced Energy Programs, "Conceptual Design and Systems Analysis of Photovoltaic Systems, Final Report", March 19, 1977;

Westinghouse Electric Corporation Research and Development Center, April 1977;

General Electric Corporation-Electric Utilities Systems Engineering Division, "Requirements Assessment of Photovoltaic Power Systems" carried out for EPRI, March 1978;

Sumary work has been accomplished by E.J. Rattin in "An Overview of Photovoltaic Market Studies", draft presentation March 1978.

the residential market for the United States as a whole and an analysis of the potential for central power applications in the "Sun Belt" (not defined) in the United States. The Westinghouse study divided the market into residential, intermediate and large-size markets translating roughly into homes, shopping centers, and central power. Figure 1, taken from the Rattin report, summarizes the results of the long-term studies by General Electric and Westinghouse for eventual market penetration of residences utilizing photovoltaic power systems (as well as BDM, ITC and Aerospace short and intermediate market estimates). As can be seen, the two studies are relatively close with GE estimating 35 gigawatts of installed capacity by the year 2000 and Westinghouse 25 gigawatts of installed capacity. These early studies focused on specific elements of the photovoltaic market and on relatively simplistic methods for market penetration.

The third study mentioned above, that by the General Electric Utility Systems Engineering Division, focused entirely on the potential for photovoltaic power systems operating as power plants within a gridded utility. This analysis is included as a long-term market study because it focused on projection of the value to a utility of a photovoltaic power system, clearly an application which will not become competitive in the near or mid-term. This study analyzed the Northeast Electric Systems of the Boston area, Florida Power and Light of the Miami area, and Arizona Public Service, of the Phoenix region. In each case the photovoltaic power system was operated in the simulation mode within the existing utility to calculate the value to the utility both in capacity and fuel savings of a photovoltaic power plant.

Summary of Selected Photovoltaic Market Estimates to Year 2000

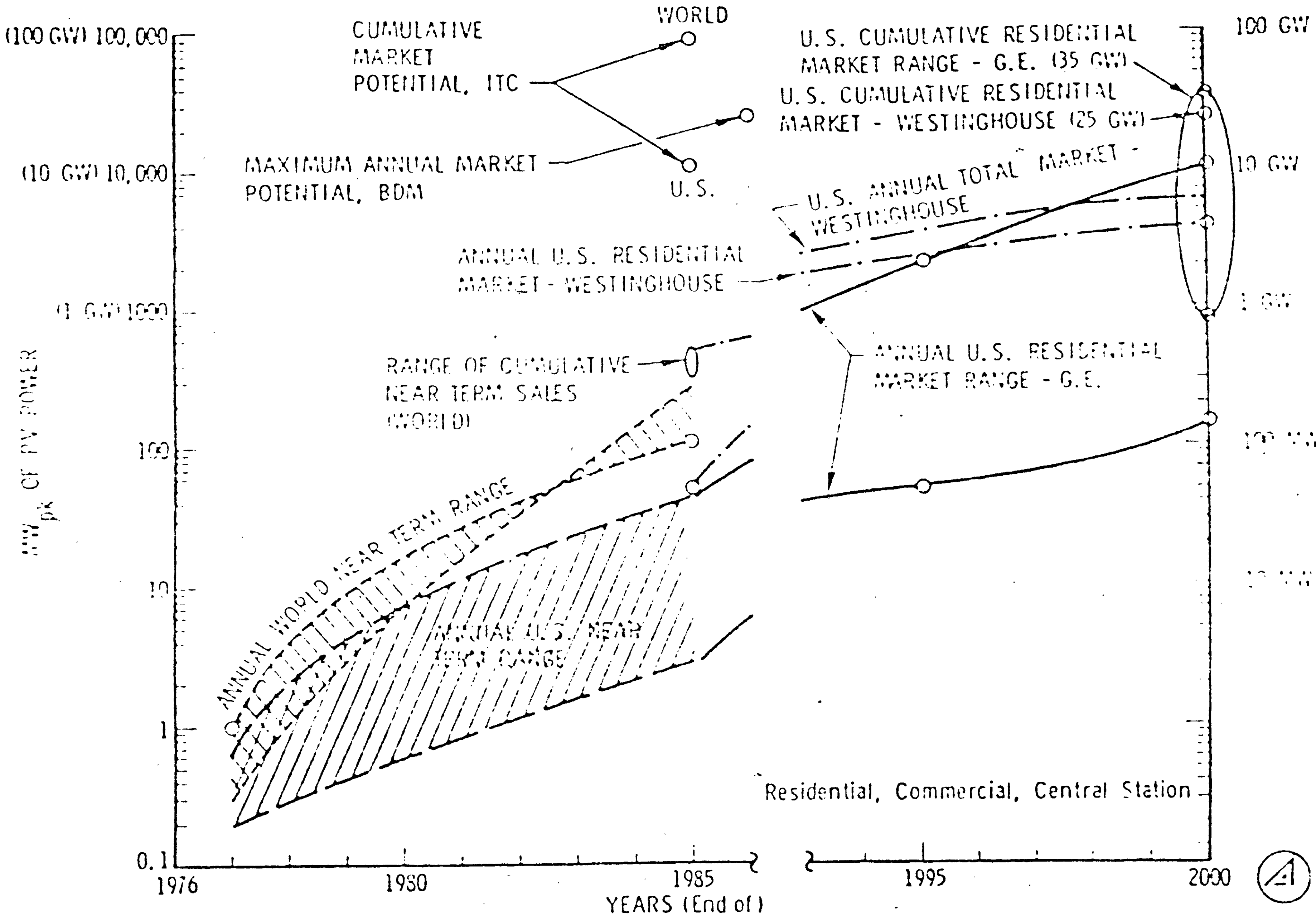

FIGURE 1
SOURCE: E.J. Rattin, "An Overview of Photovoltaic Market Studies", Aerospace Corp. Draft, March 1978

The fourth study included in this set was carried out by E. J. Rattin of Aerospace Corporation at the request of the Photovoltaics Division of the Department of Energy. His efforts were focused on the synthesis of information concerning near-, mid- and long-term markets for photovoltaic power systems. His sources were studies carried out by other corporations, such as BDM and ITC for the short- and mid-range analysis, and GE and Westinghouse for long-range market potential. As such his report and graphics offer a valuable source for any effort at estimating markets for photovoltaics. It should be pointed out, however, that the assumptions and the reporting procedures for each of the studies summarized by E. J. Rattin were sufficiently different to make comparison of the results virtually impossible. Investigation of his results as well as independent review of the sources listed above indicates little if any meaningful agreement between the reports themselves. As a result, neither the short-term, mid-term, nor long-term analyses done to date offer a clear picture of the magnitude of likely markets for photovoltaics in the future. They do offer, however, suggestions as to application areas in which photovoltaics may have an impact; though even here there is considerable divergence of opinion.

Cost and Quantity Comparisons: Three Sectors

The analytic material which follows summarizes the preliminary results of analysis of the long-term potential for photovoltaic power systems in three sectors of the United States energy economy: the residential sector, the commercial sector -- as exemplified by a school analysis, and the central power sector. The results presented are preliminary. They cover a varying number of energy regions, for residential, three regions: Boston, Omaha and Phoenix. For commercial, only one region: Boston. For central power, three regions: Boston, Phoenix and Miami. As was stated earlier, there are a number of methodologies available for estimation of the competitive position of photovoltaic power systems. For ease of presentation, this section will focus on the breakeven cost methodology as used by the MIT Energy Laboratory and will reference other methodologies such as busbar energy costs used by earlier studies. Given the difference in methodologies, it will not be possible to compare directly the results of the MIT work with that of earlier efforts.

Residential Systems[5]

The residences under study were single-family, grid-interconnected, faced with a time-of-day or peak-load pricing scheme, were airconditioned but not all-electric, and were optimally sized for the region in which the system was to operate. Table 2 shows the comparative breakeven costs for the residential grid-interconnected photovoltaic power systems in each of the three regions completed to date. It is significant to note that these systems are without battery storage. All back-up is provided by the electric utility grid. In analyzing the results of these studies, several points should be highlighted. First, studies are carried out on an hourly simulation basis for a year. The result of this analysis are then expanded to a 20-year financial life for a photovoltaic power system.

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5 Residential Studies nearing completion are:
Jesse Tatum, "Photovoltaic/Hybrid Simulation Model for Grid Interconnected Residential Applications", MIT Energy Laboratory Technical Report (forthcoming)

Paul Carpenter and Gerald Taylor "An Economic Analysis of Grid-Connected Residential Solar Photovoltaic Power Systems", MIT Energy Laboratory Technical Report May 1978

The detailed analysis undertaken, therefore, matches carefully the peak periods of electric power requirements with the peak periods of performance for the solar cells themselves. This allows photovoltaic power equipment to have a high value for a system such as Phoenix where it provides electric power during the peak, midday, air-conditioning periods, in much the same way for Boston, power is provided against high utility rates during peak requirements in both summer and winter.

Table 2: BREAK EVEN COSTS, RESIDENTIAL SYSTEMS

	$/Wp
Phoenix	1.27
Omaha	.43
Boston	.68

The second significant point of analysis is the large spread between the breakeven cost of a Phoenix house and that for Omaha even in these initial runs. No market penetration studies have been carried out to date in conjunction with the cost estimates produced in this study. It is significant, however, that the markets will open to photovoltaics over an exceptionally wide range of prices, and that these papers are considerably above those that would be paid by utilities operating in the same regions for providing electric power to residences.

Market penetration analyses for residential photovoltaic systems have been carried out by both General Electric and Westinghouse in the early conceptual design studies.[6] These studies indicated that residential photovoltaic power systems could reach levels of 25-35 megawatts of installed capacity by the year 2000. The methodologies used in both of these cases were a combination of Fisher-Pry logistic curves and market maxima methodologies. As a result, these studies do not incorporate information in dramatic divergences in price as is discussed in the paragraph above.

Service/Commerical/Institutional (S/C/I) Sector[7]

The analyses completed to date for applications in the S/C/I sector are rudimentary. Table 2A contains the description of characeristics of a school building used for first-run analysis in Boston. It should be noted that a number of simplifying assumptions have been made in this early analysis. The most significant of these is that the electrical load faced by the school contains only the power requirements for lighting and for circulating fans required by law to move air in and out

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6 GE Advanced Energy Programs, op. cit. Westinghouse op. cit.

7 The baseline school/information was derived from draft material to be presented in a Technical Report by Susan K. Raskin, "Electrical Energy use in the Service/Commercial/Institutional Sector": U.S. Educational Facilities.

Table 2A: S/C/I: SCHOOL ANALYSIS CHARACTERISTICS

SYSTEM: Primary School

160,000 Sq. Ft. Building

5,400 Sq. Meter of Arrays

Power supplied only to lighting and circulation of air

Discount rate 2%

SYSTEM WORTH: $.83/watt peak

of the building. As a result, there is no air-conditioning load included, nor is there any kitchen or laboratory load included. Further analysis is expected to improve the quality of the simulation carried out for schools and extend this simulation to other regions of the United States. Even given these caveats, it is interesting to note that the value of photovoltaic power systems per peak watt to a school application for the Northeast is greater than it is for a residential application to the Northeast. Schools, in general, appear to offer a potentially desirable market for photovoltaics. Their loads are daytime in nature, and tend to be peaked at the same times as solar insolation peaks.

Photovoltaic power systems on schools have one additional potential benefit, that of acting as a "load center" during the summer season when the school is essentially closed. During this period of time the photovoltaic generating capacity can be utilized by the utility grid as a "peak-shaving" source during summer air-conditioning peaks

Central Power Applications

The central power applications research work reported in this analysis is derived from the simulation work carried out by General Electric.[8] This research activity was the first in which photovoltaic power systems were simulated as a portion of an electric utility system rather than being used as a "replacement" for specific pieces of existing hardware within a utility. As a result, the analysis carried out by General Electric offers a first approximation of "worth" analysis rather than the

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8 General Electric, Utility Systems Engineering Division Requirements Assessment of Photovoltaic Electric Power Systems (G.E.,Schenectady, 1977), carried out for the Electric Power Research Institute, Palo Alto, Calif.

traditional busbar energy analysis. Which follow the methodology developed in "The Cost of Energy in Utility-Owned Solar-Electric Systems: A Required Revenue Methodology for ERDA/EPRI Evaluations", March 1978.

The General Electric analysis arrived at a total value calculation for a given utility of having a specified level of photovoltaic penetration in their grid. From this total value it is possible to calculate a breakeven system cost per peak watt of installed capacity by netting out both fixed and annual costs associated with the installation and maintenance of a photovoltaic power systems. Our analysis which follows has assumed two values, 30 cents and 50 cents per peak watt required for "rest of systems" costs for a utility photovoltaic application. In general the higher value (.50) is used because it appears more likely. When this is done, the resultant values of photovoltaic modules range from 9¢ to 0¢ per peak watt (29¢ to 9¢ at low "rest of system" cost). Phoenix appears a viable utility system within which photovoltaics may be effective. For New England, the NEES system shows little, if any, economic value from photovoltaic power systems. Florida Power and Light shows no potential value to photovoltaic power systems, given the criterion listed above.

Photovoltaics Long-Term Demand Curve

There are at present no available long-term demand curves for photovoltaic power systems. The paragraphs which follow will lay out a methodology for estimation of long-term demand for a technology such as photovoltaics when integrated with an electric power grid, and will then discuss the implementation of that methodology for central power applications using the information generated by General Electric.[9]

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9 ibid.

Estimating the demand curve for photovoltaics requires the simulation of the potential economic breakeven point for a set of hypothesized penetration levels within specific utilities. The simulation of the central power sector carried out by General Electric created the information required to calculate a demand curve for the individual utilities studied. GE determined, for penetration levels of 5, 10, 15 and 20% of rated capacity the total worth of photovoltaic power systems for each of three utilities, Phoenix, Boston and Miami. Given total worth "rest of systems" cost and installed capacity, subtraction and division nets the average value per peak watt for each penetration level for each utility studied. Because the General Electric study was carried out in 1995 dollars, it has been necessary to bring the resulting values back to 1975 dollars. Here we have assumed an annual fixed rate of inflation of 6%, 1975 to 1995.

Table 3 and Figure 2 present the results of the "demand" estimation for the three utilities. The shape of the curve presented is as would be anticipated, downward sloping to the left. The interpretation of the shape of the curve is also intuitive; with a technology such as photovoltaics it would be anticipated that as the level of penetration of the technology into the given utility increased the value of the marginal unit to the utility would decrease given the requirements for additional back up capacity to accomodate the "run of the sun" characteristics of the technology. A set of questions not yet addressed by the work of either General Electric or of the Energy Laboratory Photovoltaics project is valuation of the technology given even smaller penetration levels

Table 3

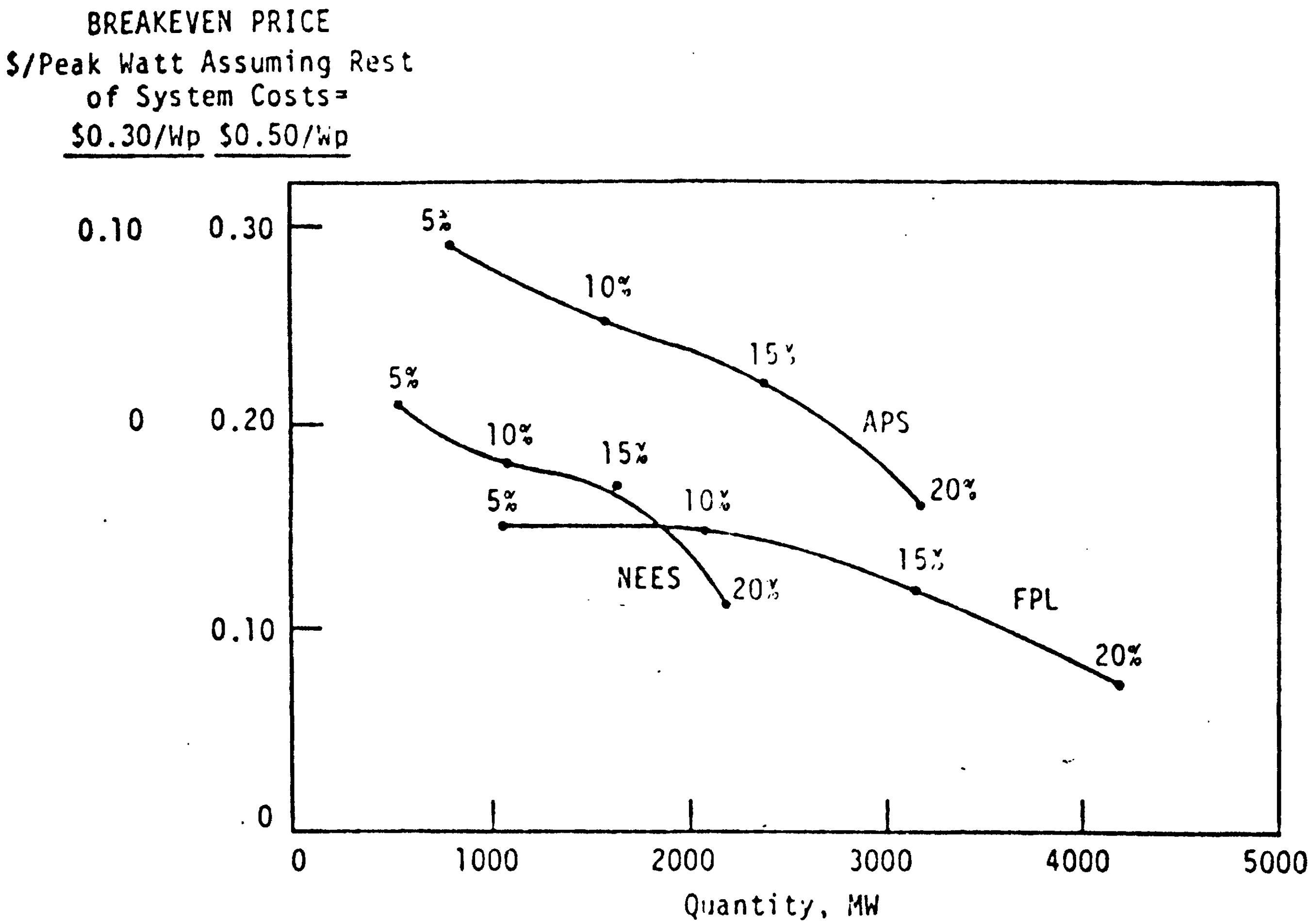
3/25/78

"BREAKEVEN PRICES" for 3 Utilities (without storage)

1 % Penetration	2 Peps Value	3 Peak MW	4 Effective Capacity MW	5 %	6 $/wp 1995	7 $/wp 1975 @ 6%	8A Net Module Costs. FOB $/wp
NEW ENGLAND ELECTRIC SYSTEMS							
5%	900	550	199	35	1.64	.51	.21 - .1[1]
10%	1700	1100	300	27	1.55	.48	.18
15%	2500	1650	400	24	1.52	.47	.17
20%	2900	2200	485	22	1.32	.41	.11
FLORIDA POWER and LIGHT							
5%	1500	1050	223	21	1.43	.45	.15
10%	3000	2100	340	16	1.43	.45	.15
15%	4250	3150	415	13	1.35	.42	.12
20%	5000	4200	450	11	1.19	.37	.07
ARIZONA PUBLIC SERVICE CO + SALT RIVER PROJECT							
5%	1500	800	367	46	1.88	.59	.29 - .09
10%	2800	1600	690	43	1.75	.55	.25 - .05
15%	4000	2400	950	40	1.67	.52	.22 - .02
20%	4700	3200	1080	34	1.47	.46	.16 -

Source: GE PEPS Study, See Figure 9 for complete citation
Note: Data in columns 1,2,3,4 Derived in part from graphs within the report and therefore subject to error.

A Net Module costs: $.30 and $.50 per peak watt "rest of system" costs have been netted out of 1975 Gross System Value.



Source: Calculated from data contained in: G.E. Electric Utility Systems Engineering Division, "Requirements Assessment of Photovoltaic Power Systems", carried out for Electric Power Research Institute, Palo Alto, California, March 1978, Final Report.

"Demand" Curve for Three Utilities as Analyzed by G.E. PEPS Study

Figure 2

(less than 5%) into their grid. There are two ways in which these small penetrations could occur. The first, and the most likely is that of adoption of the technology by individual homeowners, or industrial establishments. This adoption pattern has been modeled in the work of both Tatum and Carpenter and Taylor. The analysis of the impact of dispersed photovoltaic systems upon the economics of the utilities in which they operate is a major research area for the year ahead. The second way in which small penetrations could occur would be through utility purchase and operation. Given the shape of the curve (Figure 2) one would hypothesize that the value of smaller proportions of photovoltaic power systems within a grid would be even higher than shown with the five percent penetration level. The significant question is whether this level will increase to a ceiling and at what level. The level should be a function of the utility within which the photovoltaic system is operating and the alternative peaking equipment available. It is unlikely that the worth to the utility of photovoltaic equipment would be greater than the cost per peak watt of the most expensive peaking equipment. The simulation model required to answer this question is under preparation at the present time. It is a detailed utility operating simulation model which can be used to evaluate the worth to a utility of photovoltaic power systems within the grid.

Estimation of the value to a utility of photovoltaic generation capacity is only the first step in creation of a technology specific demand curve.[10] The second stage requires the projection of an

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10 Technology specific demand curve estimations are not unique to this effort, instance: Robert Baron, Odgen Hammond and David Wood, "Relation between Demand for Energy Services and Energy Supply Technology Choice", MIT Energy Laboratory.

'equilibrium' penetration level based on economic value, i.e. assuming that utilities will adopt the level of photovoltaic technology reflected by their breakeven worth to the individual utility. To accomplish second stage requires the estimation -- at some point in the future -- of the total demand requirements for a specific utility, the translation of that demand to a requirement for installed capacity and thence an estimation, at a given penetration level, of the quantity of photovoltaic equipment the utility would be willing to 'buy' at that price

A first approximation of this technique was used to estimate the equilibrium demand curve for photovoltaics in the United States using a three region model with each region being represented by one of the three utilities analyzed in the General Electric Study. Total U.S. Electrical energy demand for 2000 was estimated from Brookhaven BESOM scenario "Limited Nuclear Power Year 2000". Table 4 summarizes the calculations required and the assumptions made. Table 5 shows the calculation of the total demand for photovoltaics at the penetration levels -- and corresponding prices. One significant uncertainty in these rough numbers now comes even more strongly to the fore, the role that "rest of systems costs" have in determining the value of photovoltaic hardware to the user. As was shown in Table 3, the nonmodule costs account for a major proportion of the total systems costs such that if one assumes a low value of .30 per W_p for rest of systems costs the allowable value for Photovoltaic systems is 29¢ per peak watt in New England. If you assume a rest of system cost of 50¢ per peak watt, the allowable value for photovoltaic modules drops to nearly zero for all penetration levels in New England. Figure 3 reflects this uncertainty in rest of systems costs in presenting two vertical axes. The first with 30¢ and the second with

Table 4

United States "Regional" Electric Capacity, 2000

Based Upon Two Scenarios of Electrical Energy Demand, 2000

	[1] 1974 Installed Capacity (1)	[2] 1974 Kwh x 10^6 (1)	[3] [2]/[1]	[4] % of U.S. Total Kwh	(2) [5] Kwh x 10^9 / [6] KW installed x 10^6	(3) [7] Kwh x 10^9 / [8] KW installed x 10^6
"Northeastern" Region						
New England	18,528	64,485				
Middle Atlantic	66,041	205,848				
East North Central	86,642	339,197				
West North Central	35,186	108,011				
	206,397	715.541	3.47×10^3	46	3175 / 915,	2159 / 622,
"Southeastern" Region						
South Atlantic	86,425	318,774				
East South Central	42,102	150,246				
	128,527	469,020	3.65×10^3	30	2071 / 567	1408 / 385
"Southwestern" Region						
West South Central	60,121	217,491				
Mountain	24,689	73,361				
Pacific	54,441	79,612				
	139,251	370,464	2.66×10^3	24	1656 / 622,	1127 / 423,
United States Total	474,175	1,555,025	3.28×6^3	100%	6903	4694

(1) Source: EEI 1974 p. 8.

(2) Source: Calculated from Brookhaven BESOM "Limited Nuclear Power, Year 2000."

(3) Source: Calculated from Brookhaven BESOM "Scenario No New Initiatives, Year 2000."

Table 5

Table of Regional Demand at given P.V. Module Price

F.O.B. Factory*

Demand Total Southwest Region

\$/wp[1] (High)	%	I[2] GW	II[2] Total
.29	5	31.141.	21.176
.25	10	62.282	42.352
.22	15	93.424	63.528
.16	20	124.564	84.704

Demand Total Northeastern/North Central Region

\$/wp (High)	%	I Total	II Total
.21	5	45.755	31.113
.18	10	91.510	62.226
.17	15	137.264	93.339
.11	20	183.019	124.451

Demand Total Southeastern Region

\$/wp	%	I Total	II Total
.15	5	28.37	19.29
.15	10	56.74	38.58
.12	15	85.11	57.87
.07	20	113.47	77.16

1. Values listed in this column are for remainder of system costs of \$.30/wp at \$.50/wp These values are reduced by \$.20/wp.

2. Refer to Scenarios I and II.

* Assumptions for U.S. long-term Demand Curve

1) Distribution of power demand by "Region" same in 2000 as in 1974
2) Kwh/kw installed ratio constant 1974 to 2000
3) 2000 Electric Demand for U.S. taken from Brookhaven Model
   a. Scenario IV limited nuclear power= 4694 x 10^9 kwh
   b. Scenario 0 no new initiatives 6903 x 10^9 kwh

50¢ per peak watt for rest of system cost. Given current information we would suggest the use of 50¢ rather than 30¢ as being more likely!!

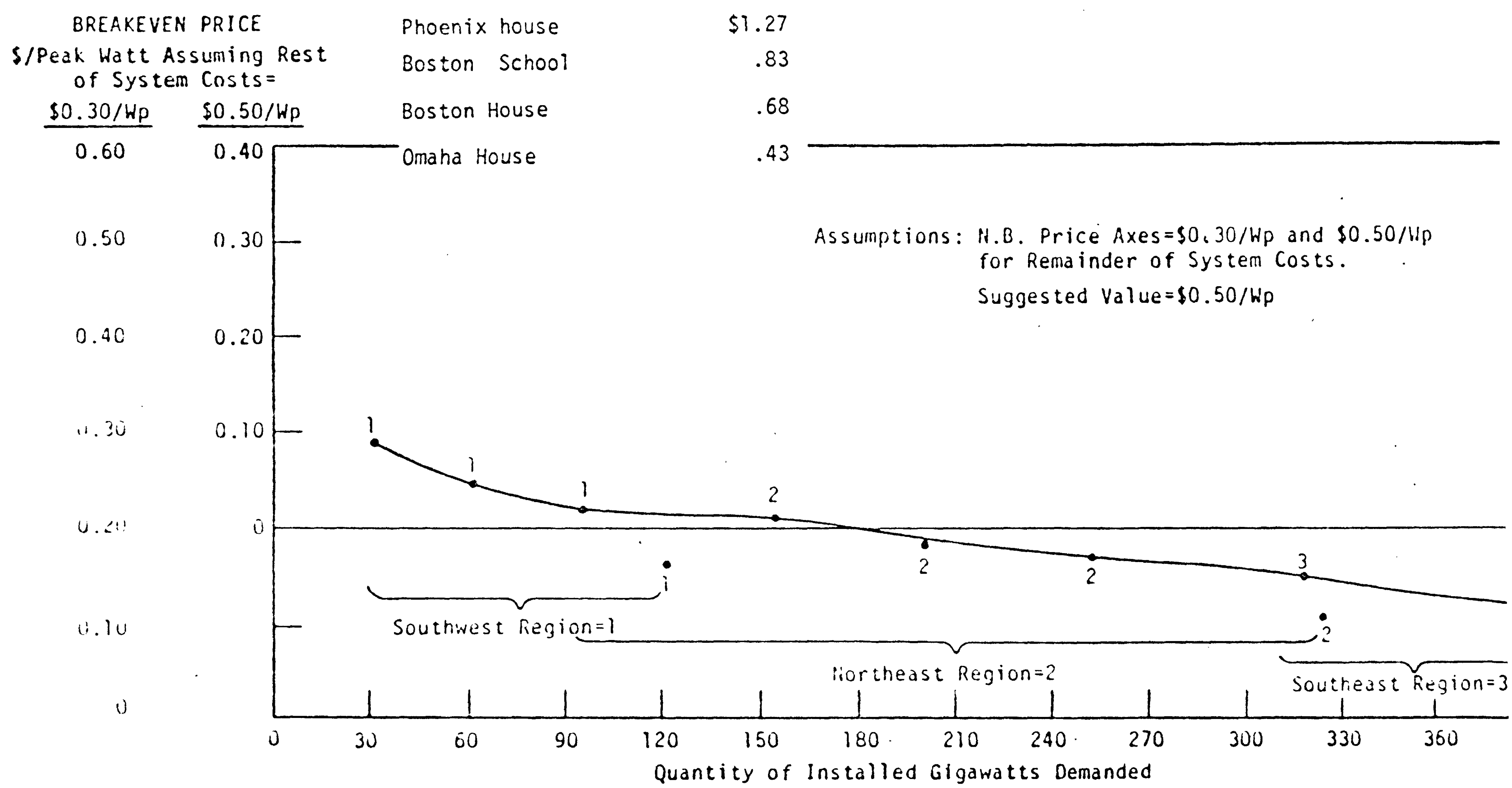
Given these caveats and the relatively rough method of calculation of penetration levels, Figure 3 presents, for the first time, an equilibrium demand curve for Photovoltaics. It is acknowledged that this is "average" and not marginal but we see the next step correcting this inconsistency.

The level of demand calculated through this methodology represents, at the lower photovoltaic module costs, an upper bound on the level of likely demand. At the higher module cots this demand would be augmented by additional demand from dispersed residential, commercial and industrial systems for whom photovoltaic systems would be cost effective at these higher prices. In so much as systems which are cost effective sooner than utility plants are grid interconnected, the impact of these systems on total demand should be estimable given knowledge of utility pricing, level of penetration and impact on utility operating system costs.

Long-Term International Markets for Photovoltaics

The final portion of this paper covers an area of work in which we have considerable academic interest and in which there has been a good deal of interest on the part of DOE, the international market for photovoltaics.

The long-term international market for photovoltaics may be segmented into three submarkets: developed nations with minimal oil such as those in Europe, oil-rich developing nations such as the Middle East, and resource-poor developing nations, such as the Indian subcontinent and much of Southeast Asia, Africa and Latin America. The primary difference



Photovoltaic Demand Curve Based on General Electric Results

FIGURE 3
Source: Calculated by MIT Energy Laboratory from information contained in Table 5.

in analysis potential of long-term markets for photovoltaic power systems in these areas may most readily be summarized through consideration of the appropriate discount rates. For the developed nations, concern about energy resource availability in the long term is highly similar to that of the United States. Appropriate expenditures in energy technology are a function of the application sector and the availability of alternative energy sources in fossil fuels or nuclear. Given the existence in most of these areas of highly developed electrical grids, the attraction of an on-site, dispersed electrical technology such as photovoltaics is somewhat diminished. While photovoltaic power systems appear, in the longer run, to be more attractive in Europe than in some areas of the United States, this is a function of the relatively high cost of fuels to many of these nations.

The oil-rich developing nations represent an area with a very low effective discount rate. At the present time their foreign exchange inflow is high due to levels of earnings from oil exports. These nations are today focusing on long-term investments, i.e., investments that imply real discount rates of 1 or 2% or lower. Their opportunity cost for capital is extremely low, making them a small but potentially active purchaser of energy capital stock in the mid- to long-run.

The final category is that of the developing countries. Developing countries face extremely high energy costs for many applications. In specific applications such as water pumping for irrigation, these high costs may be carried by high benefits of increased productivity. As a result, developing nations have a potential for purchase of photovoltaic systems in the short- to medium-run which may offer an attractive market for U.S. manufacturing. Projection of longer-run markets is, however, more difficult. Developing countries today are subject to extremely high discount rates. The opportunity cost for their capital is now, and in all likelihood, will remain high; real discount rates of 10 to 12% are not unrealistic. Such high discount rates mitigate against the purchase of high-capital cost, long-lived, low-operating-cost systems. The three international markets discussed above represent, therefore, very different potentials for photovoltaic development. Each of the key events discussed below operate differently for the three sets of nations.

To date there has been identified no long-term market research completed for international markets in photovoltaics. While the work of D.V. Smith looked at the potential for photovoltaics in the developing nations, no effort was made to project the actual market size for any of the applications under consideration.[11] It is likely that individual firms both in Europe and Japan have investigated the potential for non-U.S. markets; this information is not however available.

There are four critical pieces of information necessary for an estimation of the potential impact of international markets on United States photovoltaic production. These are market size, U.S. competitive position, cost of alternatives within any given nation, and production capability outside of the United States. As has been discussed above,the estimation of the market size both at price of competitiveness as well as market position requires a set of scenarios concerning external events. Dealing with the economics of nations other than the U.S. to predict the impact of U.S. entry and market sales is a highly uncertain process.

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11 D.V. Smith, Photovoltaic Power in Less Developed Countries, MIT Lincoln Laboratory Technical Report COG-4094-1, March 24, 1977.

The second major area of concern in the United States' entering international markets is that of the competitive position of U.S. industry. While U.S. industry at the present time, with government support, is producing solar photovoltaic power systems at lower cost than appears available from any foreign competitor, this position may shift with entry into the market of either a low-labor-cost producing nation or through major cost reductions via technology development which may occur outside of the United States. As a result, it is not possible to predict the competitive position which the U.S., may hold in this area in the 1990-2000 time frame.

As has been discussed under major uncertainties in the U.S. energy systems, the cost of alternative forms of energy in nations outside of the United States are as uncertain, if not more so, than they are within the U.S. As a result, when projecting forward energy competitiveness of a specific technology such as photovoltaics, the attractiveness of the technology is a function of the availability of alternatives. Little, if any knowledge is available at this time on expected alternative costs in nations of Europe, the Middle East, or the developing world.

The fourth area of uncertainty and information requirements for projection of foreign markets is closely related to the second and that is in terms of the in-nation production capability for photovoltaic power systems. Limited production capability is now available in several nations in Europe as well as in Japan and India. Under such circumstances, the competitive position is a function not only of the price which U.S. manufacturers may charge for photovoltaic power systems but also a function of the tariff position applied by other countries.

There is a set of key events which will largely determine the significance of international markets for the development of the U.S. photovoltaic industry. These events represent both positive and negative forces to the development of the U.S. industry. As with the likely success of photovoltaics in the United States, the most significant event which may affect the international market will be a rapid and efficient reduction in price for photovoltaic power systems. This takes on an additional dimension in the international market which will require for U.S. industry assistance that the price reduction take place in a way that the U.S. manufacturer be guaranteed a price advantage over international competition. Such would, for instance, be the case in the development of a highly successful manufacturing process or the development of a highly successful photovoltaic device not involving current silicon technology. The potential for price reduction through manufacturing efficiencies is unlikely to be sufficient to guarantee the preeminance of a U.S. manufacturer-dominated photovoltaic market.

Again, the second most significant event which will influence the photovoltaic market will be a continued, more sharp rise in the crude oil price. Such a rise without a concomitant rise in prices of other forms of energy, will encourage the adoption of renewable energy resource technologies.

Two further events are likely to have major positive impacts on the adoption of photovoltaic power systems. The first of these is directly related to photovoltaic power system usage in the developing countries, where there is the potential for a nearer-term as well as a long-term market. Here the actions of international lending agencies will determine to a large extent the swiftness with which photovoltaics can enter the energy economy of a developing nation and will determine the ease with which financing for such developments can and will occur. Referring back to the introduction of this section, developing nations of today have exceedingly high discount rates. Given international subsidization of those discount rates through aid-giving agencies, photovoltaic power systems will be still more attractive in broader applications. In terms of work with the industry of the U.S., the U.S. Agency for International Development must play a key role in encouraging this technologu if it is to make inroads into this market. The negative potential of long-run markets for photovoltaics occurs with the likelihood that developing nations, which are potential large markets such as India, will maintain or improve their competitive positions vis-a vis the U.S., in providing this technology. Given this likelihood, it is difficult to argue for a major long-term role for photovoltaics in the developing nations by U.S. industry.

The second major issue of a positive nature may be the establishment of trade and tariff rulings which will allow easy access of U.S. manufacturers to energy-related markets in other nations. Were this to be the case, then photovoltaics would find a welcome market abroad. The negative side is that if restricted tariffs are imposed on the import of energy technologies, photovoltaics will face an exceedingly difficult market in developing countries or in international markets in general.

In summary, the international markets for photovoltaics in the long-run are far less quantifiable than even those for the United States. The uncertainties are greater, the political influences far exceed those of the United States, and the significance of competing manufacturing nations becomes still more important. As a result, at this time one cannot estimate the long-run international market.