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OVERVIEW OF PHOTOVOLTAIC MARKET STUDIES

MASTER

By
E. J. Rattin

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The Aerospace Corporation
Energy and Transportation Division
El Segundo, California

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E. J. Rattin

Energy and Transportation Division
THE AEROSPACE CORPORATION
El Segundo, California

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INTRODUCTION

In December of 1977, the Aerospace Corporation was requested by the Photovoltaics Program Office of the Department of Energy (DOE) to prepare a summary report covering the results of recent studies sponsored by DOE (and earlier by ERDA) and dealing with potential photovoltaic terrestrial solar energy systems markets. This report was to concentrate on summarizing quantitative data developed by these studies to assist in planning test and applications programs and in estimating the level of photovoltaic system production capacity required to meet future market needs. An evaluation of the accuracy of the study results was not requested.

As indicated on Chart 1, a review of major past and current studies disclosed four studies concerned with potential photovoltaic markets in the 1976 through 1985 time period, and two studies of potential photovoltaic residential, commercial, and utility applications which were likely to materialize in the post-1985 time period.

Two of the studies, by InterTechnology Corporation and BDM Corporation, were incomplete at the time of this study. Only drafts of the final reports submitted to DOE for approval were available for review. It is possible that this review process may bring about minor changes in the reported results. Also, some of the tabular data presented herein were read from poorly legible plots in the original source reports and small errors may consequently have been introduced. It is not believed, however, that such errors would affect the conclusions which it may be possible to draw from this summary.

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Overview of Photovoltaic Market Studies

- OBJECTIVE

- PROVIDE SUMMARY OF RESULTS OF RECENT STUDIES
 - SYSTEM ANALYSES CONTAINING MARKET FORECASTS
 - SPECIALIZED MARKET ANALYSES AND FORECASTS

- SCOPE

- NEAR-TERM MARKETS, 1976 - 1985
 - AEROSPACE, BDM, INTERTECHNOLOGY
- MID-TERM MARKETS, 1986 - 2000
 - WESTINGHOUSE, GENERAL ELECTRIC

- TIME

- SUMMARY PREPARED IN DECEMBER 1977 - MARCH 1978 PERIOD
 - NOT ALL REPORTS AVAILABLE IN FINAL APPROVED VERSION

This report summarizes the results of the terrestrial photovoltaic solar energy market studies listed on Chart 2. The studies performed by BDM Corporation (Ref 1, 2) and InterTechnology Corporation (Ref 3) concentrated on forecasts of photovoltaic markets, while the forecasting activities conducted by Aerospace Corporation (Ref 4), General Electric (Ref 5), and Westinghouse (Ref 6) represented only portions of efforts devoted to subjects of larger scope. As a consequence, the BDM and InterTechnology (ITC) studies represent much more detailed analyses of current and future markets for both the U. S. and worldwide.

Additional reviews of photovoltaic markets have been published by MIT-Lincoln Laboratory, (References 7 and 8). Reference 7, however, is essentially an overview of the data developed by some of the studies listed on Chart 2, while Reference 8 presents a methodology for determining when photovoltaic power could economically compete with conventional power sources in irrigation applications but offers no quantitative market penetration forecasts.

At the time of preparation of this report, the results of the BDM and ITC studies were available only in draft reports covering only a portion of the work effort. It is possible, therefore, that when the definitive final reports of these studies are published, some revision of the results presented here may be required.

Major Photovoltaic Marketing Studies — 1976-1978

- AEROSPACE CORPORATION
 - FOR ERDA
 - NEAR-TERM MARKETS IN U.S.
 - PART OF GENERAL MISSION ANALYSIS EFFORT
 - WORK PERFORMED BETWEEN 1/76 - 9/76
 - REPORT PUBLISHED MARCH 1977

- BDM CORPORATION
INTERTECHNOLOGY CORPORATION
 - SPECIFIC MARKET STUDIES FOR ERDA
 - NEAR-TERM AND FUTURE WORLDWIDE MARKETS
 - WORK PERFORMED BETWEEN 1/77 - 12/77
 - REPORTS TO BE PUBLISHED

- GENERAL ELECTRIC CORPORATION
 - FOR ERDA/SANDIA
 - MARKETS AFTER 1985
 - PART OF SYSTEM AND DESIGN ANALYSIS STUDIES
 - WORK PERFORMED MID 75 - FALL OF 76
 - REPORT PUBLISHED MARCH 77

- WESTINGHOUSE ELECTRIC CORPORATION
 - FOR ERDA/SANDIA
 - MARKETS AFTER 1985
 - PART OF SYSTEM AND DESIGN ANALYSIS STUDIES
 - WORK PERFORMED MID 75 - FALL 76
 - REPORT PUBLISHED APRIL 77

- BDM CORPORATION
 - FOR DoD/FEA - DIRECTED BY MERADCOM
 - DoD MARKETS ONLY
 - WORK PERFORMED FROM 76 - 77
 - REPORT PUBLISHED JUNE 77

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NEAR TERM MARKETS

The four studies by Aerospace Corporation, InterTechnology Corporation and BDM Corporation discussed in the following report section cover markets with high potential of being initiated and partially saturated by the mid-1980's. The first three studies address primarily commercial applications although governments may actually procure much of the equipment, particularly in countries other than the U.S. The last study included in this section deals with U.S. military applications only.

U.S. AND WORLD MARKETS

Because these three studies exhibit some commonality in the types of applications examined, the studies by Aerospace Corporation, BDM, and InterTechnology for ERDA/DOE will be discussed as a group.

The ground rules to which the Aerospace study conformed were provided by ERDA on an informal basis and called for a review of U.S. non-military markets during the near-term, i.e., during the 1976 to 1985 time period. The ERDA work statement that formed the basis of the BDM and InterTechnology work, however, specified several tasks. The first task required a definition of the 1976 market with respect to applications already utilizing photovoltaic power and a forecast of the growth of this market to the 1985/86 time period when array prices were assumed to have decreased to \$0.50/W_{pk}, both in the U.S. and worldwide. The second task of this work plan called for the identification of all conceivable classes of applications on a worldwide scale and forecasts of their maximum market potential, rather than sales, existing in 1985/86. The third task was to select the four or five new classes of applications most likely to generate "significant" markets. The fourth task called for the development of detailed product definitions for the new applications selected in the previous task and the preparation of detailed market forecasts for them. At the time this report was prepared, the approved final reports were not available for either the BDM or the InterTechnology studies.

Chart 3 depicts the market segments included in each of the three studies and illustrates that direct comparisons between study results are not possible in all of the market segments since ground rules and assumptions were interpreted differently for each of the studies. The BDM and InterTechnology entries on this chart cover only their activities under Task 1 of their work statements since those more closely correspond to the scope of the Aerospace effort. Their Task 2 results are discussed in a subsequent section of this report. Particularly to be noted is the fact that only BDM included both military and DOE Test and Demonstration buys, as well as buys for space applications. The other studies excluded these segments of the market.

The Aerospace and InterTechnology studies carried their forecasts through the end of 1985, while BDM included 1986. Results have, however, been summarized in this report for the period ending with 1985.

NEAR-TERM PHOTOVOLTAIC SALES FORECASTS

- AEROSPACE CORPORATION - U.S. MARKETS (1976 STUDY)
- BDM CORPORATION - DOD MARKETS (1976 STUDY), WORLDWIDE MARKETS (1977 STUDY)
- INTERTECHNOLOGY CORPORATION - WORLDWIDE MARKETS (1977 STUDY)

● <u>FORECASTS INCLUDE:</u>		A	BDM	ITC
○ U.S. COMMERCIAL SALES				
- CURRENT APPLICATIONS		●	●	●
- NEW APPLICATIONS		●	--	--
○ FOREIGN SALES				
- CURRENT APPLICATIONS		--	●*	●
- NEW APPLICATIONS		--	--	●
○ U.S. GOVERNMENT SALES				
COMMERCIAL BUYS				
○ CURRENT APPLICATIONS		●	●	●
○ NEW APPLICATIONS		●	--	--
- MILITARY/SPACE (CURRENT APPLIC.)		--	●	--
DOE BUYS FOR TEST & DEMONSTRATION		--	●	--

* EXCLUDES MARKING, WARNING, MONITORING, SENSING DEVICES, AND CONSUMER APPLICATIONS

Chart 4 is presented on the next two pages and shows the applications groupings which were used by the three studies. These group listings are arranged to show where correspondence between the studies exists, and which groupings are excluded from a particular study. The latter instance is indicated by the term "no equivalence", abbreviated as "n.e." on the chart. The exact degree of equivalence (or correspondence) could not be determined in all market segments because of a tendency, in some instances, to report market data for higher-level groups without defining the subgroups contained within. For example, cathodic protection in the instance of the InterTechnology Corporation (ITC) study undoubtedly included pipelines, well casings, etc., but these markets were not separately enumerated.

Asterisks on this chart indicate applications groupings for which both U.S. and foreign markets were evaluated by the BDM and ITC studies.

Chart 4a

Market Segments Included in Sales Forecasts

<u>BDM</u> For Markets Existing in 1976 (Note 1) (Task 1)	<u>Aerospace</u> For All Markets Existing in 1976 or Having Potential Between 1977 and 1985 (Note 2)	<u>ITC</u> For Selected U. S. and Foreign Markets (Note 3) (Task 1)
U.S.C. G. Nav aids Offshore Platforms Airways Navigation Highway Sign Defrosting Corrosion Protection Bridges Pipelines & Tanks (USAF) Pipelines, Commercial* Well Casings* Precipitation Gauges Remote Weather Stations Weather Monitoring River Level Gauges Power Field Sensors Remote Intrusion Power Data Acquisition Microwave Repeaters* Radio Repeaters* Telemetry* Remote Rural Telephone Call Boxes Educational TV*	Marine Navigation (n. e.) (n. e.) Highway Powered/Illuminated Signs Bridges (n. e.) Pipelines Well Casings Environmental (n. e.) Intrusion Detection (n. e.) Microwave Repeaters UHF/VHF Repeaters Radio Control Highway Call Boxes (n. e.)	Navigation Aids* Cathodic Protection* Telecommunications* (n. e.) Mass Communications*

For notes see end of chart.

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Market Segments Included in Sales Forecasts (Cont'd)

<u>BDM</u> For Markets Existing in 1976 (Note 1) (Task 1)	<u>Aerospace</u> For all Markets Existing in 1976 or Having Potential Between 1977 and 1985 (Note 2)	<u>ITC</u> For Selected U.S. and Foreign Markets (Note 3)
(n.e.) Watches, Calculators, Flashlights* Sailboats, Battery Chargers* Recreational Vehicles* General Aviation, Trickle Charging** Military Test Sites & Space Applications Water Pumping* ERDA Buys (n.e.) (n.e.) (n.e.) (n.e.) (n.e.) (n.e.) (n.e.) (n.e.) (n.e.) (n.e.) (n.e.) (n.e.)	Battery Chargers for all Consumer Items Direct Powered Consumer Items Emergency Position Indicating Radio Beacons (EPIRB's) only Float Charging Only Emergency Location Transmitter (ELT) & Starting, Lighting, Ignition (SLI) Battery Trickle Charging (n.e.) Drip Irrigation Only (n.e.) Earthquake Sensors Forest Lookouts Railroad Signals Railroad Cabooses Camp Toilets & Lights Visitor's Centers Highway Rest Areas (n.e.) (n.e.) (n.e.)	Battery Chargers for Radios* Consumer Applications Consumer Applications (n.e.) Navigation Aids* (n.e.) Water Pumping* (n.e.) (n.e.) (n.e.) (n.e.) (n.e.) (n.e.) (n.e.) (n.e.) Desalination* Rural Electrification* Lighting*

- (1) Provides both U.S. and foreign sales except that marking, warning, monitoring, sensing devices are for U.S. only. Restricts itself to current applications only.
- (2) Excludes military and foreign markets. Includes both current and new applications.
- (3) Excludes U.S. government sales. Restricts U.S. markets to current applications, but allows new applications for foreign markets. Provides no military sales

* Includes foreign markets.
(n.e.) = no equivalent

Chart 5 shows additional background information of interest in evaluating the results of the near-term market studies. Both BDM and ITC worked to a ground rule which required that Task 1 market estimates be made only for terrestrial applications which were already utilizing photovoltaic power in 1976. No attempt was made to establish when initial use actually took place. The dates earlier than 1976 shown under the Aerospace column do not necessarily represent the earliest date of terrestrial use, but are estimates of the first date that sales in more than experimental quantities took place.

BDM provided estimates of the year when 10% penetration of the market was or would be achieved. It is not clear from the draft copy of the report whether the penetration refers to the annual market considered to be a potential for photovoltaic conversion or to the cumulative total market. In any case, the 10% penetration date was taken by BDM to be the later of two estimates: the year when reliable operation was demonstrated or the year when breakeven cost was attained. The BDM study required an estimate of this date in order to utilize the mathematical formulation of a substitution model resembling that developed by Fisher and Pry (Reference 9). The Aerospace study did not utilize a substitution model for market penetration forecasting, nor does it appear that ITC used such a model.

Chart 5a

Critical Dates Associated with Market Segments

BDM Task I (Note 1)		Aerospace (Note 2)		ITC Task I (Note 1)
	<u>Year of 10% Penetration</u>		<u>Probable Market Initiation</u>	
USCG Nav aids	1979		1976	All of the segments show markets already initiated in 1976. No other dates provided.
Offshore Platforms	1977	(n. e.)		
Airways Navigation	1979	(n. e.)		
Highway Sign Defrosting	1986	Powered/Illuminated Signs	1978	
Corrosion Protection				
Bridges	1976	Bridges	1977	
Pipelines & Tanks (USAF)	1979	(n. e.)		
Pipelines, Commercial	1980	Pipelines	1977	
Well Casings, Shallow, U.S.	1979	Well Casings	1975-1976	
" Foreign	1983			
Deep, U.S.	1984			
" Foreign	1985			
Precipitation Gauges	1976	Environmental	1970	
Water Monitoring	1976			
River Level Gauges	1976			
Weather Stations	1976			
Power Field Sensors	1977	(n. e.)		
Remote Intrusion	1977	Intrusion Detection	1978	
Power Data Acquisition	1976	(n. e.)		
Microwave Repeaters, U.S.	1978	Microwave Repeaters	1977	
Foreign	1977			
Radio Repeaters, U.S.	1979	UHF/VHF Repeaters	1977	
Foreign	1980			
Telemetry, U.S.	1977	Radio Control	1978	
Foreign	1977			
Remote Rural Telephone Call Boxes,		Highway Call Boxes	1976	
U.S.	1977			
Foreign	1977			
For notes, see end of chart.				

For notes, see end of chart.

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Chart 5b

Critical Dates Associated with Market Segments (Cont'd)

BDM Task I (Note 1)		Aerospace		ITC Task I (Note 1)
	<u>Year of 10% Penetration</u>		<u>Probable Market Initiation</u>	
Educational TV	1977	(n.e.)		All of the segment show markets already initiated in 1976. No other dates provided.
Battery Chargers, Sailboats	1986	EPIRB's only	1983	
Watches, Calculators, Flash-lights	1982	Direct Powered Consumer Items	1977	
Recreational Vehicles	1985	Float Charging Only	1977	
General Aviation	1980	ELT & SLI Battery Trickle Charging	1980	
Military Test Sites, & Space	1973-1976	(n.e.)		
Water Pumping, U.S.	1984	Drip Irrigation Only	1979	
Foreign	1984			
ERDA Buys	1976	(n.e.)		
		Earthquake Sensors	1974	
		Forest Lookouts	1978	
		Railroad Signals	1979	
		Railroad Caboose	1979	
		Camp Toilets & Lights	1978	
		Visitors Centers	1980	
		Highway Rest Areas	1980	

(1) BDM shows only markets already existing in 1976, as does ITC, for Task I. However, ITC does not show 10% penetration year.

(2) Aerospace dates represent estimates of sales for commercial uses rather than for experimental or test and demonstration purposes.

(n.e.) = no equivalent

The following three charts provide the results of the three near-term market studies in tabular form. Chart 6 shows the annual and cumulative sales forecasts for the four major groupings of U.S. applications examined by The Aerospace Corporation (Ref 4). Subgroupings under these major headings were shown earlier on Chart 4.

Aerospace did not utilize substitution models because such models require historical data on sales corresponding to 7-10% substitution of the total market in order to predict such characteristics as take-over time, i.e., the time required to reach 90% market substitution. For the new photovoltaic technology, sales up to 10% substitution of the total potential market had not been made by 1976. In addition, substitution models are intended to measure the degree of replacement of an older technology with a newer one. When photovoltaics is the new technology, comparisons must be made separately against various remote power sources, such as engine generator sets, thermo-electric generators, batteries, and utility power. The required data base includes, therefore, the total market of each of these conventional energy sources in the applications areas of interest, as well as the sales of photovoltaic systems already made in those markets. For these reasons, the Aerospace forecast is, instead, based on a number of interviews with users of remote, powered equipment who were judged to be most likely to adopt photovoltaic power systems in the near-term because of favorable breakeven costs. Previous mission analysis studies have indicated that array prices of \$0.50 per peak watt or less would be required for most other-than remote applications and that such costs would not be attained prior to 1986. Expert judgment was supplemented by trend forecasting when that proved feasible.

In addition to these remote applications, the Aerospace study also identified a number of urban applications which would provide economic incentive for utilization of photovoltaic power. Although these applications are generally of very low power level and do not appear to constitute a large market, even collectively, they were included in the forecast shown on Chart 6. In addition, a number of other applications were defined but could not be sized during the term of the study. It was recognized that these additional applications might well result in additional markets as large or larger than those included in the estimates indicated on this chart. As mentioned earlier, the Aerospace forecasts do not include military sales, purchases for government test and demonstration projects, or purchases for non-terrestrial applications.

Chart 6

AEROSPACE CORPORATION U.S. PHOTOVOLTAIC SALES FORECAST (kW_{peak})

APPLICATIONS GROUP	YEARS									CUMUL.
	1977	1978	1979	1980	1981	1982	1983	1984	1985	
SENSORS*	50	110	175	208	224	227	218	191	130	1,533
GENERAL POWER & LIGHTING	100	250	900	2,250	3,950	5,400	6,650	7,600	7,900	35,000
SIGNALS	20	30	380	850	1,420	2,030	2,480	2,880	3,170	13,290
COMMUNICATIONS	30	70	680	1,220	1,650	1,950	2,150	2,280	2,100	12,130
TOTALS	200	460	2,135	4,528	7,244	9,607	11,498	12,951	13,300	61,953

* SENSORS/DATA PROCESSING/TRANSMISSION

The forecasts by InterTechnology of the domestic U.S. and the worldwide markets are shown on Chart 7. Although a detailed enumeration of the market for subgroups under the major groupings shown on this chart were not available from the draft report (Ref 3), essentially the same domestic applications were examined as in the other two studies (see Chart 4). As indicated earlier, the ITC study excluded all government purchases from the U.S. market forecast, but did include them in foreign markets. Also, the foreign market included new applications which were excluded from the U.S. market. As in the instance of The Aerospace Corporation study, military, space, and test and demonstration buys were excluded from the U.S. market. In contrast to the Aerospace study, however, the U.S. market forecast addressed only application areas already penetrated in 1976.

The draft report appears to indicate that forecasting of the U.S. market was based on expert judgment obtained from interviews with producers and users of photovoltaic systems, and that trendline forecasting was used when feasible. No mention is made of the application of substitution models. The forecasts of markets in less developed countries (LDCs) were based on detailed examination of economic development plans and related funding in five countries representative of the LDCs, utilizing a correlation between gross domestic product (GDP), fixed capital formation (FCF), and spending for energy and energy sources. This correlation defines a constant (k) in the following expression:

$$k = \frac{\text{Energy Market (in kW)}}{\text{GDP (in \$ U.S.)} \times \text{FCF (in \%)}}$$

The photovoltaic penetration into the energy market was determined by judgment and was assumed not to exceed 5%, and in most cases not to exceed 1%, of the energy budget of a country. Nigeria, Saudi Arabia and Iran were used as models for LDCs belonging to OPEC, and 0.015 was adopted as the appropriate value of k for such countries. India and Pakistan were used as models for the remaining developing countries, and 0.057 was adopted as the approximate value. A similar procedure was used to estimate markets in the developed foreign countries, with k set equal to 0.0006 (on the basis of historical statistics for the U.S.). Utilization of these constants, along with appropriate economic data for 100 nations, permitted the development of annual market forecasts for the application groups as shown on Chart 7. These world forecasts are admittedly gross in nature.

Chart 7

INTERTECHNOLOGY CORPORATION PHOTOVOLTAIC SALES FORECAST (kW_{peak})

A. U.S. SALES

APPLICATIONS GROUP	1977	1978	1979	1980	1981	1982	1983	1984	1985	CUMUL.
COMMUNICATIONS	110	220	420	700	1,100	1,390	1,730	2,000	2,100	9,770
CORROSION PROTECTION	19.4	15.0	26.4	41.5	41.6	41.7	42.0	68.5	68.9	365
NAVIGATION AIDS	54.4	75.0	70.5	58.0	38.0	24.0	23.0	24.2	25.3	392
CONSUMERS	30.0	50.0	70.0	95.0	125.0	160.0	215.0	315.0	715.0	1,775
TOTAL	214	350	587	895	1,310	1,620	2,010	2,410	2,900	12,300

B. WORLD SALES

LIGHTING	0	200	370	1,100	7,000	16,000	52,600	118,000	254,000	449,000
MASS COMMUNICATIONS	18	140	310	540	1,100	2,400	6,900	11,000	16,000	38,600
TELECOMMUNICATIONS	110	330	610	990	1,400	1,800	2,200	2,400	2,400	12,200
WATER PUMPING	0	28	84	180	480	1,000	2,100	3,600	6,200	14,000
MISCELLANEOUS	48	91	150	190	230	260	340	460	960	2,400
DESALINATION	0	0	2.7	9.9	29	68	140	440	1,000	1,700
RURAL ELECTRIFICATION	.2	3.2	16	42	87	160	250	370	580	1,500
CATHODIC PROTECTION	25	21	36	57	57	57	62	99	104	520
NAVIGATION AIDS	73	99	94	73	51	34	30	32	34	520
TOTAL	274	912	1,673	3,182	10,430	21,800	64,600	136,000	281,000	520,000

The BDM Corporation sales forecasts for near-term U. S. and worldwide markets are shown on Chart 8. As indicated earlier, they include military, space, and test and demonstration purchases by the U.S. government but are, by ground rules specified by ERDA/DOE, restricted to applications already served by photovoltaic systems in 1976 and thus are not representative of the total market which may be available to this technology in the near term. BDM indicates that a substitution model approach was used in developing the forecasts of this near-term market. Because of the unavailability of sufficient historical data to use in such substitution models, judgment was used to estimate the years in which 10% and 90% substitution of the total cumulative market had or would take place. Take-over times, the number of years between these two substitution levels, were assumed on the basis of historical data for analogous applications. The 10% substitution date was taken to be the later of two dates, either the date by which reliable operation of a photovoltaic generation system had been demonstrated, or the date by which cost breakeven had been attained. There is, of course, no assurance that these dates would coincide with a 10% substitution of the cumulative market. The take-over times assumed by the study ranged from 0 to 10 years for most of the applications, and up to 25 years for a few. Among the latter were digital watches and recreational vehicles. A zero take-over time indicates, of course, that the market is already saturated. Examples of the latter are remote, unmanned weather stations and other environmental instrumentation. The substitution model used by the BDM study appears to be similar to the Fisher-Pry formulation shown on Chart 25 later in this report.

BDM provided data in graphical form out to the year 1986. The numbers on Chart 11 were read from these relatively small plots and may therefore be subject to small inaccuracies. Also, the forecasts have been cut off at 1985 to permit better comparison with those by Aerospace and InterTechnology.

Chart 8

BDM CORPORATION PHOTOVOLTAIC SALES FORECAST (kW_{peak})

Chart 8

A. U.S. SALES

APPLICATIONS GROUP	1977	1978	1979	1980	1981	1982	1983	1984	1985	Cumul. 1985
MARKING & WARNING	180	320	490	590	590	760	1,100	1,500	2,100	7,630
CATHODIC PROTECTION	120	300	1,700	4,200	4,800	6,500	9,400	13,000	17,000	57,020
MONITORING & SENSING	2	13	23	33	33	33	33	33	33	236
COMMUNICATIONS	210	410	780	1,400	2,200	3,100	3,900	4,500	4,900	21,400
CONSUMERS	9	20	50	160	200	280	410	580	790	2,499
GENERAL POWER	200	300	1,100	2,700	4,600	7,300	9,600	13,000	19,000	57,800
TOTAL	721	1,363	4,143	9,083	12,423	17,973	24,443	32,613	43,823	146,585

B. WORLD-WIDE SALES

MARKING & WARNING	180	320	490	590	590	760	1,100	1,500	2,100	7,630
CATHODIC PROTECTION	120	300	1,700	4,500	5,300	7,200	10,300	15,000	25,000	69,420
MONITORING & SENSING	2	13	23	33	33	33	33	33	33	236
COMMUNICATIONS	420	1,200	2,000	3,000	4,600	6,300	8,100	9,500	10,100	45,220
CONSUMERS	9	20	50	160	200	280	410	580	790	2,499
GENERAL POWER	240	660	3,000	10,000	17,000	27,000	37,000	52,000	75,000	221,900
TOTAL	971	2,513	7,263	18,283	27,723	41,573	56,943	78,613	113,023	346,905

Chart 9 presents the previously shown tabular annual market forecast data in graphical form and includes the data from all three studies dealing with the near-term U.S. market. As previously discussed, the differing ground rules under which the three studies were conducted make direct comparisons difficult. Also as previously indicated, the Aerospace study defined many more applications than could be included in its quantitative forecast. A judgmental estimate placed the annual market size in 1985 of these additional applications about equal to that which had been forecast. If this judgment holds true, then the Aerospace and BDM forecasts would move closer together, as indicated on the plot by the notation "Aerospace Probable Sales".

If new applications expected to arise between 1977 and 1986 were included in the BDM and ITC estimates and if other assumptions were brought into closer correspondence, the range of forecasts shown on this chart would not only narrow but would shift upward. No data were available, however, to permit the probable extent of this shift to be indicated on the chart.

As previously stated, the BDM forecasts are shown only through 1985 to match the other studies, even though data through 1986 were provided.

U.S. Photovoltaic Annual Sales Forecast – Near Term

Since the Aerospace study excluded foreign markets, Chart 10 records in graphic form only the forecasting results of BDM and ITC for worldwide markets over the near-term. These results have already been presented in tabular form on Charts 7 and 8. Considering the differing ground rules and methodologies employed by the two studies, the correlation between their results is surprising. Had the ground rules under which BDM conducted its study been expanded to permit the inclusion of new applications, as was done by ITC, the correlation in results might have been even better.

World Photovoltaic Annual Sales Forecast

NOTES:

ITC IS THE INTER TECHNOLOGY CORP

BDM IS THE BDM CORP

In spite of the differences in ground rules under which the three near-term market studies were conducted, it is desirable to determine whether the combined results permit some insight as to the more important market segments of the near future. Individual application subgroupings were combined into major market segments containing equivalent applications, thus allowing the probable ranges of markets for such segments to be estimated. Chart 11 presents eight such segments and also provides, in graphical form, an indication of the upper limit of the range for each segment. As is apparent, the range for most of the segments is so large that the same chart cannot also be used to show the lower limits for each segment because the chart scale does not permit it. The graphical portion of this chart, therefore, represents the most optimistic of the three estimates used in determining the market segment ranges. The range used for this display includes worldwide markets. U.S. data only are shown, however, for those segments for which foreign markets were not forecast, (as in the instance of highway signals) and are so labeled. Only the ITC study covered village power and desalination applications in developing countries. Data from all three studies were available to establish the range of sales shown for the other segments. In view of the relative minima for Cathodic Protection and for Communications, their relative ranking, as third and fourth, is probably not too meaningful and could be reversed. It is clear, however, that the four largest market segments in the near-term may be village power, with specific reference to lighting of dwellings or communal buildings in LDCs; water pumping and other rural power applications; corrosion protection; and remotely powered communications facilities such as relays and repeaters.

The range of breakeven costs is quite large, larger, in fact, than the range of market forecasts for the same segments. It is likely that these extremes are due to differing assumptions concerning competing conventional power. For example, one study may have computed breakeven costs by comparing the photovoltaic system for a specific application against engine generator systems, while another study may have used utility power as the comparison basis. Even if both studies used utility power, different power line extensions could have been used. The consensus appears to indicate that most of the applications will reach cost breakeven well before 1985 and array prices of \$0.50 per W_{pk} .

Near-Term Photovoltaic Sales Forecasts

As indicated earlier, Task 2 of the work statement to which BDM Corporation and InterTechnology Corporation performed their market study required that all conceivable new classes of photovoltaic applications be identified on a worldwide scale and that the market potential offered by these applications be estimated. The term 'new applications' in this context referred to applications which had not already utilized photovoltaic power in 1976 in either a commercial or in a test-and-demonstration use category. This task did not require the preparation of a sales forecast for any particular time period but only the development of a quantitative measure of "market potential". As in the instance of Task 1 of the same work statement, the two studies chose to interpret this study goal differently, as indicated on Chart 12. The Aerospace Corporation study did not address such a goal and its data are therefore not part of the summaries that follow.

As indicated by Chart 12, ITC chose to interpret the potential market to mean both the potential retrofit market to installations already in place by 1985 as well as new installations in that year, while BDM evaluated only the potential market offered by new installations taking place in 1986. Another important difference is the interpretation given to the term "potential". ITC took this to mean potential sales and therefore applied penetration assumptions to the total market it identified. BDM provided estimates of the maximum market available, without estimating the fraction of the market which photovoltaic systems might penetrate. In the case of irrigation, for example, the BDM forecast states the total power in MW of all of the irrigation pumps to be installed in 1986 but does not attempt to estimate the total power of all photovoltaic pump installations that might occur in that year. ITC, on the other hand, lists the total cumulative sales that might have occurred through 1985.

The BDM study also estimated the array breakeven costs for the applications covered by its forecast. ITC did not provide this information, except, in some cases, to exemplify the methodology. Some of the BDM breakeven costs are well below \$0.50/W_{pk} so that the corresponding applications do not really offer market potential in 1986.

Although the BDM data include forecasts of military application market potential, these differ from those in their special DOD study (Reference 2) which is summarized later in this report.

FORECAST OF PHOTOVOLTAIC MARKET POTENTIALS FOR 1985/86

- BDM - WORLDWIDE MARKETS (1977 STUDY)
- INTERTECHNOLOGY CORPORATION - WORLDWIDE MARKETS (1977 STUDY)

● <u>FORECASTS INCLUDE:</u>		BDM	ITC
○ U.S. CIVILIAN MARKET POTENTIAL, CURRENT & NEW APPLICATIONS			
- ANNUAL ONLY FOR 1986		●	--
- TOTAL INVENTORY IN PLACE IN 1985		--	●
○ U.S. MILITARY MARKET PCTENTIAL, CURRENT & NEW APPLICATIONS			
- ANNUAL ONLY		●	--
- TOTAL INVENTORY		--	●
○ FOREIGN MARKET POTENTIAL, CURRENT & NEW APPLICATIONS			
- ANNUAL ONLY		●	--
- TOTAL INVENTORY		--	●
○ MARKET PENETRATION ASSUMPTIONS		--	●
○ BREAKEVEN COST		●	--

(NOTE: BDM INCLUDES APPLICATIONS WITH BREAKEVEN PRICES WELL BELOW \$0.50. THESE MAY, THEREFORE, NOT HAVE MARKET POTENTIAL IN 1986.)

Although the assumptions by BDM and ITC underlying their Task 2 market studies were different, it was still desirable to find some basis of comparison. In order to facilitate this, the application sub-groupings for which potential markets were estimated by the studies were aggregated into relatively equivalent market segments. Chart 13 shows these aggregations and their market potential forecasts. They also show the photovoltaic system breakeven costs calculated by BDM using a life cycle method (LCC) for the applications examined by that study. ITC did not provide breakeven costs except to exemplify their methodology. The BDM data did not segregate U.S. market potentials, while ITC estimated both U.S. potential sales and world sales (which included the U.S. sales).

As indicated by the system breakeven costs listed by BDM for their application subgroups, not all applications are ready for penetration by 1986, since a number of them have breakeven system costs which are less than the costs that are expected to prevail by the end of 1985. (The DOE array price goal of \$0.50/W_{pk} in 1986 corresponds to a system price goal that is in the neighborhood of \$1.00/W_{pk}, as estimated by BDM for this purpose.) Nevertheless, such applications have not been excluded from the totals used in the comparison between the studies presented on subsequent charts.

ITC presented their world forecasts on the basis of two forecasting methods. The first involved the assumption that applications would consume energy at the same level as predicted for the U.S., and that the product mix and penetration assumed for the U.S. would hold worldwide. Chart 13 shows results corresponding to this assumption. The other approach forecasts developed and developing country markets by utilizing a product of "k" factors, gross domestic products, and fixed capital formation rates, derived as previously explained, to relate the U.S. market to that of a specific country. This second method thus takes into account budgetary limitations operating in foreign economies, and results in a total world market only about one third of that shown on these charts. The ITC values also take into account limitations on penetration of photovoltaic sales in each application class. The BDM values do not.

Chart 13a

Comparison of Application Groupings

BDM's 1986 Maximum Market World Potential			ITC's 1985 Cumulative Potential Sales		
General Power	Market MW _{pk}	System (LCC) Breakeven Cost \$/W _{pk}	General Power	Market MW _{pk}	
				U.S.	World
Visitor Controls	1.3	0.30	Portable Power Packs	150	2600
Recreational Vehicles	21.0	2.5-3.0	Central Station Power	140	2300
Electric Vehicle Chargers	140	0.40	Water Treatment	120	2000
Oil Barge Pumps	78	1.8	Electric Vehicles	63	1100
Miscell. Utilities Applic.	463	0.3	Construction Trailers	43	720
Building Power	248	0.24-0.44	Portable Medical Machines	9.6	48
Engine Generator Replacement	238	1.5-2.3	Emergency Power	5.8	96
Air Compressors	3120	0.4	Remote Clinics	4.9	630
Portable Winches	22	0.22	Police and RR Stations	2.7	41
Industrial Electric Vehicles	120	0.16	Electronic Filtering	.48	8.6
Miscell.	46	0.24	H ₂ Production	.36	5.1
Total	4500		Safety Equipment	.14	.96
			Simple Industry	.06	9.7
			Totals	540	9550
<u>Water Pumping</u>			<u>Water Pumping</u>		
Irrigation	1100	0.09-0.85	Irrigation	8060	48,300
Submersible Pumps	233	0.5-6.0	Portable Water	260	4,300
Total	1333		Pumped Storage	180	
			Totals	8500	52,600
<u>Lighting</u>			<u>Lighting</u>		
Military Areas	1.3	7.0	Rural	160	2800
Highways	1500	1.30	Outside	64	410
Commercial Outdoors	3451	0.40-0.7	General	2.4	400
Resid. Yards	15	2.30			
Recreat. Facilities	33	0.5-0.9	Totals	226	3610
Total	5000				

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Chart 13b

Comparison of Application Groupings (Cont'd)

BDM's 1986 Maximum World Potential			ITC's 1985 Cumulative Potential Sales		
	Market	System (LCC) Breakeven Cost		Market MW _{pk}	
<u>Residential/Consumer</u>	MW _{pk}	\$/W _{pk}	<u>Residential/Consumer</u>	U.S.	World
Residential Power	3692	0.10-.40	Refrigeration (Food)	420	7200
Toys	45	7.0	Ventilating Fans	320	5400
Boat Pumps	6	0.18	Air Conditioning	100	1800
Golf Carts	230	.30	Closed Water System	2.9	144
Mopeds	55	.27	Educational Devices	.36	6
Total	4028		Calculators	.36	5.1
			Phonographs	.30	5.0
<u>Forestry/Agriculture</u>			DC Battery Chargers	.17	2.9
Crop Sprayers	24	0.70	Garden Appliances	.13	2.4
Farm Power	665	0.25-0.95	Watches	.04	.61
Earth Coring Drills	24	2.90	Pool Pumps	10.1	170
Ranger Stations	1.5	1.15	Boats, Sailboats	14	8.6
Total	715		Radios	4.9	82
			Power Skier's Radio	.24	3.7
<u>Military</u>			Backup to Utility	16	230
Installation Power	800	.17	Electric Toys	.15	2.4
Water Purification	9	2.25	Totals	890	15,063
Miscell.	4	0.4-4.0			
Total	813		<u>Forestry/Agriculture</u>		
			Food Preservation	360	6000
			Tractors	.4	47
			Food Sterilization	.07	.97
			National Parks	8.6	
			Totals	369	6,048
			<u>Military</u>		
			Totals	13.6	79

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Chart 13c

Comparison of Application Groupings (Cont'd)

BDM's 1986 Maximum Market World Potential

<u>Communications</u>	<u>Market</u> MW _{pk}	<u>System</u> (LCC) Breakeven Cost
Life Boat EPIRB's	8.4	n. a.
FM Transmitters	25.0	0.5
Portable Transceivers	25.0	2.0
Community Antennas	5.0	0.73
Recreational Boating Applications	4.5	0.18
Miscell.	10.0	0.5-16.0
Total	77.4	
<u>Monitoring/Sensing</u>		
Burglar Alarm	38	0.24
Closed Circuit TV	139	0.24
Intrusion Detection	10	0.24
Total	187	
<u>Signals</u>		
Flashing Lights	7.0	5.0-450.0
Seasonal Signs	0.2	14
RR Crossings	1.2	36.0
Other RR Signs	1.4	10.0
Total	9.8	
<u>Mining</u>		
Pumps	4620	.25
Motive Power	600	.25-.30
Machinery	5100	.25
Total	10,320	
Overall Total	26,983	

ITC's 1985 Cumulative Potential Sales

	<u>Market</u> MW _{pk}	<u>U.S.</u>	<u>World</u>
<u>Cathodic Protection</u>		70	960
<u>Communications</u>			
Rural TV	170		2900
Television	17		290
Educational TV	.32		5.5
Remote Repeaters	12		200
Remote Communications	1.6		3200
National Commun. Equip.	1.1		16.2
National Alert Network	.04		.47
Telephone Systems	.17		2.9
CB Radios	.14		2.4
Remote Telephones	.08		.41
Totals	203		6618
<u>Monitoring/Sensing</u>			
Crop Harvest Time	1.8		4.2
Detectors			
Insolation Meters	.24		3.5
Surveying Instruments	.12		2.9
Remote Alarms	.12		2.2
Intrusion Defense	.08		.24
Intrusion Detectors	.05		.82
Instrumentation	.05		.82
Totals	2.5		14.7
<u>Signals</u>			
Flashing Lights	30		510
RR Signals	24		310
Buoys	.67		3.2
Traffic Signals	.04		7.3
Totals	54.7		831
Overall Totals	10,900		95,400

The detailed listings on the previous charts are summarized on Chart 14. It must be emphasized that the markets shown on this chart have been developed using different ground rules. In the instance of the BDM estimate, they represent maximum annual potentials, whereas the market data by ITC represent a cumulative potential sales total (through 1985). Direct comparison is therefore meaningless and the values on this chart cannot even be used to define a range as was done for the results of Task 1 discussed earlier.

Also, the breakeven prices shown on this chart are system prices, roughly twice as great as the corresponding array breakeven prices, on the basis of a BDM estimate.

Mid-1980 to Mid-1990 Photovoltaic Market/Sales Potentials

MARKETS IN GW_{pk}

APPLICATION GROUPS	BDM	ITC		RANGE OF BREAKEVEN PRICES*, \$/W _{pk} (BDM)
	WORLD	U. S.	WORLD	
MINING	10.3	--	--	0.25 - 0.3
WATER PUMPING	1.3	8.5	52.6	0.5 - 6.0
LIGHTING	5	0.23	3.61	0.4 - 7.0
GENERAL POWER	4.5	0.54	9.55	0.2 - 3.0
RESIDENTIAL/CONSUMERS	4	0.89	15.06	0.2 - 7.0
MILITARY	0.8	0.014	0.08	0.2 - 4.0
FORESTRY/AGRICULTURE	0.7	0.37	6.05	0.3 - 3.0
MONITORING/SENSING	0.2	0.003	0.015	0.24
COMMUNICATIONS	0.08	0.20	6.62	0.2 - 16.0
SIGNALS	0.01	0.055	0.83	5 - 500
TOTALS	26.98	10.80	94.40	
TIME SPAN	1986 ANNUAL POTENTIAL	1985 TOTAL POTENTIAL CUMULATIVE SALES		

NOTE: PENETRATION ASSUMPTIONS FACTORED INTO ITC DATA ONLY

*System Breakeven Prices

Chart 15 presents the tabular data of Chart 14 in graphical form. Some of the problems in comparing the two study results relate to the fact that BDM forecasts annual (1986) market potential while ITC estimates cumulative sales to 1985. The methodologies used by the two studies are, of course, also quite dissimilar. As already described for Chart 13, ITC assumed that unit energy consumption per application, product mix, and penetration determined for the U. S. would hold world wide. BDM, on the other hand, presents merely the estimates of 1986 annual production of powered equipment systems which could utilize photovoltaic power, based on considerations of competitive energy costs and other factors, without attempting to predict the actual percentage of the markets represented by these systems that might be captured by photovoltaic systems.

As is noted above, the market projections displayed in Charts 14 and 15 are presented by BDM and ITC as referring to the 1985-86 period. The breakeven array prices computed by BDM, however, are, for many of the market segments, well below the DOE 1986 array price goal of \$0.50 per peak watt. It would thus appear that many of these markets will not, in fact, materialize until well after 1985. For this reason, the titles of the charts both refer to the "mid-1980 to mid-1990" period.

As in the instance of the near-term existing market discussed earlier, the new applications market shown on this chart also appears to emphasize lighting, water pumping, and other general power applications. The residential and consumer market segment is now introduced as a potentially good market, but probably mainly in the post-1985 time period, if account is taken of the low breakeven costs computed by BDM. The Forestry/Agriculture segment does not include irrigation power, which has been associated with the water pumping segment. The mining segment has not been studied by ITC.

Chart 15

Mid-1980 to Mid-1990 Photovoltaic Market Sales Potential

Chart 16 represents an attempt to gain further insight into the nature of the future potential market as seen by the two studies which forecast total world potential markets (albeit on the basis of different ground rules). The forecasts prepared by BDM and ITC were normalized internally and expressed as fractions of the total potential markets. However, these still show little correlation. The BDM study sees the largest market as developing in the mining sector, in commercial outdoor lighting, in portable air-compressors and in the general residential application. ITC, on the other hand, emphasizes irrigation, selected residential applications, portable power packs, utility-type power, and water treatment. The closest agreement appears to exist with respect to residential power, which is given a 15% share by BDM and a 16% share by ITC.

Comparison of Potential Market Forecasts

- BDM WORLD MAXIMUM ANNUAL MARKET POTENTIAL (1986) - 27 GW_{pk}
- ITC WORLD CUMULATIVE SALES POTENTIAL (1985) - 95.4 GW_{pk}

MARKET SEGMENTS	SHARE OF TOTAL		MAJOR COMPONENTS WITHIN SHARE	
	BDM	ITC	BDM (%)	ITC (%)
MINING	38	-	MACHINERY (49) PUMPS (45)	(NOT ESTIMATED)
LIGHTING	19	4	COMMERCIAL OUTDOORS (69) HIGHWAY LIGHTING (30)	RURAL VILLAGES (78) OUTDOOR (11)
GENERAL POWER	17	10	AIR COMPRESSORS (69)	PORTABLE POWER PACKS (27) CENTRAL STATIONS (24) WATER TREATMENT (21)
RESIDENTIAL/CONSUMER	15	16	RESIDENTIAL POWER (92)	REFRIGERATION OF FOOD (47) VENTILATING FANS (36) AIR CONDITIONING (12)
WATER PUMPING	5	54	IRRIGATION (83)	IRRIGATION (92)
OTHER	6	16	MILITARY (50) FORESTRY/AGRICULTURE (44)	COMMUNICATIONS (43) FORESTRY/AGRICULTURE (40)

Chart 17 shows the final list of most promising new applications developed by BDM from an initial list of potential photovoltaic applications that reportedly exceeded 1000. The criteria used in arriving at a list of 31 applications shown here as most promising are said to have included system break-even cost, market potential, diversity of use, and diversity of end user. As indicated on the chart, five of these applications were chosen for detailed product definition and market evaluation. In selecting the final five, BDM applied the additional requirement that array area exceed 1 m² per unit application, a size considered a building block size for major power systems. In addition, schools were selected because of a DOE desire to include investigation of a major load center. Similarly, the desire to include a developing country application led to the selection of village power and/or water pumping for more detailed examination.

The role of interviews with potential users in this selection process and in market sizing was not clarified by BDM. The draft copy of the BDM final report available at the time of preparation of this summary report lacked legibility, thus preventing the listing of estimates of market size for the applications shown on this chart.

BDM Corporation's Most Promising New Applications

IRRIGATION

SMALL SUBMERSIBLE PUMPS
OIL FIELD PUMPS
COMPRESSORS
SUMP PUMPS
OIL BARGE PUMPS
SMALL ENGINE DRIVEN PUMPS

STREET AND HIGHWAY LIGHTING

AREA LIGHTING
PLAYGROUND LIGHTING
YARD LIGHTS
HIGHWAY FLASHING LIGHTS

RESIDENTIAL ATTIC FAN

SMOKE DETECTORS

RECREATIONAL VEHICLES

TOYS

PORTABLE CB RADIOS

BURGLAR ALARMS

UTILITY BATTERY CHARGERS

SILO LOADERS

POWER TOOLS

DoD WATER PURIFICATION

REMOTE RANGER STATIONS

SCHOOLS

RESIDENCES

SHOPPING CENTERS

HOSPITALS

WAREHOUSES

OFFICES/BANKS

VILLAGE POWER
AND/OR
WATER PUMPING

= SELECTED FOR:

PRODUCT DEFINITION
MARKET SCENARIO

Chart 18 shows the final list of most promising applications, old and new, derived by ITC. This study also started with listings of several hundred potential applications identified in a series of meetings with groups of U.S. and foreign experts. Considerations of market size and penetration potential led to the selection of the applications listed on this chart. The reduction to the four applications to be subjected to detailed product definition and market analysis was accomplished by analysis of the results of a series of mailed questionnaires. Market penetration estimates and demand curves were then developed via interview techniques applied to the four application categories which the questionnaire results had highlighted as most promising. Market penetration was, however, determined on a parametric basis as a function of variable attributes such as initial cost difference between photovoltaic and conventional power sources, operating cost savings, and potential tax credit effects.

Intertechnology Corporation's Most Promising New Applications

IRRIGATION

CROP DRYING, CROP HANDLING, etc
AGRICULTURAL DEVICES - SMALL
- INSTRUMENTS, FENCE ELECTRIFICATION, etc
POTABLE WATER PUMPS
INSECT KILLERS

BATTERY CHARGERS

- 6 AND 12 V
SMALL ELECTRIC VEHICLES

REFRIGERATION OF FOOD

OUTSIDE LIGHTING

- YARDS, HIGHWAY REST STOPS, etc
CORROSION PROTECTION
RADIO REPEATERS
RADIO TRANSCEIVERS
EMERGENCY RADIO BEACONS
CALL BOXES

UTILITY POWER

- PEAK LOADS, REMOTE VILLAGES, etc
REMOTE HOUSES
INDUSTRIAL
CONSTRUCTION TRAILERS
EMERGENCY CLINICS
ANCILLARY POWER FOR SOLAR THERMAL COLLECTORS
GREENHOUSE CONTROLS
NAVIGATIONAL AIDS
SECURITY EQUIPMENT
REMOTE MONITORING

☐ - SELECTED FOR:
PRODUCT DEFINITION
MARKET SCENARIO

Chart 19 shows the results of the detailed market analyses performed by BDM and ITC for some of the applications previously discussed as most promising.

BDM appears to have used substitution modeling in developing its forecasts which, however, are described as market potential forecasts rather than sales forecasts. ITC utilized market demand models based on questionnaires and interviews to develop penetration forecasts which were parametric with respect to initial cost difference between the photovoltaic system and the conventional power source, to the amount of fuel savings, and to tax incentives in the instances of outside lighting and irrigation. In only two application classes, those of compact refrigerators for use in recreational vehicles and vacation cabins and of outdoor security lighting on farms, did ITC transform these parametric penetration values to actual sales forecasts. Information is provided, however, to allow the reader to develop sales forecasts for the other two application classes on the basis of total potential market size estimates to be provided independently by the prospective user of the ITC study results. Except for the case of Indian village power for lighting and water pumping, all of the forecasts shown on this chart are for the U.S. market only.

Although BDM concludes that no U.S. market would exist in 1936 for photovoltaic irrigation systems, this conclusion is based on the use of an 8% discount rate, that rate which was commonly used in evaluating all other applications. BDM states that if special incentives were to lower the cost of money to 4%, the potential irrigation market could exceed 100 MW_p as early as 1986.

Comparison of these data with the maximum market potentials or sales shown earlier on Chart 13 is not feasible for several reasons. The values credited to BDM on that chart encompass the entire world market potential whereas the detailed forecasts on Chart 19 cover only the U.S. market. The ITC maximum sales forecasts on Chart 13, on the other hand, are cumulative sales, whereas the detailed forecasts of Chart 19 are annual sales in 1986. In addition, the applications analyzed in detail are only subsets of the more encompassing application classes sized on Chart 13.

RESULTS OF DETAILED MARKET ANALYSIS

BDM

- STREET AND HIGHWAY LIGHTING
1986 ANNUAL POTENTIAL - 240 MW_p
- ATTIC FANS
NO MARKET POTENTIAL IN 1986
- SCHOOLS
1986 ANNUAL POTENTIAL - 750 - 1100 MW_{pk}
 - IF SCHOOL OWNS SYSTEM
 - IF SALE BACK TO UTILITIES

AT COMMERCIAL POWER RATES
- IRRIGATION
NO MARKET POTENTIAL IN 1986
- INDIAN VILLAGE
1986 ANNUAL POTENTIAL - 0.2 - 4 MW_p
 - AT 10 kW_p PER VILLAGE

ITC

- IRRIGATION
NO SALES FORECAST*
- BATTERY CHARGERS
NO SALES FORECAST*
- COMPACT REFRIGERATORS
1986 ANNUAL SALES - 19 MW_{pk}
- SECURITY LIGHTING (FARMS)
1986 ANNUAL SALES - 29 - 33 MW_p

*INSTEAD, % PENETRATION OF MARKET
OF UNDEFINED SIZE IS PROVIDED

BDM DoD PHOTOVOLTAIC MARKET STUDY

Chart 20 outlines the ground rules and assumptions underlying another BDM Corporation study (Ref. 2) that addressed, specifically, the market available on military installations for both fixed and mobile military systems. As in the instance of Task 2 of the civilian market study performed by BDM (Ref. 1) and discussed earlier in this report, only potential markets were forecast, not potential sales. In other words, the degree of penetration by photovoltaic power systems was not determined. The 1986 annual market potentials were determined for all applications. In addition, for applications of the central station power type on military installations, the market potentials estimated are both annual and cumulative to the year 1986, starting with 1982. In some instances, the estimates of markets existing on several specific installations were extrapolated to all installations of the same or similar type, as, for example, in the case of remote military test sites in the U.S. Similarly, the central-station-type power demand at Army installations was extrapolated to all DoD installations. In other instances, only several examples of specific power needs were cited, without extrapolation to all other applications within the same category; remote island bases are an example of this practice.

A range of array breakeven costs, market potentials, and other parameters were determined for several scenarios that were based on the assumptions shown on this chart.

BDM DoD PHOTOVOLTAIC MARKET STUDY

- PROVIDES ESTIMATES OF TOTAL POTENTIAL MARKETS ONLY
 - NO PENETRATION ESTIMATES - THEREFORE NO SALES FORECASTS
 - FRACTIONAL MARKETS ONLY IN SOME CASES, I. E.,
 - REMOTE ISLANDS
 - OFFSHORE APPLICATIONS
- ESTIMATES RANGE OF POTENTIAL MARKETS UNDER SEVERAL SCENARIO ASSUMPTIONS

	1981	1986 (END OF)
- PV ARRAY COST \$/W _{pk}		
BASELINE	2.60	0.50
ACCELERATED	1.14	0.41

- DISCOUNT RATES OF 6.5 AND 10%
- INFLATION RATES OF 0 AND 4.3%
- ESCALATION OF CONVENTIONAL ENERGY OF UP TO 4.4% IN COST
- ARRAY LIFE TIMES OF 20 AND 30 YEARS (IN MOST CASES)
- FOR MOST APPLICATION GROUPS, SHOWS ARRAY BREAKEVEN COST, BREAKEVEN YEAR, ANNUAL PRICE ELASTICITY, 1986 ANNUAL MARKET POTENTIAL
 - FOR INSTALLATION POWER, ONLY ESTIMATES CUMULATIVE MARKET POTENTIAL TO 1986 (FOR CENTRAL STATION SYSTEMS)

The BDM DoD market study estimated market potential for five groups of military applications, as shown on Chart 21. The subgroupings shown under the main headings on this chart are examples only; the study examined market potential for additional subgroupings. For some of the groups, total markets were estimated from samples. This was done for the remote military test sites, mobile electric power, and DoD installation power. In the other instances, data pertinent to photovoltaic applications were calculated for example applications only, with the resulting market potential estimates thus covering only a fraction of the total potential market.

Examples of DoD Applications Considered by BDM Corporation

- REMOTE TEST SITES
 - INSTRUMENTS
 - RADAR
 - TRACKING TELESCOPES
 - CCTV
- REMOTE ISLANDS, COMMUNICATIONS SITES
 - RADAR
 - UHF/MICROWAVE REPEATERS
 - SWITCHING CENTERS
 - UTILITY POWER
 - SATELLITE GROUND STATIONS
 - CATHODIC PROTECTION
 - NAVIGATION AIDS
- OFF-SHORE POWER
 - BUOYS
 - ENVIRONMENTAL PLATFORMS
 - SURVEILLANCE RADAR
- MOBILE ELECTRIC POWER
 - BATTERY CHARGING
 - SURVEYING DEVICES
 - AIR TRAFFIC CONTROL
 - COMMUNICATIONS
 - SURVEILLANCE SENSORS
 - WATER PURIFICATION UNITS
 - SCATTERABLE MINES
- DoD INSTALLATIONS (CONUS)
 - CENTRAL STATION POWER

Chart 22 summarizes the estimates of the potential military market developed by the BDM study. It also shows the array breakeven costs and the dates of probable initial penetration which formed the basis of the estimates. As stated earlier, these markets do not represent forecasts of actual sales, since consideration of the degree of penetration did not enter into the analysis. The study primarily determined potential demand by computing breakeven costs, thereby determining the dates by which photovoltaic systems could compete economically with the current power source. It then assumed that substitution for all of the newly purchased equipment for applications in which photovoltaic systems could compete would constitute at least part of the potential market. It is not clear to what degree retrofit was considered in the installation power market. In the other instances, it was assumed that if a conventional power source such as a mobile engine generator reached the end of its economic life after the photovoltaic system had reached economic competitiveness for that class of application, the application which it served would join the potential market. In that sense, retrofit applications are part of the defined potential market.

The total market for military test sites was extrapolated from a more detailed analysis of the inventories of instrumentation existing on three representative test sites. These were the White Sands Missile Range, the Naval Weapons Center, and the Pacific Missile Range. The total Mobile Power market was estimated on the basis of the assumption that 20% of all mobile diesel and gasoline engine generator sets in the military inventory between 1.5 kW and 750 kW in rated power would be candidates for photovoltaic system replacement. Only five island bases were analyzed to provide examples of this type of application. These included Eleuthera, Grand Turk, Midway, San Nicholas, and Bermuda. The Defense Communication System repeater stations served as examples of fixed site communication applications and the Mount Laguna radar installation provided an example of a large, fixed radar site.

Only the 1986 annual potential markets are shown for the non-installation markets. The numbers shown on the chart were read from small graphs in the BDM report and may therefore be subject to correction. The market potential range covers a variety of scenarios as indicated on Chart 21. Central station type power was not found to be competitive in the period up to 1986 except in the instance of the scenario indicated on Chart 22 which assumes a relatively high rate of real escalation of commercial utility power cost, and a rather long photovoltaic system life (30 years).

Summary of BDM DoD Market Potentials

	RANGE FOR BASELINE SCENARIO ONLY*		RANGE OVER ALL SCENARIOS
	ARRAY BREAKEVEN COST, \$/W _{pk}	YEAR OF BREAKEVEN	1986 ANNUAL MARKET POTENTIAL MW _{pk}
• REMOTE MILITARY TEST SITES - 26 SITES (EXTRAPOLATED FROM 3 EXAMPLE SITES)	0.80 - 30.0	'77 - '85	1.1 - 3.3
• REMOTE ISLAND BASES, COMMUNICATIONS, OTHERS - EXAMPLES ONLY	0.20 - 6.6	'79 - '86	0.6 - 4.9
• MOBILE POWER - TOTAL (EXTRAPOLATED FROM EXAMPLES)	0.31 - 366	'77 - '84	38 - 42
• OFF-SHORE APPLICATIONS - EXAMPLES ONLY	0.31 - 178	'77 - '87	0.034 - 0.048
•• TOTAL	0.20 - 366.0	'77 - '87	~40 TO ~50
• DoD INSTALLATION POWER** (CENTRAL STATION TYPE) - UP TO 1,600 MW _{pk} CUMULATIVE TO 1986 (BASED ON INFLATION OF 4.3%, DISCOUNT RATE OF 10%, REAL ESCALATION OF COST OF UTILITY POWER OF 4.4%, PV SYSTEM LIFE OF 30 YEARS)			

*PV ARRAY COST \$0.50 AT END OF 1986

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MID-TERM MARKETS

Only two studies were found to address the terrestrial photovoltaic market probably to be initiated in the post-1985 time period. These studies, by General Electric Corporation and by Westinghouse Electric Corporation, were studies of larger scope, dealing with system concepts and preliminary systems design of photovoltaic systems for residential, commercial and utility applications. In both studies, some effort was also devoted to the exploration of the potential size and the timing of the markets for these applications. It is this effort that is reviewed in the next report section.

GENERAL ELECTRIC CORPORATION

Market forecasting in the General Electric Study (Ref 5) concentrated primarily on the residential market. An estimate of central station market penetration was offered for the U.S. "sunbelt" only and was stated to reach about 13,000 MW in the year 2000, or about 2.5% of the total electrical generating capacity in place in that year in that region of the country. No documented rationale was offered for this estimate. The forecast for commercial building applications was confined to an estimate of the commercial roof area to be available in the year 2000, which, if every building were equipped with photovoltaic systems, would offer a maximum potential of up to 100 GW_{pk} of cumulative array sales.

Two methods were used to forecast the residential housing market. One, called the Regional Competitive Cost Analysis, was based on the assumption that initiation of sales in a geographic region would depend, in part, on insolation and on competitive energy prices of that region, since these are two of the three major parameters determining cost competitiveness of a photovoltaic energy system. Since only all-electric houses were considered, utility electric power was assumed to compete with photovoltaic power. The third factor important to the initiation of sales is the price of the photovoltaic system.

Groundrules and assumptions for the Regional Competitive Cost Analysis method of forecasting are shown on Chart 23.

GENERAL ELECTRIC MARKET FORECAST ASSUMPTIONS

- o REGIONAL COMPETITIVE COST ANALYSIS - RESIDENTIAL MARKET
 - o BASIC MODEL - NEW CONSTRUCTION ONLY
 - / 60% OF ANNUAL NEW CONSTRUCTION IS MAXIMUM POTENTIAL MARKET
 - REGIONS BECOME VIABLE MARKETS IN DIFFERENT YEARS
 - / FUNCTION OF CONVENTIONAL ENERGY PRICES
 - / FUNCTION OF INSOLATION
 - / MARKET ENTRY WHEN PV POWER COST = CONVENTIONAL POWER PRICE
 - GROWTH OF PV MARKET IN EACH REGION IS EXPONENTIAL UP TO 60% OF ANNUAL NEW CONSTRUCTION
 - o ASSUMPTIONS - LEARNING CURVES
 - / 70% FOR CELLS
 - / 90% FOR OTHER SYSTEM COMPONENTS
 - / COMPOUND RATE IS .79% BETWEEN 1985 - 2000
 - ALL-ELECTRIC HOUSE
 - / 10 kW_{pk} ARRAY (NO STORAGE)
 - / PV SHINGLE ROOF
 - / ENERGY-CONSERVING DESIGN
 - / PV ARRAY LIFE IS 30 YEARS
 - ARRAY PRICE IS ~\$1.00/W_{pk} IN 1985
 - CONSUMER OWNERSHIP
 - INITIAL MARKET GROWTH AT 15% PER YEAR. MAXIMUM GROWTH OF 59% PER YEAR REACHED IN ~10 YEARS.
- !!! UTILITIES WILL BUY EXCESS ELECTRICITY FROM HOMEOWNER AT SAME PRICE AS SELLING PRICE

A total of six regions were defined as being successively penetrated by photovoltaic sales for residential applications, with the initial region consisting of Hawaii, New York City, and Puerto Rico where sales of photovoltaic systems were assumed to begin in 1985. The last region to be penetrated, in about 1995, was the Northwestern part of the U.S., characterized in terms of insolation and energy prices by the state of Oregon. The rate of penetration was arbitrarily set equal for each of these regions as shown on Chart 24, which also shows estimates of cumulative sales by region and by year as developed by this method. The varying time intervals represented in this table arise because of the use of learning curves to forecast reduction in the price of photovoltaic systems. As annual photovoltaic sales increase in each region in accordance with the assumed market growth rate, total cumulative production also increases, thereby leading to array price reductions in accordance with learning curve assumptions. The year in which the photovoltaic market is initiated in a given region therefore depends on the growth of the market in regions where the market was initiated earlier.

Chart 24

GENERAL ELECTRIC FORECAST OF RESIDENTIAL PHOTOVOLTAIC SALES
BY COMPETITIVE REGIONS

CUMULATIVE SALES IN MW_{pk}

REGION	YEARS						
	1985	1990	1993	1994 1/2	1996	1997 1/2	2000
1	I	500	910	1220	1650	2080	2740
2		I	590	970	1580	2500	4020
3			I	1310	3190	7240	19,820
4				I	1080	3060	6250
5					I	620	2140
6						I	30
TOTALS		500	1500	3500	7500	15,500	35,000

I = INITIAL SALES

ANNUAL MARKET GROWTH RATE IN EACH REGION, %		15	26	59	59	59	32
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The other market forecasting approach used by General Electric was based on the Fisher-Pry market substitution model (Ref 9). This model results in the construction of a logistic curve when cumulative market substitution is plotted against chronological time. As shown on Chart 25, the mathematical formulation of the model is relatively simple and is based on the presumption that adoption of a new technology in any one year is a function of the degree of adoption which has preceded it, in a manner similar to that in which bacterial disease is spread. (These models are often called contagion models).

GE MARKET FORECAST ASSUMPTIONS

● FISHER-PRY SUBSTITUTION MODEL - RESIDENTIAL MARKET

o BASIC MODEL - FRACTION OF TOTAL CUMULATIVE MARKET CAPTURED AT TIME $t = \frac{e^{f(t)}}{1 + e^{f(t)}}$

/ WHERE $f(t) = \frac{4.4(t - t_m)}{\Delta t}$

/ Δt = YEARS BETWEEN 10% AND 90% CUMULATIVE MARKET CAPTURE

/ t_m = MIDPOINT OF PERIOD Δt

o ASSUMPTIONS - Δt IS 15 YEARS (10 AND 20 YEARS ALSO EXAMINED)

- 25% OF U.S. HOME INVENTORY IN YEAR 2000 BUILT AFTER 1985

- 60% OF HOMES CONSTRUCTED AFTER 1985 REPRESENT MAXIMUM MARKET POTENTIAL

- 20% OF HOME INVENTORY IS MAXIMUM RETROFIT MARKET

● BUT ONLY 60% OF THIS IS MAXIMUM PV MARKET

o 2 CASES OF RETROFIT MARKET CONSIDERED

● PV RETROFIT STARTS 5 YEARS AFTER NEW CONSTRUCTION PV STARTS

● PV RETROFIT STARTS COINCIDENT WITH NEW HOME INSTALLATIONS

●●●

GOVERNMENT INCENTIVES, ENERGY SHORTAGES, OTHER EVENTS COULD SHORTEN t_m (TAKEOVER TIME) CONSIDERABLY

Chart 26 shows the cumulative sales which were forecast by General Electric on the basis of the model illustrated in the preceding chart (Chart 25). Results are given for four time periods, and for both new construction housing and for retrofit applications. In both instances, 60% of the housing market is considered a potential market for photovoltaic application. In the retrofit market, however, only 20% of the total existing inventory is assumed to constitute the potential market to which the 60% factor is applicable. The exclusion is based on considerations of siting, climate, and the remaining economic life of each house.

The data on Chart 26 are based on the assumption of a 15 year take-over time, that is, the number of years between 10% and 90% cumulative market substitution, as defined on Chart 25. G.E. also shows market forecasts for 10 and 20 year take-over times. The estimates for the year 2000 for these latter take-over times are also shown on this chart, but for new construction only. It is of interest to note that, although the previously described method specifies different regional adoption starting times on the basis of insolation, competitive energy prices, and differing photovoltaic breakeven cost requirements per region, the use here of the Fisher-Pry substitution model is based on the assumption of a uniform start over the entire nation. Also, the previous method based its forecast on new construction only, while the possibility of retrofit was taken into account in the instance of the substitution model. Two alternative take-offs of the retrofit market are postulated. In one, the retrofit take-off lags the new construction take-off by 5 years on the basis that retrofit is more expensive and more difficult; in the other alternative, both markets are initiated at the same time.

No data on the rate of sales prior to 1986 were provided.

GENERAL ELECTRIC FORECAST OF RESIDENTIAL PHOTOVOLTAIC SALES
 BY USE OF SUBSTITUTION MODEL,
 IN CUMULATIVE MW_{PK} (FOR $\Delta t = 15$ YEARS)

	1986	1990	1995	2000
NEW CONSTRUCTION ONLY	5	74	270	870
NEW CONSTRUCTION PLUS RETROFIT WITH 5 YEAR DELAY	41	631	2,352	5,500
NEW CONSTRUCTION PLUS RETROFIT- NO DELAY	60	910	3,390	11,470
ALTERNATIVE TAKE-OVER TIMES*				
10 YEARS	—	—	—	3,825
20 YEARS	—	—	—	737

*NEW CONSTRUCTION ONLY

The cumulative market growths estimated by G.E., using both methods, are plotted on Chart 27. In order to match data derived from the Regional Competitiveness Model, the data derived from use of the Fisher-Pry Substitution Model are shown in terms of cumulative photovoltaic power installed, rather than in terms of the fraction of total market substituted. Because of this, the substitution model data do not exhibit the characteristic S Curve or Logistic Curve shape. To maintain plot legibility, the results obtained via the substitution model for alternate take-over times are represented in the graph only in the form of single data points for the year 2000. These values are for new construction only and therefore relate, for comparison purposes, only to the curve labelled #1 on the chart.

Residential PV Market Growth, G. E. Forecasts

CUMULATIVE MW_pk

WESTINGHOUSE CORPORATION

The Westinghouse Electric Corporation study (Ref 6) was devoted primarily to definition of systems for generating photovoltaic power for three classes of applications: residential, intermediate-size applications (as applicable to commercial and industrial installations), and central station power generation. Market forecasts were presented for all three types of applications but with only a limited discussion of the methodology and background assumptions underlying the forecasts. More information has been provided for the residential market than for the others. Chart 28 outlines the assumptions used in forecasting the residential market. The "pre-commercialization" activities which are to lead to the installation of 600,000 residential systems by 1990, a quantity considered critical to a successful commercial take-over of the market, include government measures by local and federal agencies. Among these measures would be government-guaranteed array prices, government ownership of manufacturing facilities, tax credits for photovoltaic production as well as consumption, use of photovoltaic systems in public buildings, etc. However, no specific information about the costs of such a "precommercialization" program were provided.

Retrofitting was not assumed in the estimation of market size. A variety of energy system concepts were examined, ranging from those that only provide power to lights and appliances commonly requiring a 115 V AC supply, to those providing 220 V AC for central air conditioning and electric clothes drying as well. By-product thermal energy was assumed to be used for space heating and for hot water, or to supplement heat pumps in some of the concepts. Electrically driven vapor compression air conditioning was assumed in all cases. The array sizes required for these various energy systems, in the seven locations for which performance calculations are shown, range from 35 m² to 110 m². In estimating the residential market size, Westinghouse assumed an average of 50 m² of array per residence. In translating this into peak power rating, we have assumed a 10% array efficiency, i. e., a peak power output of the residential system of 5 kW.

None of the market forecasts appear to have made use of forecasting models. They appear to be based primarily upon judgment, coupled with selected interviews in the industries involved.

WESTINGHOUSE MARKET FORECAST ASSUMPTIONS

- U.S. RESIDENTIAL MARKET
 - BASIC MODEL - NEW CONSTRUCTION
 - / PRE-COMMERCIALIZATION PHASE BETWEEN 1985 - 1990
 - • • GOVERNMENT SUBSIDY FOR PORTION OF 600,000 HOUSES TO BE BUILT DURING THIS PERIOD
 - AMOUNT OF SUBSIDY NOT SPECIFIED
 - / GROWTH RATE STEEP
 - ~10,000 HOMES/YEAR IN 1985
 - ~37,000 HOMES/YEAR IN 1986
 - / GROWTH EQUAL IN ALL REGIONS OF U.S.
 - ASSUMPTIONS - TOTAL ENERGY HOUSE
 - / BOTH THERMAL & ELECTRIC STORAGE
 - / UP TO 10 kW_{pk} OF ARRAY/HOUSE (AVERAGE OF 5 kW_{pk})
 - / ENERGY CONSERVING DESIGN
 - / WATER AND AIR-COOLED ARRAYS
 - / SYSTEM LIFE IS 30 YEARS
 - / CONSUMER OWNERSHIP
 - / MARKET FORECAST IS NOT INFLUENCED BY USE OF UTILITY BACK-UP FOR EITHER OR BOTH THERMAL & ELECTRIC SYSTEMS, OR USE OF STAND-ALONE SYSTEMS

Chart 29 shows the quantitative market estimates provided by the Westinghouse study. Cumulative values were shown only for the residential application and indicate that sales were expected to begin well before 1985 in order to permit 60,000 residences to have received photovoltaic installations by the end of that year.

The intermediate power systems were defined as being between 100 kW and 1 MW of peak power in size. In contrast to the residential system, where consumer ownership is favored, intermediate size systems were found to favor utility ownership from an economic and operational point of view. Also in contrast to the residential application, total energy systems were found to be economic in only a few applications where low temperature thermal energy can be used. No special precommercialization program is discussed, but the study indicates that government support will be required in the form of installation of demonstration photovoltaic systems in schools and government buildings.

The central station power systems were defined as being between 50 and 1000 MW^{pk} in size. Photovoltaic systems are stated to be more attractive to publicly owned utilities than to investor owned companies. However, Westinghouse concluded that government subsidies would be required not only to initiate the market in the late 1980's but to sustain it through the year 2000. No information was provided on the rate of such earlier sales or on the probable date of their initiation.

Chart 29

WESTINGHOUSE PHOTOVOLTAIC MARKET FORECASTS

APPLICATION	YEAR		
	1985	1990	2000
• <u>RESIDENCES</u>			
ANNUAL RATE OF PV INSTALLATION, 1000'S	10	200	750
CUMULATIVE INSTALLATION, 1000'S	60	600	5000
ANNUAL ARRAY AREA* INSTALLED, 10^6 m^2	0.5	10	37.5
CUMULATIVE ARRAY AREA* INSTALLED, 10^6 m^2	3	30	250
ANNUAL MW _{pk} INSTALLED **	50	1000	3750
CUMULATIVE MW _{pk} INSTALLED **	300	3000	25,000
• <u>COMMERCIAL/INDUSTRIAL (INTERMEDIATE SIZE)</u>			
ANNUAL ARRAY AREA INSTALLED, 10^6 m^2	0.5	2	7
ANNUAL MW _{pk} INSTALLED	50	200	700
• <u>CENTRAL POWER STATIONS</u>			
ANNUAL ARRAY AREA INSTALLED, 10^6 m^2	1.5	3	15
ANNUAL MW _{pk} INSTALLED	150	300	1500
• <u>TOTALS</u>			
ANNUAL MW _{pk} INSTALLED	500	1500	6000

* BASED ON 50 m^2 PER RESIDENCE

** BASED ON AN AVERAGE ARRAY EFFICIENCY OF 10%

Chart 30 shows a plot of the data provided by Westinghouse for the residential forecast, both in terms of numbers of residences receiving photovoltaic installations, and in total peak power of such installations. Both annual and cumulative values are shown.

Westinghouse Forecast

NEW RESIDENCES
USING PV
IN THE U.S.
AFTER 1985

Chart 31 contains plots of the annual installation rates of photovoltaic power, as forecast by Westinghouse for the three application classes covered by their study. Information on annual rates prior to 1985 is not provided, and there is no discussion of the means of bringing about any such sales prior to the time period when array prices would permit competition with conventional energy systems.

Annual Rate of Array Installation, in MWpk

WESTINGHOUSE ESTIMATE

SUMMARY

To summarize the results of five of the six studies discussed in this briefing, Chart 32 was prepared. It shows a composite overview of annual and cumulative photovoltaic sales forecasts by these five studies, and the forecasts of potential markets which were provided by two of the studies. All of the data on this chart have been previously discussed in greater detail. The BDM DOD study results are not shown because the military market potentials defined therein are only fractions of the probable totals, and because both Ref 1 and Ref 3 include what appear to be more inclusively estimated military markets.

It is of interest to note the relatively close match between the forecast market range for the near-term U.S. photovoltaic market in the 1985-'86 time frame and that forecast for the U.S. residential market, which is assumed to be ready for take-off in 1985. The actual market range may well be higher than here indicated, as already discussed in connection with Chart 9. It appears, therefore, that the near-term market might serve to prepare the production base for the residential market. Since many of the segments making up this near-term market would tend to saturate (reach high substitution levels), with consequent declines in annual sales in the 1985-'90 time period, the industry might then be able to accommodate the growing residential market in a relatively smooth transition.

The total cumulative market potentials shown for 1985 and 1986 overlap in size the cumulative residential markets estimated by G.E. and Westinghouse for the year 2000. Because of the time frame difference, this is probably only coincidental. The annual residential market estimates ascribed to G.E. on this chart are estimates based on the G.E. cumulative market forecasts.

Although it may be realistic to assume that U.S. markets would be mostly satisfied by U.S. industry, it must be noted that the high cumulative market potential range shown for 1985 and '86 includes world markets whose demand may, to a major extent, be met by foreign production. The ITC report (Ref 3) indicates an intent by at least one of the countries to establish an indigenous photovoltaic industry. In addition, European and Japanese firms are competing for LDC business.

Summary of Selected Photovoltaic Market Estimates to Year 2000

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CONCLUSIONS

It is more difficult to draw conclusions concerning the size of the future photovoltaic market than its segmentation into application classes from the studies summarized in this report. This is because the groundrules to which these studies were performed are notable more for variety than for consistency. As mentioned earlier, the market range defined for the 1985-86 time frame exclude new applications, in two of the three studies, at least from the U.S. market segment. If such new applications were included, and if other unifying adjustments were made to the groundrules, the market range would likely shift upward. Since only the original study authors would have the requisite data to make such adjustments, it is recommended that consideration be given to requesting such retrospective amplification of these studies. Improved market forecast data for the mid 1980 time period are particularly important because of the anticipated initiation, in that time frame, of substantially larger market segments which await the lower photovoltaic system costs anticipated to materialize at that time. These segments, the residential, commercial, and institutional building markets, the industrial market, and some early central station applications, will require a substantial production base to sustain their likely growth and it would be very useful to know whether the near-term markets can generate this base.

The intermediate and far-term markets also require better definition than has been provided by the market studies performed thus far and summarized in this report. The studies currently underway at General Electric, Westinghouse, RTI, and BDM, and covering residential and commercial buildings as well as agricultural applications, will contribute to this better definition. Industrial applications also may be viable in that time period and their market potential should be further defined. Finally, considerable effort still appears to be required to define the photovoltaic market potential in the utility sector. Better market data for these sectors should permit better manufacturing capacity planning and may contribute to the ability to make choices between manufacturing technologies which may be needed at an early date.

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