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MISSION ANALYSIS OF PHOTOVOLTAIC SOLAR ENERGY CONVERSION
VOLUME 2

Survey of Near-Term (1976-1985) Civilian Applications in the United States

By
E. J. Rattin

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Work Performed Under Contract No. EY-76-C-03-1101

The Aerospace Corporation
Energy and Transportation Division
El Segundo, California

MASTER

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Solar Energy

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THE AEROSPACE CORPORATION
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PROJECT AGREEMENT 8

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FOREWORD

This document constitutes the second volume of a four-volume final report on a study carried out under Contract No. EY76-C-03-1101, Project Agreement 8, "Mission Analysis of Photovoltaic Solar Energy Systems" for the Division of Solar Energy in the U.S. Energy Research and Development Administration. This volume covers the work on Task 1, Analysis of Near-Term Missions. The other volumes in the report are: Vol. I, Executive Summary; Vol. III, Major Missions for the Mid-Term (1986-2000); and Vol. IV, Supplementary Studies.

The study was conducted by the Energy Systems Group of the Energy and Transportation Division of The Aerospace Corporation. Dr. Leonard Magid, Acting Chief of the Silicon Technology Programs Branch, was the ERDA Program Manager for this contract, and Dr. A. B. Greenberg, General Manager of the Energy and Transportation Division, was the Principal Investigator. Dr. M. B. Watson is the Director of the Energy Systems Group, and Dr. S. L. Leonard, Director, Photovoltaic Projects, provided the program management.

This volume was prepared by E. J. Rattin, with valuable contributions by W. Kammer.

The author of this volume wishes to express appreciation to R. C. Anthony and S. L. Larson of the Aerospace Corporate Library for their assistance in the literature search for this study, and Dr. R. J. Lutz, Assistant Professor of Marketing, University of California at Los Angeles, for his advice in the field of market research. The help of Janet Hallett in technical editing and in overseeing the production of this report is gratefully acknowledged. Appreciation is also expressed for the assistance rendered by the many individuals contacted during the course of this study in providing valuable information. Of particular value have been the special efforts made by the following individuals: Messrs. Dowling and Fowler of the Electronic Compatibility Analysis Center (DoD), Mr. W. Miller of the Bureau of Indian Affairs, Mr. R. Snow of the Federal Railroad Administration, and Mr. D. Gedney of the Federal Highway Administration.

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SUMMARY

The purpose of this market study was to identify and evaluate potential terrestrial civilian photovoltaic applications in the U.S. which were most likely to contribute significantly to the growth of near-term (to 1985) markets.

A survey was conducted which led to the identification of many potential applications for photovoltaic power. These applications were subjected to a screening process which selected about 50 application groupings with considerable promise as near-term markets for photovoltaic arrays. For 21 of these 50 promising application groups, it was possible to make quantitative market estimates that totaled 13 MW_{pk} in projected annual array sales in 1985. The markets associated with the remaining 29 groups could not be quantitatively evaluated because of lack of an adequate existing data base and because the primary research required in order to provide such a data base was not feasible within the resources available in the study. If the average size of the markets associated with the unquantified groups, however, is comparable to the average for the quantified cases, then the total non-military US market for arrays may well exceed 25 MW_{pk}/year in 1985. Foreign and U.S. military markets should add significantly to this total. In fact, the consensus of the photovoltaic industry representatives who were contacted is that the total foreign market over the near term may be several times as large as the domestic one. Although it had not been completed at the time of preparation of this report, a study of military applications by another organization under sponsorship of the Federal Energy Administration should yield estimates of the U.S. military market, which also may be quite large.

Most of the application information and market data were obtained from secondary sources, such as literature and published statistics; the rest of the data were generated by an extensive telephone survey and some visits, as well as by team brainstorming. A limited questionnaire

mailing also was carried out under the auspices of the Bureau of Indian Affairs to develop data on applications on Indian Reservations. A comprehensive listing of likely early applications for photovoltaic power was organized into applications tree format in order to utilize the morphological properties of such trees in calling attention to application variants.

The predictions of photovoltaic array prices between 1976 and 1985, which were derived from previous ERDA goals statements and ranged from \$20.00 to \$1.00 per peak watt, directed the applications search primarily to uses which are remote from existing utility power distribution systems. These predictions also led to emphasis on evaluation of applications with power demand levels less than 5 kW, the power range in which photovoltaics could be competitive with engine generator sets at array prices in the \$2.00 to \$1.00 per peak watt range.

The calculated break-even array price was used, in conjunction with the ERDA array price goals to estimate the year of initial photovoltaic penetration of the market in each case. Because of the lack of historical sales data on photovoltaics or on analogous products, substitution modelling could not be used and market size and rate of penetration estimates had to be based, when possible, on trend data and on expert judgement obtained from personnel associated with the various use areas.

A set of uniform assumptions, both technical and economic, supported the life-cycle-costing calculations used to determine the break-even prices of photovoltaic arrays in the various applications. Break-even prices for flat plate, non-concentrating arrays were computed using primary batteries, gasoline and diesel engine generator sets, and the utility grid as cost references, although all three alternative power sources were not necessarily considered for each application. Present value costs were used in these cost comparisons.

The principal results of the market survey are summarized in the table on the next page. In general, for array prices projected for the near term, substitution of photovoltaic systems with secondary battery

Summary of Market Forecasts

Application	Cumulative Power by 1985, in kW _{pk} *	Sales in 1985, in kW _{pk} *
Battery Chargers for Consumer Products	15	3
Intrusion Detection	1,300	120
Earthquake Observation	9	3
Environmental Observations	34	6
Highway Call Boxes	250	10
Emergency Location Transmitters		
Aircraft	65	15
Marine	50	20
Radio Control	700	100
Repeaters		
Common Carrier	4,300	600
Private Microwave	3,500	800
UHF/VHF	3,200	550
RR Crossing Signals	1,400	160
Highway Signs	9,000	3,000
Marine Navigation Aids	400	35
Other RR Applications	1,000	400
Drip Irrigation	22,000	5,000
Recreational	1,700	350
Industrial Corrosion Protection	8,300	2,000
Bridge Decking Corrosion Protection	4,000	150
Highway Rest Areas	500	100
Miscellaneous	35	9
Total Forecast	62,000	13,300

* peak power output of array in watts.

Markets with Potential for Which Quantitative Forecasts Were Not Feasible

Fire Detection Sensors

Approach Sensors

Pollution Monitoring Instrumentation

Status Sensing Instrumentation for Water Utilities

Location Sensors

Community Call Boxes

Air Traffic Beacons and Radio and Lighted Landing Aids

Railroad Block Signals and Controls

Highway Traffic Signals and Controls

Fixed and Mobile Radio Stations

Rural Telephone Systems

Radio and TV receivers (remote locations)

Utility Meter Reading Systems

Billboards and Lighted Annunciators

Offshore Platforms

Obstruction Lights

Drinking Water Well Pumping (ranches)

Miscellaneous Farm Applications

Water Well Casing Corrosion Protection

Water Distribution Piping Corrosion Protection

Indian Reservation Needs

Grade Crossing Illumination

Campground Power

Highway Illumination

Highway Maintenance Depots

Boat Battery Float Charging

Water Purification

Construction Site Applications

storage for primary battery power will have a significant market for a variety of industrial, scientific, and communications applications, although prospects are limited for the consumer market. Remote instrumentation will be an important market, as may be a variety of emergency communication systems. It is predicted that remote radio repeaters will be an important growth market, as will a variety of powered signs and signals located from fractions of a mile to several miles from utility power. A particularly interesting application is drip irrigation, both in terms of its own market potential, and because it exemplifies a relatively ideal photovoltaic near-term application in which load demand nearly matches insolation, demand density is well within available insolation density, and geographic application preference is in regions of better than average insolation. Impressed current cathodic corrosion protection is another very promising growth market, which is already being penetrated by private enterprise but which has potential for expansion into applications not yet receiving market development.

The summary table shows a number of the potential photovoltaic markets which could not receive quantitative evaluation, for reasons already mentioned. Of particular interest in this listing are Indian reservations since their needs are similar to those of developing countries in many respects. Test and demonstrations on reservations could assist the growth of the export market.

A probable average growth rate of about 70% per year over a ten-year period is indicated for those applications which were quantitatively evaluated. This market appears sufficient to provide a substantial production base and should furnish important resources for industrial investment in improved production techniques leading to lower photovoltaic array and system costs.

The size of these near-term markets could be increased by several means. Array costs could be reduced by technological innovations in materials and processing, and by the pursuit of design and marketing concepts in which byproduct thermal energy sales reduce the effective cost of electrical energy produced by photovoltaic systems. If these events materialize, new and important markets may yield to penetration prior to 1985.

The market segments already identified can be penetrated earlier, and their rates of penetration can be increased, by emphasis on removing user concerns. Thus, early adoption of photovoltaics would be aided if performance standards and model purchase specifications were developed on a priority basis to afford the lay user confidence in the quality of his procurement. Similarly, demonstration of critical performance characteristics concerning resistance to environmental factors, long operating life, and low operating costs deserves the strongest emphasis in the ERDA program.

Other recommendations resulting from this study include a suggested shift of marketing study emphasis from the near term, in which markets are largely constrained to special purpose applications, to the intermediate term, the 1985-1990 time period. Evaluation of this intermediate term market requires investigation of photovoltaic applications (including on-site total energy applications) in such mass markets as residential housing and medium-sized energy consumers like commercial and industrial structures and processes. With respect to the test and demonstration program, it is recommended that emphasis be placed on applications which might be created by the availability of photovoltaic power, such as powered highway signs and signals, and on Indian reservation applications which could provide an important test bed for systems with extensive export potential.

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SECTION 1

INTRODUCTION

1.1

PURPOSE

The purpose of the study effort described in this report is to support the orderly development of near-term markets (1976-1985) for silicon cell photovoltaic technology through identification and evaluation of those potential photovoltaic applications that are most likely to contribute significantly to the growth of such markets. Only U.S. civilian markets were to be considered. It was not planned, furthermore, to make an attempt to evaluate the market stimulation effect of special government purchases of solar cell arrays for test and demonstration purposes, or of possible incentives, either direct or tax-related, also directed toward market stimulation. This study was intended to be complementary to two other investigations being conducted at approximately the same time. The first of these is a survey of potential military applications of photovoltaic power generation systems being conducted for the Federal Energy Administration by the U.S. Army Mobility Equipment Research and Development Command. The second is the ongoing study of government and special civilian applications being carried out by the NASA Lewis Research Center as part of its Photovoltaic Test and Applications Project activities.

The evaluation of applications identified as promising for photovoltaic power utilization was to include both technical and economic factors. In addition to determining gross technical performance requirements for each promising application, costs of the photovoltaic power generation system were to be compared with those of competing alternative power generation systems, with consideration being given to the geographic and climatological factors impacting such comparisons. Non-economic factors affecting the choice of a power generation system were to be explored only for the more promising applications, as were such external issues as environmental impact.

Finally, among the prime objectives of this study were (1) the delineation of the potential cumulative market for each specific application, up to 1985 and (2) an estimate of the total annual rate of photovoltaic array production which could be reached by that year as a consequence of realization of the projected market.

1.2 APPROACH AND SCOPE

The approach selected for the conduct of this study was based, in part, on the recognition that the expected large number of identifiable candidate applications would require screening to eliminate those whose potential for photovoltaic power utilization was limited by technical considerations, or those where economic factors would force postponement of initial market introduction beyond 1985. Further, because of time and resource limitations, detailed economic and technical evaluation could only be performed on a fraction of the applications surviving this screening. It was also recognized that extensive primary market research would be beyond the resources allocated to this study and that, consequently, secondary data sources would have to be heavily utilized.

Figure 1 depicts the four primary study phases into which this activity was divided. A literature search was conducted to produce a listing of candidate applications. This was supplemented by visits, telephone calls, and other communications with producers of solar cells, current users of photovoltaic power sources, potential users, and individuals and organizations who might be aware of candidate applications. Further, reviews were conducted of battery applications, of areas of utilization of engine generator sets, and of current uses of wind power in expectation that these fields would suggest new photovoltaic applications. Although the survey was, by agreement with ERDA, constrained to the U.S. market, the importance of foreign markets in contributing to the growth of U.S. silicon cell and array production capacity was recognized. Because of this, a special effort was made to obtain information regarding potential applications on Indian reservations since many such uses parallel the needs of developing countries to the extent that utility grids might be equally remote, if existing at all, and

Figure 1

STUDY FLOW FOR POTENTIAL PHOTOVOLTAIC MARKETS

on-site generation of power from engine generator sets might face similar difficulties of high fuel and maintenance costs.

The study team also used brainstorming sessions during the construction of the applications tree (described in Section 3) to develop new applications. The morphological attributes of the applications tree were utilized to suggest new applications or variants of old ones.

In addition to the classification into use categories which the applications tree permitted, grouping by load characteristics was also done in order to allow the selection of a limited number of applications for further technical and economic analysis. The economic evaluation of candidate applications was based on determining the break-even cost of the array in competition with currently used or available conventional power sources. The break-even cost of the silicon cell array used in a power generation system,

when compared with the price goals for such arrays projected by ERDA (Ref. 1) for the years between 1976 and 1985, was used to estimate the date when the early adopters of an innovation might purchase such systems. Figure 2 shows these goals. Using the terminology of Rogers and Schoemaker (Ref. 2), innovators may precede these early adopters, as shown in Figure 3, since they may not need cost break-even for a buy decision. However, the number of units sold to innovators (less than 2.5% of the market) is usually too small to serve as an indicator of initial market penetration. Innovators, in this context, are purchasers not necessarily motivated by economic advantage. They are venturesome risk takers. The early adopters are characterized by successful and discrete use of new ideas and tend to provide opinion leadership.

Technical evaluation of the application at this phase of the study consisted of a determination of such load characteristics as average and peak power and duty cycle in order to permit sizing of array, storage, and power conditioning equipment so that the cost of the photovoltaic power system candidate could be estimated. The competing alternative power source received similar evaluation, with consideration given to remoteness and to terrain characteristics associated with specific applications when such factors would affect the cost of power.

Applications for which the estimated break-even array price was higher than the currently (late 1976) achieved price of \$13.00 to \$20.00 per peak watt (depending on source and quantity), or lay between this price and the 1985 price goal of \$1.00 per peak watt, were examined in more detail. Estimates of the associated cumulative market for arrays in the 1976-1985 periods as well as the annual market during 1985 were then developed when permitted by the available market data for each of these applications.

It was originally planned to utilize standard quantitative forecasting techniques to estimate market size and penetration; however, these methods were to be applied only to those application groups which exhibited large market potential when compared to the ERDA production goal of

Figure 2
ERDA TERRESTRIAL SOLAR ARRAY PRICE GOALS - IN 1975 DOLLARS
(Ref. 1)

Figure 3
ADOPTER CATEGORIZATION (Ref. 2)

500 MW_{pk} per year by 1985. The absence of application groupings for which such sizable markets could be projected, and the scarcity of historical sales data on which to base quantitative forecasts, forced modification of original plans. It had been hoped that market substitution analysis could be applied to determine penetration as a function of time. However, in order to produce acceptable results, substitution models require historical data on a specific market, or data on analogous markets within a general industrial grouping. Scarcity of such data available to this study required fall-back to trendline projections, or to expert judgment when trend data were lacking.

Total market penetration, as well as rates of penetration, can also be estimated from interviews with appropriately sized samplings of prospective users, or from responses to properly designed questionnaires. Statistically valid sampling, however, is expensive with either approach, and, in agreement with ERDA, was not undertaken in view of the relatively small size of even the most promising individual market segments uncovered during this study. It is important to note, however, that these markets are only small in relation to the ambitious and challenging goals established by ERDA; they are quite large when compared to current sales of photovoltaic arrays. It is also significant to recall that only U.S. non-military markets were sized and that considerable foreign market potential can be presumed to exist.

The services of a consultant, Dr. R. J. Lutz, Assistant Professor of Marketing at the University of California at Los Angeles, were utilized during the later phases of this study.

SECTION 2

METHODOLOGY

2.1 SOURCES

The initial search for potential applications of photovoltaic power concentrated on past application surveys but was then broadened to include literature references to potential applications as well as to existing uses. Contacts with many additional sources, by phone or visits, resulted in the identification of many more potential applications for consideration, while others were generated in brainstorming sessions by the study team.

In addition to a search of literature available in the Aerospace Corporate Library, a number of external searches were specifically requested in support of this study. The following listing covers the data sources used.

Computer Bibliographies:

- a. ERDA Technical Information Center
- b. Smithsonian Institution Scientific Information Exchange
- c. Solar Application Information Center of the Franklin Institute
- d. NASA Scientific and Technical Information Facility
- e. Defense Documentation Center
(The above searches were conducted to match a number of key terms relating to terrestrial applications of photovoltaic power.)
- f. Transportation Research Board of National Research Council
(This search concentrated on highway and road signs, signals, and lighting.)

Hand Searches:

- a. TID 3351, "Solar Energy-A Bibliography," published by the U.S. Atomic Energy Commission in December, 1974

- b. Science and Engineering Indices available in the Aerospace Corporate Library
- c. Reports and papers stored at the Aerospace Corporate Library

This literature search resulted in the discovery of only two reports, References 3 and 4, which described market surveys of potential terrestrial photovoltaic applications. A number of other reports and papers presented at meetings were also found which discuss a range of applications but are not in any sense market surveys. A list of the applications described in all these references is presented in Table 1. Other references discussing specific applications are listed with the specific market discussions in Section 3. Table 1 is organized to match the application tree structure, also described in Section 3.

Reference 3, the Heliotek report of 1973, was the most extensive market survey found in the literature. It does not, however, attempt to make quantitative forecasts of either a specific or a total photovoltaic market. It does, instead, provide conceptual designs of photovoltaic systems for ten candidate applications and qualitatively selects three applications as most likely of realization. These are (1) educational TV receivers in remote areas, (2) water pumping, and (3) barrier flashers and warning lights for traffic control applications. Reference 4, a translation of a French report issued by the Centre National d'Etudes Spatiales in 1974, covers a smaller range of photovoltaic applications, including a number of applications of particular interest to developing countries. It estimates break-even costs with competing power systems for a variety of application classes, and attempts to forecast a quantitative market as a function of time. It predicts a worldwide market of about 100 MW_{pk} in 1985, reaching about 500 MW_{pk} by 1990. In addition to these reports, an account of a limited application survey was published by the Jet Propulsion Laboratory in 1969 (Ref. 5), but in that study no attempt was made to forecast market size.

With few exceptions, most of the applications mentioned in these surveys are remote and involve small power consumption. Only

Table 1
SUMMARY OF APPLICATIONS CONSIDERED BY
PUBLISHED MARKET SURVEYS
AND OTHER GENERAL REFERENCES

Applications Group	Heliotek (Ref 3)	C. N. E. S. (Ref 4)	JPL (Ref 5)	Other References
1.1 LAND - REMOTE				
1.1.1 Sensors/Data Processing & Transmit	Intrusion Fire Detection Vehicle Detection Gas Accumulation Residential Weather Station * Failure Detection Pollution * Status Reporting Snow Pack Measurement Wildlife/Cattle Monitoring Hydrological Instrum. Camper/Visitor Control Metal Locators Survey Equipment Closed Circuit TV Surveillance *	Vulcanology Hydrology Meteorology Seismology Aeronomy Fire Detection Military	Remote Data Station Weather Hydrology Seismology Pollution	Seismic (Ref 6) Geological, Failure & Status Detection (Ref 8) Measurement of Natural Phenomena (Ref 10) Hydrological, Meteorological (Ref 17), Sounding Balloons (Ref 13) Rain Gauges (Ref 14)
1.1.2 Communications	Repeaters, Emergency Telephone Equipment Rescue, Fire Rail, Air Traffic Control Vehicle Locators Cargo Locators Radio Monitoring & Control Irrigation Control	TV Receivers Portable Consumer Electronics Emergency Telephones Repeaters Transmitters Radio Beacons	Repeaters, Transmitters Highway Call Boxes Fire Call Boxes	Portable Radio (Ref 6) Educational TV (Refs 7, 8, 15, 16, 18) Gas Pipeline Communication System (Ref 17) Microwave Repeaters, Radio Beacons (Ref 18) Portable Radios (Ref 19) Radio Telemetry (Ref 14) Radio Repeaters (Ref 21) Irrigation Control (Ref 22)

* Indicates detailed consideration

Table 1 (Continued)

Applications Group	Heliotek (Ref 3)	C.N.E.S. (Ref 4)	JPL (Ref 5)	Other References
1.1.2 Communications (Cont.)	Water Supply Command & Control Educational TV* Satellite Tele- phone Relays* Lifeguard Tower Radio Forestry Communications*			
1.1.3 Signals	Shore Naviga- tional Aids Road Flashers* Emergency Beacons Billboards Landing Field Lights Traffic Signals	V.O.R., I.L.S. Railway	Shore Navigat. Aids	Shore Navigat. Aid (Refs 6, 10, 14, 21) Navigat. Aids, Shore & Land (Ref 8) Radio Beacons (Ref 18)
1.1.4 General Power/ Lighting	Emergency Lighting Security Perim- eter Lighting Portable Power Refrigeration, Outdoor Appliances Standby Power Battery Charg- ing Water Desalinization Water Pumps*	Battery Charging Electronic Consumer Items Highway Rest Areas Water Pumps Train Dispatch Stations Remote Housing Isolated Industries Copper Refining		Refrigeration (Refs 7, 15) Water Pumping (Refs 7, 8, 9, 11, 15, 22; 23, 24) Small Appliances (Ref 15) Water Purification (Ref 7) Food Processing (Ref 7) Irrigation Control Gate Power (Ref 22) Battery Charging (Ref 19)

*Indicates detailed consideration

Table 1 (Continued)

Applications Group	Heliotek (Ref 3)	C.N.E.S. (Ref 4)	JPL (Ref 5)	Other References
1.1.4 General Power/ Lighting (Cont.)	Insecticide Dispenser Cooking Cabin/Camp Power Fire Tower Power Sanitary Facility Power Sewage Processing Camera Power Mobile Homes			
1.2 <u>LAND - RURAL</u>				
1.2.1 Sensors/Data Processing & Transmit	as in "Remote"	as in "Remote"	as in "Remote"	
1.2.2 Communications	as in "Remote"	as in "Remote"	as in "Remote"	
1.2.3 Signals	as in "Remote"	as in "Remote"	as in "Remote"	
1.2.4 General Power/ Lighting	as in "Remote" plus Swimming Pool Power	as in "Remote" plus Construction Yard Power	as in "Remote"	Cathodic Protection (Refs 8, 22) Village Lighting (Ref 27) Village Power, Rural Workshops (Ref 7) Hospital Power (Ref 7) Food Processing (Ref 7)
1.3 <u>LAND - URBAN</u>	as in "Rural"	as in "Rural" plus Homes, Commercial & Industrial Build- ings, Small Power (1 MW)	as in "Rural"	

Table 1 (Continued).

Applications Group	Heliotek (Ref 3)	C. N. E. S. (Ref 4)	JPL (Ref 5)	Other References
2. AIRBORNE				
2.0.1 Sensors/Data Processing & Transmit	Balloon Surveillance System			
2.0.2 Communications	Aircraft Emergency Location	Balloon Radio Relays, Repeaters, & Transmitters		
3. MARINE				
3.0.1 Sensors/Data Processing & Transmit	Ocean Data Stations	Ocean Data Stations		
3.0.2 Communications	Emergency Radio Radio Beacons	Radio Beacons		Radio Beacons (Ref 18) Life Boat Equipment (Ref 19)
3.0.3 Signals	Navigational Aids Offshore Traffic Control	Navigat. Aids Drilling Platform	Navigat. Aids	Navigat. Aids (Refs 6, 8, 10, 12, 14, 17, 21, 22)
3.0.4 General Power/Lighting	Sailboat Power* Battery Chargers	Sailboat Power Aquaculture Pumping		

*Indicates detailed consideration

Reference 4 listed a generator akin to a central power station but apparently visualized it for on-site power generation since it limited its power level to 1 MW. Reference 4 also estimated housing, commercial building, and industrial markets without, however, providing the data sources on which these estimates were based.

Of the individual large power consuming applications shown in Table 1, water pumping was the one most frequently mentioned as having strong potential (and actual test experience in Russia), usually in connection with remote, relatively undeveloped regions of the globe.

Other applications, not listed in Table 1 but included in the market discussions of Section 3, were derived from numerous telephone conversations and from visits with various government and industrial personnel and with prospective users, as well as from other contacts made in the data search. Where appropriate, the discussions of Section 3 concerning specific applications include reference to such contacts. Most of the data underpinning the market estimates, as well as suggestions for the more promising application concepts, were derived from these personal contacts, many of which were with executive and policy-making personnel.

2.2 TECHNICAL METHODOLOGY AND ASSUMPTIONS

As reported earlier, the decision was made to use the break-even array price as an indicator of the ability of a photovoltaic system to compete with other power generating systems for a particular application. It was also decided to use ERDA array price goals in conjunction with the break-even price to indicate the approximate year in which significant initial use of the system could be anticipated. This approach led to the need to prepare rough conceptual system designs for both the photovoltaic system and its competition. Such conceptual designs had to provide sufficient information on physical and performance characteristics to allow estimation of capital and operating costs. In addition, however, they had to be simple to prepare, since it was assumed that the survey would disclose potential applications which

might number in the hundreds. As a consequence, an adequate approach was judged to be one which uses gross estimates of break-even price only for initial screening against probable competitive power sources. Particularly appealing applications, i.e., those with near-term potential for mass markets, could then receive better design definition if a more precise market penetration forecast were desired.

Duty cycle and average electrical load demand were used to determine the equivalent continuous load of an application. In the instance of the photovoltaic power source, this load value was multiplied by a factor proportional to an integrated insolation value and the size of the desired energy storage to determine the actual size of the array for which break-even costs were to be determined. This array size is measured in watts of peak power, i.e., the power output under standard peak insolation of 1 kW/m^2 . Capacities of other components of the system, such as the storage battery, were directly determined by the equivalent continuous load. For example, a three days' energy storage capacity in kWh is determined by multiplying the equivalent continuous load by 72 hours. Alternative power systems against which the photovoltaic system was to be compared had their sizes and costs determined solely by the equivalent continuous load. This was a simplification, considered justified because it was used only in the screening process, since peak loads, in some applications, can be more size- and cost-determinative than the average load.

All of the applications for which system sizes were determined were assumed to be located in the Southwestern region of the U.S. and to utilize flat panels inclined at an angle equal to the local latitude. Under these conditions, the insolation data available at The Aerospace Corporation indicated that, for the purpose of this study, one can assume that the ratio of peak array power (as defined above) to equivalent continuous load power is approximately 7.2, with some exceptions as indicated in Section 3.

Flat photovoltaic panels without concentration were used in all cases because of the remote nature of most of the applications with sizable

load demand which appeared to have market potential in the near-term. Since the costs of reliable tracking systems for such remote, unmanned locations are uncertain at this time, it could not be concluded a priori that concentrator systems could reduce photovoltaic systems costs in the period up to 1985. The assumption of non-concentrating, flat panel arrays was, therefore, the more conservative course.

Another assumption important to photovoltaic system sizing and, hence, to cost, was that of required energy storage. Again, Aerospace Corporation insolation data specific to the Southwest suggested that the adoption of a standard three-day energy storage requirement (secondary batteries) would meet the needs of this study for rapid screening. This assumption places the photovoltaic system at a cost advantage in other sections of the country with less favorable insolation, and regionally specific market studies must select more appropriate storage periods. The energy storage cost figures used in this study were based, in general, on the assumption that lead-acid secondary batteries were used; for energy storage capacities of less than 20 Wh, however, sealed Ni-Cd batteries were assumed.

Power conditioning equipment for photovoltaic systems was not sized, except when critical to the cost break-even determination. Cost assumptions did include lump-sum allowances for such equipment for both competing systems.

Primary batteries, engine generator sets, and the utility grid were the only competitive power sources against which photovoltaic generators were compared. Primary batteries were assumed to be of the Zn-air type when capacities exceeding 150 Wh were considered. Alkaline cells were used below that level. Discharge to 50% depth was assumed feasible in terms of allowable voltage drop. Gasoline generators were assumed to be used when the required power was 3.0 kW or less, with diesel generators being employed at higher power ratings. Additional assumptions concerning batteries and engine generator sets are included in the discussions of Section 3.2.1.

When the utility grid was the power source against which the photovoltaic system was to be compared, supply at 12 kv AC was assumed to be available from utility power distribution lines. Since all of the applications required lower voltage feed, a transformer would be required, either through purchase by the power consumer as a direct capital cost, or by utility installation reflected in higher subsequent service costs. Most of the applications required DC power, necessitating the assumed installation of a rectifier, for costing purposes, in connecting utility power.

When relatively small applications required an uninterrupted power source, it was assumed that storage batteries were provided as backup to utility power. For larger loads, utility power was backed by engine generator sets and their power rating selected to provide 95% availability. In instances where engine generators were used as the primary power source, backup consisted of engine generators or secondary batteries, depending on the applications. Backup for photovoltaics were batteries, with Zn-air primaries used in a few applications, and lead-acid secondaries in all others, except for very small loads for which Ni-Cd batteries were assumed.

Operating life assumptions were as follows:

20-Year-Life--Photovoltaics, (except in marine applications, where a 5-year life was assumed, or in other specially noted cases) diesel generator sets, and utility power line extensions. The latter assumption again favors photovoltaics in most sections of the country, including the Southwest, where both wood poles and conductors could expect a longer operating life. More precise marketing analyses would make appropriate adjustments for specific geographic regions, or would price residual value as a credit to the utility grid.

5-Year-Life--Secondary batteries, and for shelf-life of Zn-air batteries used for backup.

1-Year-Life--Shelf life for alkaline primary batteries used for backup.

2.3 ECONOMIC EVALUATION METHOD AND ASSUMPTIONS

2.3.1 General

The primary objective of the relatively simple economic evaluations performed during this study was to rapidly screen for further

consideration those potential applications which offered promise of initiating market penetration in the period 1976 to 1985. At the same time, the evaluation was intended to offer a means for dating all potential market entries within this near-term period. The ERDA array price goals as a function of time (Figure 2) provided the means of dating market entry, given the array price at which a photovoltaic system could compete economically with the power system commonly used for the application under study.

Economic decisions to buy are based on considerations which vary with the relative sophistication of the purchaser. Government and industrial/commercial organizations, purchasing more than one unit at a time, would tend toward buy decisions influenced primarily by competitive life cycle costing. In contrast, direct consumers might be influenced primarily by payback period considerations, i. e., they might be persuaded to tolerate a higher initial cost, if this cost increment could be recovered in a relatively short time through operating savings. Since the cost of concern to this study is the cost to the purchaser of the power, or of the system producing the power, cost and price are the same and the terms are used interchangeably throughout this report.

A preliminary review of the potential applications concluded that any substantial near-term applications would involve governmental or industrial customers primarily. It was, therefore, elected to use a life-cycle costing approach. By setting equal the present value costs of owning and operating several alternative power generation systems, a photovoltaic array price was determined, at which the system containing the array could price-compete (cost break-even) with alternate power sources. This competitive array price and Figure 2 data were used to estimate the year in which initial sales might be made. This latter assumption is deliberately simplistic and ignores such non-economic factors as convenience, environmental impact, reduction of dependence on fossil energy sources, absence of operating noise, etc., which might legitimately affect the purchase decision and thus could induce an important buy at higher-than-competitive array prices.

Equations (1) and (2) show the formulations used to arrive at the present-value costs of the systems to be compared:

- (1) Present value of capital investment, CI

$$CI_{pv} = (1 + g)^P \cdot \sum_t \left[CI \left(\frac{1 + g}{1 + k} \right)^t \right]$$

- (2) Present value of a stream of annual recurring costs, RC

$$RC_{pv} = (1 + g)^P \cdot RC \left(\frac{1 + g}{k - g} \right) \left[1 - \left(\frac{1 + g}{1 + k} \right)^N \right]$$

where

p = Number of years from beginning of pricing year to beginning of first year of operation

g = Escalation (inflation plus real cost growth) rate, assumed constant over the life of the system

k = Discount or interest rate

N = Total system life in years

t = years between initial year of system operation and year of purchase

The exponent (t) equals zero when the capital investment occurs in the same year in which the power generation system begins its operation. In the instance of the photovoltaic array, for example, (t) would be zero when total system life and the array life are both assumed to be 20 years. In the case of the secondary batteries associated with the photovoltaic system, with an assumed life of only 5 years, the present value factor $\left(\frac{1 + g}{1 + k} \right)^t$ would be computed for 4 different investment years and then summed before multiplying the one-time investment cost of batteries, CI, to determine the present value of this stream of intermittent investments. The years for which the present value factor would be computed in this example are years 0, 5, 10 and 15, since the total system life was assumed to be 20 years.

The exponent (p) also was set equal to zero for all of the cost break-even calculations, except for the generalized case of engine generators compared to photovoltaic systems described later in this section and in the Appendix. Except for that example, all of the prices and costs were expressed in 1975 dollars in order to match the ERDA price goals of Figure 2, which are in 1975 dollars. Setting (p) equal to zero is equivalent to choosing to carry out the break-even calculation in 1975 dollars and the result is valid for any year of initial operation, provided that the cost elements in the calculation are all escalated at the same rate between 1975 and the first year of operation. In the engine generator case described in the Appendix, the calculation was carried out in 1980 dollars to explore the effect of alternative fuel prices predicted for that year. Wherever break-even array prices are quoted elsewhere in this report, however, even when the alternative is an engine generator, they are expressed in 1975 dollars.

As stated, present-value costs for the photovoltaic system were computed with the cost of the array itself remaining unknown, to be determined when the cost of the competing system was set equal to that of the photovoltaic system. Land costs, site preparation costs, structural costs associated with equipment housing, and so forth, were not included in the capital investment costs assumed for this study (except for the special analysis of generator sets) because the relatively small power level of most potential applications would make these negligible. Costs for photovoltaic system maintenance, such as array washing, also were not included except for the special analysis of generator sets. Engine generator set operating and maintenance costs were included, but were based on manufacturers' data, as discussed in the Appendix, and may therefore be somewhat optimistic.

Cost escalation was assumed to be uniform over the lifetime of all systems installations and covered both inflation and real cost growth. A value of 5% was used for this purpose. The cost of money, the discount rate, was set at 9%, based on bond yields prevailing in early 1976. Present value costs were calculated as of the first year of operation.

The present value of system capital investment costs, as derived by Equation (1), allowed for in-life replacement of components of different operating lifetimes. System lifetimes were allowed to vary for different applications. In some instances, they were determined by operating environment, in others by application lifetimes. For example, in marine applications the life of a photovoltaic array was assumed to equal 5 years, whereas for land use it was assumed to be 20 years. For the sake of simplifying the cost break-even computations, the life of the other photovoltaic system components was assumed not to exceed that of the array, but could be considerably shorter; e.g., the assumed 5-year life of the secondary battery. In the instance of deep gas wells, the assumed life of the photovoltaic system was set by the application at 15 years, the assumed average remaining life of such wells at the time of cathodic protection system installation, although the use environment was similar to other applications in which the photovoltaic system life was assumed at 20 years. In such instances, no allowance was made for residual value of the photovoltaic system. Similarly, when competing against power lines with presumably longer lifetimes than photovoltaic systems, no residual value was allowed the power line.

Cost break-even was not computed for every application surveyed in this study. Rather, related applications were grouped such that the computation of break-even for a typical member of the group would serve to illuminate the probable market entry date of the entire group.

The reader is cautioned to regard market initiation dates determined by relating array break-even costs to the ERDA cost goals represented by Figure 2 as only approximate. For example, in many cases cost break-even has been computed against utility power competition in which the major cost-determining factor is the length of the power line extension required by the application. Break-even costs are almost directly proportional to variations in this length. Since only standard extensions of 1 mile were used in this study, market initiation dates for longer or shorter lines could vary by

several years. For this reason, little emphasis has been placed in this report on estimates of initial penetration dates. Each individual application at its specific site will have a different date at which it will be cost competitive against its preferred alternative power source, even assuming that ERDA array price goals will be met. However, as a general conclusion, for cases where primary battery replacement by photovoltaic systems is realistic operationally, break-even costs are sufficiently high as to make such replacement economic at this time. Initial displacement dates for engine generator power and utility power, must, in contrast, be determined on a case-by-case basis, taking into consideration power level, difficulties of fuel resupply, problems with labor skills associated with specific sites, and, of course, distance from an existing power line.

2.3.2 Cost Assumptions Specific to Batteries

Secondary batteries used for energy storage were uniformly costed at \$50/kWh regardless of storage capacity, except for storage capacities of less than 20 Wh when a cost of \$0.25/Wh of storage was charged for NiCd batteries. Because of the relative modularity of lead-acid cells, this assumption is grossly valid. Primary battery cost assumptions are shown in Table 2.

The general case of primary battery competition with photovoltaic power generation was examined briefly (see Appendix) to provide guidance for the evaluation of individual applications. Break-even cost is, of course, primarily a function of battery cost assumptions. When battery costs are presumed constant regardless of continuous load, break-even cost is also independent of load. When battery costs are allowed to change with load as a result of price reductions associated with increased quantity purchase, a small variability with load results, as shown in Figure 4 for carbon-zinc, alkaline, and zinc-air cells. Against these battery types, photovoltaic systems have been cost-effective for some time.

2.3.3 Cost Assumptions Specific to Utility Power

Because of the large range of power line costs reported in the literature, data were obtained directly from utilities and from customer experience. It was found that flat terrain line costs (for 12 kV service) ranged

Table 2
BATTERY CHARACTERISTICS

Type	Nominal Voltage	Initial Current Drain, mA	Energy, Wh	Unit Price, * \$	Price per kWh, \$ (Retail)
<u>C-Zn</u>					
D Size	1.25	120	0.70	0.20	285.0* (850.0)
C Size	1.25	100	0.40	0.20	500.0*
<u>Alkaline</u>					
D Size	1.25	120	3.2	0.30	93* (280.0)
C Size	1.25	100	1.4	0.30	215.0*
<u>Ni-Cd</u>					
D Size	1.3	800	5.2	1.00	0.75** (1.50)
<u>Zn-Air</u>					
100 Ah	1.5	5000	150	2.25	15.0

*Manufacturer's selling price, FOB Plant, 1973
 **Assumes 1000 cycles, 25% discharge allowed, recharge from house main at 50 mills/kWh. Optimistic, because the average user will discharge to greater depth and thus reduce cycle life. Not to be confused with the cost of storage, which represents a capital investment, not an energy charge.

from \$6000/mile for a middle-western REA utility to about \$15,000/mile for commercial utilities on either East or West Coasts. Power line extensions over hilly or mountainous terrain could range up to \$35,000/mile. Burying the power line can double these costs, so that a buried line in mountainous terrain was, in one instance, reported to have cost \$75,000/mile. However, the break-even costs derived for screening purposes in this study are based on a uniform \$15,000/mile power line cost.

Figure 4
ARRAY BREAK-EVEN COST AGAINST PRIMARY BATTERY
POWER AS A FUNCTION OF LOAD DEMAND
OVER A ONE-YEAR PERIOD

Other costs associated with power line service are those of power conditioning and the actual charge for energy. Table 3 shows the rates charged for electric energy in Arizona for rural commercial service, which were taken as sufficiently representative for the Southwest and thus used for this study.

Other costs include the service connection which is charged at \$250 and covers fuse box, meter holder, outlets, and miscellaneous hardware. AC/DC rectification equipment cost is dependent on voltage and power rating desired, and will range from about \$500 for 100 watts to about \$1500 for 5-10 kW without filtering, and up to \$6000 at 10 kW with filtering. Regulation of DC power to the battery, and from battery to load, is charged at \$20 each for the purpose of this study. If the load is small, the utility will also charge for the transformer from line voltage to 115 V (or other voltage) at \$150-\$200. These rather large investment costs explain why photovoltaic systems for low power loads are so competitive with the energy from the utility grid; they are so even in urban situations where no power line extension is needed and where the application is situated near a power pole or on it. However, when house current at 115 V can be used and is available from a conventional outlet, equipment costs are considerably less, ranging from about \$5 to \$15 for a combined transformer/rectifier at power levels up to 5 W. In such instances, photovoltaic systems are far less competitive.

Table 3
RURAL COMMERCIAL ELECTRIC ENERGY
RATES FOR ARIZONA

Load, kW	Annual Energy, kWh	Annual Cost, \$	Average Cost, Cents/kWh
0.01	87.6	18.6	21.2
0.02	175.2	20.1	11.4
0.10	876.0	55.0	6.3
0.20	1752.0	99.0	5.6
1.0	8760.0	428.0	4.9

As in the case of primary batteries, the general case of photovoltaic system competition against utility power was examined for guidance in evaluating specific applications (see the Appendix). Figure 5 shows the dependence of array break-even cost on power line extension when competing against utility power. The higher the continuous equivalent load to be supplied with arrays, the longer the permissible power line extension. It also indicates that even at power levels as high as 10 W, break-even costs expected to be attained prior to 1980 will favor photovoltaics even if no power line extension is required, i.e., the load is adjacent to an existing 12 kV distribution line. Figure 5 also demonstrates the sensitivity of break-even cost, and consequently initial market entry, to the actual power line extension required by a specific application.

Figure 5
BREAK-EVEN PRICE FOR ARRAY VS UTILITY POWER
AS A FUNCTION OF POWERLINE EXTENSION

2.3.4 Cost Assumptions Specific to Engine Generator Sets

Manufacturers' data were used to develop costs of power from engine generator sets. Table 4 shows equipment prices used in this study. Specific fuel consumption and other cost assumptions pertaining to operating, maintenance, and overhaul costs were the same as those shown for the general case analyzed in the Appendix. The 1975 fuel price was assumed at \$0.40/gal for all of the specific applications evaluated, although for the general case, the impact of higher fuel prices on the cost of generated energy was evaluated. The general analysis reported in the Appendix was used, as in the instances

Table 4
ENGINE GENERATOR SET PRICES

Type of Engine Generator and Rated Power	Average Price in \$/kW (1976 Dollars)
<u>Gasoline Sets</u>	
0-5 kW	200
5-15 kW	320
<u>Diesel Sets</u>	
0-15 kW	350
15-100 kW	185
100-500 kW	120
500-3000 kW	135

Average price
includes: Engine
 Generator
 Base
 Fuel Tank
 Electrical Control

Note (1) Radiator for liquid-cooled sets
 is additive and will be required
 for higher power diesel engine
 sets (above 15 kW)

(2) Equipment is assembled on
 single base.

of the previously discussed alternative power sources, for guidance in the evaluation of specific applications. Figure 6 summarizes the results of this analysis and compares the levelized cost of energy from engine generators to the levelized cost of energy from photovoltaic arrays priced at various levels. The conclusions to be drawn from this figure are summarized in Table 5 and indicate that photovoltaic systems will be able to compete against engine generator power only at low power levels during the near-term period of interest but should be able to capture markets for applications requiring power in excess of 10 kW in the post-1985 time period. This conclusion is based on the assumption that 1980 diesel fuel prices are likely to be in the \$1.00/gal range.

Table 5
AREAS OF COMPETITIVENESS: ENGINE GENERATORS
VS PHOTOVOLTAIC SYSTEMS

1980 Fuel Price, \$/gal	Fuel Price Escalation %	Array Price in \$/W _{pk}			
		0.50	1.00	2.00	4.00
0.50	5	< 1 kW	none	none	none
	10	< 5 kW	< 1 kW	none	none
1.00	5	< 8 kW	< 3 kW	none	none
	10	15 kW plus	< 10 kW	< 2 kW	none

2.4 METHODOLOGY FOR ESTIMATION OF MARKET SIZE AND PHOTOVOLTAIC PENETRATION

Among the objectives of this study was the provision of forecasts on both the size of the cumulative market for photovoltaic systems in the 1976 to 1985 time period and the rate at which such systems would be produced. This required that (a) the market size be determined for specific applications for which photovoltaic systems could be cost-competitive in the near-term period, (b) that the total penetration of such systems into this market by 1985, i.e., the fraction of the total market, be estimated, and finally, (c) that the expected time rate of penetration be estimated.

Figure 6
ENGINE GENERATOR ENERGY COSTS COMPARED
TO PHOTOVOLTAIC ENERGY COSTS

Although a variety of quantitative and qualitative forecasting methods are available to the market researcher, very few of these were found suitable for the purposes of this study. This is because of the lack of historical data on market substitution by photovoltaic systems that would be required for the quantitative methods, and because the large number of applications to be surveyed made the use of the more desirable semi-qualitative methods (such as mass questionnaire mailings, mass interviews, or group objective analysis) impractical in view of limited study resources. It had been planned during the formulative phase of this study to select a few of the applications, those with the largest market potential, for such questionnaire and interview coverage. However, it was subsequently decided in consultation with the ERDA Program Office that the increased precision in market and penetration estimates expected from such primary research efforts did not warrant the added expense, and this final survey phase was cancelled.

Forecasting of market penetration often utilizes substitution modelling techniques by which the fraction of the existing market for conventional power systems to be replaced by the newer technology can be estimated on a year-by-year basis until the maximum expected penetration is attained. However, the simpler substitution models, such as the Fisher and Pry model (Reference 26) require historical market displacement data, to perhaps as much as 10% penetration, before the constants of the logistics curve represented by the model can be estimated with any degree of reliability. More complex modelling techniques exist, such as that described by Blackman (Reference 27) which allow market substitution estimates without historical data, but which rely instead on correlations developed by analogy from related industry data. This approach is time-consuming and requires development of data not available from secondary sources for some of the industries covered by this study. Also, substitution models cannot be used to predict new functions and new needs, whereas the availability of photovoltaic systems could promote such new functions and needs. This approach also was judged unsuitable for a survey covering, with limited resources, so many potential applications and therefore concerned with gross estimates only.

The market sizing and penetration estimating approaches actually used were developed through discussion with a marketing consultant (Prof. R. J. Lutz of UCLA) and tailored to the data available for specific applications or groups of applications. They are described for each such grouping in the detailed discussions of Section 3. In general, where trend data were available, straight-line trend extrapolation was used. When historical data were not obtainable, expert judgment was developed through telephone interviews with prospective users and/or the original equipment manufacturer who might incorporate the photovoltaic system into his product. The solar cell manufacturing industry was not found to be a cooperative source for market data of this type.

In some instances, projected penetration rates, i.e., growth of the photovoltaic market, had to be arbitrarily inhibited by limits on production of the equipment to be used with the photovoltaic system. An example of this is railroad grade crossing signals, whose annual production rate limit was estimated by the American Association of Railroads to be about 5000 units. On the other hand, when good market growth rate data could not be obtained, and when the cost-effectiveness of photovoltaic systems was expected to be much higher than that of the conventional power source, projections of the market growth for such applications were in some cases allowed to equal the 250% annual production growth goal established by ERDA (Reference 2). The inability to use questionnaire or interview techniques, as well as the lack of historical data, prevented any attempt at determining price elasticity effects.

SECTION 3

SURVEY RESULTS

3.1 APPLICATIONS TREE

As mentioned in Section 2.1, current and potential photovoltaic system applications were derived from a review of the literature and from a large number of telephone and visit contacts. Additional potential applications for consideration were generated internally by the study team. However, it was found that brainstorming was not highly productive, as most of the applications identified had already been considered elsewhere, and in some instances, had been adopted. The potentially suitable applications were organized into a tree structure using morphological concepts, i.e., grouping generically related applications into a hierarchical order so that the lower levels of the tree represented sub-groupings of the applications above them. The tree structure served two primary purposes:

- a. Grouping of the applications into generically related sets would assist in reducing the scope of the economic and conceptual design analyses by allowing such analyses to be performed on typically representative applications.
- b. The morphological organization of the tree would assist in identifying similar applications in the various tree domains and would thus help assure that consideration would be given to all viable applications.

Figure 7 provides an overview of the tree organized into the three major application domains investigated in this study - land, airborne, and marine. It also shows an example of detailing of the tree to the 5th level of organization under the "Signals" branch. The definition of "remote" as being more than 10 miles from the nearest utility power line, etc., is arbitrary and was developed merely to indicate that the power line would be a prohibitively expensive alternative energy supply for small loads in remote areas. Similarly, the definition of "rural" in Figure 11 as more than 5 miles from the utility grid

is equally arbitrary and is intended to allow some differentiation between applications on the basis of power line extension costs. The self-evident assumption follows that urban and suburban applications are less than 5 miles from the utility grid line system.

Figures 8 to 13 show additional examples of the tree structure with alternate branches detailed to the 5th level, with Figures 9, 10, and 11 illustrating how the 6th level of organization can be developed. In order to enhance ease of comparison between the land, airborne and marine domains, all applications investigated by this study are discussed in the following sections under the headings shown under the "Land-Remote" domain of Figures 7 through 10, amended as required for the other domains.

The tree structure was found useful in performing its intended function, but is not shown here in its totality because its value lay in its problem-solving characteristics rather than in the contribution it would make to the exposition required for this report. A number of applications which had been identified for one domain did indeed stimulate investigation of similar photovoltaic applications for other domains. For example, emergency locator transmitters, which are required on civil aircraft and had been identified for the airborne domain, prompted investigation of similar devices for marine applications where they were found not yet a requirement for recreational boating.

In some instances, applications are listed simultaneously on the tree under separate headings. For example, "Locators" are shown under both Sensors and Communication because of the differing functional characteristics which such devices may exhibit. In some instances, locators independently sense both the presence and the specific nature of the object of interest and report these data. In others, the locator acts merely as a transponder without an actual sensing function. Because of study resource limitations, not all application groupings received equal attention. This will become evident in the detailed discussions to follow. Generally, minimum study coverage has been given to those applications which exhibit an apparently minimal market potential. Exceptions to this practice are flagged in the detailed discussion by the presence of recommendations for additional effort.

Figure 7

OVERVIEW OF LAND DOMAIN OF PHOTOVOLTAIC APPLICATIONS TREE
WITH DETAIL TO 5TH LEVEL UNDER "SIGNALS"

Figure 8
 DETAIL OF 5TH LEVEL OF LAND DOMAIN OF PHOTOVOLTAIC APPLICATIONS
 TREE UNDER "SENSORS/DATA PROCESSING/TRANSMIT"

Figure 9
 DETAIL OF 6TH LEVEL OF PHOTOVOLTAIC APPLICATIONS TREE
 UNDER "INTRUSION SENSORS"

Figure 10

DETAIL OF 6TH LEVEL OF PHOTOVOLTAIC APPLICATIONS TREE
UNDER "COMMUNICATIONS"

Figure 11

OVERVIEW OF RURAL DOMAIN WITH DETAIL OF 6TH LEVEL OF PHOTOVOLTAIC APPLICATIONS TREE UNDER "GENERAL POWER AND LIGHTING"

Figure 12

OVERVIEW OF URBAN DOMAIN OF PHOTOVOLTAIC APPLICATIONS TREE
WITH DETAIL TO 5TH LEVEL

Figure 13

OVERVIEW OF AIRBORNE AND MARINE DOMAINS WITH DETAIL TO 5TH LEVEL

3.2 MARKETS

3.2.1 Market Generation by Displacement of Batteries and Engine Generators

3.2.1.1 Primary Batteries

The primary battery market was investigated to pursue two objectives: (1) to determine potential new solar cell applications from a review of current battery uses, and (2) to learn whether displacement of battery power by photovoltaic power could lead to a major increase in production of solar cell arrays. Trade associations in the battery manufacturing field and the manufacturers themselves were found to be poor sources of market data. The U.S. Census of Manufacturers (Reference 28) and a private market research report were instead used as primary sources for these data. Additional battery applications were identified on the basis of information from a variety of sources.

Table 6 lists the major categories of primary battery usage in the U.S. today. Of these, the consumer market is the largest. Table 7 shows actual sales during 1973, as well as forecasts through 1985, in the three major primary battery market divisions, with consumer sales at \$251 million, or 73% of the total. As the table shows, the two largest markets within the consumer segment were for lighting and electronic equipment uses. Consumer electronic equipment includes portable radios, cassette recorders, calculators, etc.

Closer examination of these markets discloses that each of the approximately 70 million households in the U.S. in 1973 purchased, on the average, \$3.50 worth of primary batteries annually, of which about \$1.50 was expended on flashlight batteries, primarily Leclanché (C-Zn) D and C size cells. Because of their present low cost, flashlights are being purchased as disposable items, with one-half of the households buying one light each year. Conversion to rechargeable lights is proceeding at a slow rate because of the relatively low cost of both flashlights and Leclanché cells. In 1973, only about 10% of the larger, higher priced lanterns used rechargeable batteries, and these generally replaced more expensive alkaline batteries,

Table 6

PRIMARY BATTERY MARKET CLASSIFICATIONS

- Lighting
 - Flashlights/Lanterns (Consumer, Industrial, Military)
 - Standby (Consumer, Industrial, Military)
- Other Consumer Goods
 - Toys, Games, etc.
 - Calculators
 - Cassette Recorders, Players, Radios, TV, CB
 - Watches, Clocks
 - Photo Accessories
- Emergency Reserve Power
 - Lights
 - Instruments
 - Security
- Military
 - Naval Mines/Sensors
 - Torpedo Propulsion
 - Missile Guidance
- Communications
 - Radios (Industrial, Military), Transceivers, Relays
 - Emergency Location Transmitters
- Signals
 - Nav aids
 - Hazard Signs
- Instrumentation (includes Security)
 - Sensors/Transmitters/Relays/Processors
 - Controllers/Recorders
- Medical
 - Hearing Aids
 - Pacemakers

Table 7
BATTERY MARKET FORECASTS
(in \$Millions)*

(a) <u>Primary Battery Markets</u>	<u>1973</u>	<u>1980</u>	<u>1985</u>
Consumer	251	495	720
Government (includes Military)	50	100	125
Industrial	<u>44</u>	<u>75</u>	<u>115</u>
	345	670	960
 (b) <u>Consumer Primary Battery Market Segments</u>			
Lighting	110	150	200
Electronic Equipment	82	195	290
Other	<u>59</u>	<u>150</u>	<u>230</u>
	251	495	720
 (c) <u>Government Primary Battery Markets Segments</u>			
Conventional	25	47	55
Specialty Military	<u>25</u>	<u>53</u>	<u>70</u>
	50	100	125
 (d) <u>Ni-Cd Battery Market</u>			
Sealed Cells	41	100	160

*These figures are based on the wholesale price paid to the manufacturer (FOB plant), expressed in current dollars. (The corresponding figures for retail sales would be perhaps three times as great, except in the case of government purchases.)

which are more commonly used in lanterns than C-Zn cells because of their higher permissible current drain.

The relatively high rate of growth of Ni-Cd battery sales (~14% per year) in displacing primary cells is due principally to the increased consumer electronics market. Because of the higher energy requirements of

items such as cassette recorders, carbon-zinc cells provide unsatisfactory life, and alkaline or rechargeable batteries tend to predominate. Forecasts indicate that the advent of lithium and other high energy primary batteries during the next five to ten years may, however, tend to reverse the trend to rechargeables, since such batteries will be able to compete on an energy density basis and will possess the convenience advantage of being disposable. Nevertheless, even if the trend to rechargeables continues, the market for photovoltaic rechargers will be determined primarily by cost comparisons with battery chargers powered by house current. Information on sales of battery rechargers was not available to this study. The substitution method of market forecasting could thus not be used, since historical data are required in the preparation of logistic curves.

The consumer market for low cost items is almost totally "first-cost" determined, and life cycle or payback period costing plays practically no role in the buy decision. To equip an ordinary \$3 flashlight with two D-size cells will cost from \$0.60 to \$1 for a total maximum first cost of \$4. To replace these C-Zn cells with Ni-Cd cells would cost about \$4. Household battery chargers operating from house current sell for about \$10 for units capable of charging several cells concurrently. The first cost of a rechargeable flashlight is therefore \$17 ($\$3 + \$4 + \10), and the first-cost disadvantage of a rechargeable flashlight would be $\$17/\4 or about 4 to 1. If one were to consider all of the other battery purchases of the average household, a total of about \$15 in 1973, replacement by Ni-Cd cells plus charger would cost about \$70, a formidable first-cost barrier in the consumer market. The use of a photovoltaic charger would add at least \$25 to this cost at current array prices, but could drop to \$10 by 1985.

Many electronic consumer goods are being delivered with rechargeable batteries which are thus included in the initial purchase price. Most of these, however, include a recharger operating from house current with the initial purchase and no further investment is called for, except for periodic replacement of the Ni-Cd cells, usually required in intervals of several years. Often the life of the Ni-Cd battery exceeds that of the device it powers, if full life of about 1000 cycles is attained.

The market for photovoltaically powered battery chargers for the consumer battery market will, therefore, be confined primarily to the gadgeteer or to remote locations where conventional grid power or diesel/gasoline generator power is not available, and where primary battery retail prices are sufficiently high to make the higher investment in a solar recharger worthwhile. Quantitative data on this specialized market were not available to this survey. Some clues concerning the potential size of a segment of this market may be deduced from the second-home market. Based on the last reported census of second homes, in 1967 (Reference 29), a total of about 200,000 vacation cabins and other remote dwellings may exist by 1985 which will not be equipped with electric power. By 1985, the rate of construction of such dwellings will have dropped to 7500 per year. Most such cabins would be occupied less than 60 days during the year with only about 6% being occupied for more than one-half a year. If one were to assume a probability of 50% for purchase of a solar cell powered battery charger for those cabins enjoying the longer occupation period and only 10% for those experiencing short occupancies, such as from a few weekends up to several weeks per year, the total cumulative market may reach about 25,000 chargers by 1985. At 0.3 W per charger, the array peak wattage required by 1985 would amount to about 7.5 kW_{pk} , with the annual rate probably at about $1 \text{ kW}_{pk}/\text{year}$.

Information on primary dwellings without electric power was not available to this study. However, the poverty level indicated by the absence of any electric power probably would not make such households candidates for the relatively high first-cost investment represented by a photovoltaic battery charger and by the devices using rechargeable cells.

Other remote applications for portable lights and consumer electronics include camping, using recreation vehicles or tents. Although about 1 million campsites suitable for vehicular camping are available in the U.S., plus an unknown number of hike-in sites, such camping is generally of such short duration that battery replacement or recharging is not required. The photovoltaic battery charger market would not therefore be materially

increased by such applications. Other recharger markets, such as for industrial applications and for recreational vehicles and sailboats, are discussed in other sections of this report dealing with specific market segments.

It is concluded that, although real life cycle cost advantages exist in operating portable consumer lights and other portable consumer electronic devices with rechargeable batteries instead of primary batteries, considerations of first cost, availability of house current chargers, and the relatively small number of remote sites make the consumer market for photovoltaic battery chargers small.

Direct substitution of solar cells for primary batteries without involvement of rechargeable batteries would seem to offer no measurable market potential for the applications in the consumer market. Such a photovoltaically driven device could operate only during daylight hours, immediately eliminating the largest market, lighting, and thus perhaps restricting such applications to a limited number of toys. Industrial and scientific primary battery markets may exist where power use could be restricted to periods of insolation. This market is believed to be very small.

Industrial and commercial uses in which primary batteries could be replaced by rechargeable batteries associated with a photovoltaic power generator are discussed in the sections of this report dealing with specific applications.

Military applications were not specifically investigated during the course of this study since this would have duplicated the effort undertaken by the U.S. Army (Mobility Equipment Research and Development Command) for the Federal Energy Administration. However, some insight into the size of the potential military market for photovoltaically recharged secondary batteries can be gained from the sales data shown for conventional primary batteries in Table 7c. Specialty military sales should not be considered since these are for applications where recharging is normally not feasible, such as for torpedoes, missile guidance and telemetry, space applications, etc. Table 2 provided performance and cost information on commonly used primary

batteries. Considering the government expenditures in 1973 of \$25 million for conventional batteries, and assuming that the military uses a higher proportion of alkaline and other higher quality batteries than does the consumer market, about 50% as against 15%, it can be computed that the military conventional primary battery purchase for that year provided for about 200,000 kWh of energy at an average cost of \$130/kWh.

Replacing primary batteries with rechargeables delivering energy costing in the range of \$1/kWh, as shown for Ni-Cd batteries in Table 2 would, therefore, seem to be economically advantageous. The feasibility of doing so in a military environment is, however, not solely determined by economics. Even if a considerable replacement of primary batteries does occur, the number of photovoltaic rechargers required is more likely to be determined by the Tables of Organization of the military entities involved, and/or pieces of equipment such as radio sets, than by other factors, since rechargers will have to be physically close to the battery user to meet field logistics requirements. The relatively small quantity of energy supplied by these batteries, however, would indicate that the array wattage to be purchased for this application would not constitute a sizable market and would probably be, at best, in the order of tens of kilowatts per year. At least two U.S. manufacturers are already marketing solar battery chargers for military field use. In addition, the U.S. Army Mobility Equipment Research and Development Command has demonstrated a photovoltaic battery charger capable of recharging a number of D size Ni-Cd cells simultaneously. This was one of five demonstrations of military photovoltaic applications that were completed in FY 1976 as a result of a joint ERDA/DoD effort.

To sum up, displacement of primary batteries for the consumer or government market by direct photovoltaic power appears to be negligible. On the other hand, replacement of such primary batteries by secondary batteries recharged by solar cells is estimated to represent a civilian market between 10-20 kW_{pk} cumulative by 1985, with annual rates of sale at the 2-4 kW_{pk} level. These totals include the rechargers for secondary homes estimated earlier and an estimate of rechargers purchased for novelty for a variety of consumer applications.

3.2.1:2 Secondary Batteries

In contrast to the primary battery market, photovoltaic power generation would not displace storage batteries (although in some instances it might reduce the amount of energy storage required) but would mainly replace current methods of either recharging storage batteries, or would provide a means for float (or trickle) charging during periods of non-use. Table 8 shows the secondary battery market segments in actual manufacturers' sales dollars during 1973 and as forecast through 1985. Most of the applications contained in these market segments, shown in Table 9, use battery power already in association with means of convenient recharging, e.g. with engine alternators in the case of the starting, lighting, and ignition (SLI) battery market. In the motive power market, in which batteries drive electric motors,

Table 8
SECONDARY BATTERY MARKETS
(In \$Millions)

	<u>1973</u>	<u>1980</u>	<u>1985</u>
SLI*	800	1515	2150
Motive Power**	96	250	655
Government	54	85	104
Standby	49	90	135
Consumer (Non-SLI)	51	105	150
Others	<u>10</u>	<u>15</u>	<u>16</u>
Total	1060	2060	3210

* Non-automotive applications only \$42 million in 1973. Original Equipment Market only about 25% of total in '73, or \$200 million.

** Electric passenger cars may constitute a \$280 million market by 1985, included in the figure shown.

Table 9
SECONDARY BATTERY MARKET CLASSIFICATIONS

- Starting, Lighting, Ignition (SLI)
 - Cars/Trucks
 - Boats
 - Golf Carts, etc.
- Motive Power
 - Industrial
 - Fork Lifts
 - Mine Cars, etc.
 - Passenger Cars
 - Garden Tractors, etc.
 - Locomotive (Yard Engines)
- Consumer
 - Cordless Products
- Standby
 - Security
 - Lighting/Air-conditioning (Buildings, Railroads, etc.)
 - Communications
 - Signalling
- Railroads
 - Switch Gear
 - Signalling (not standby)

and in the standby market, in which secondaries are float-charged, the prime power sources are either the utility grid or diesel/gasoline generators. Thus photovoltaic generation would not result in a reduction in required battery storage capacity. A relatively small signals market, including railroads, is an exception to this generalization. A few other applications might exist in which secondary batteries are either recharged from portable equipment brought to the site or are replaced and recharged at a central location.

Float charging would appear to offer opportunities to photovoltaic power in a number of use areas. Forklifts and power-operated construction equipment often stand idle for several days in regions where grid power is not available. Civil aircraft also tend to be operated infrequently, and perhaps as many as 80% of the 170,000 general aviation aircraft in the U.S. are not in hangars where utility power for trickle charging might be available. Among non-automobile SLI battery uses, applications such as recreational boats and snowmobiles experience long periods of idleness and may benefit from float charging by photovoltaics. Golf carts and most garden tractors, on the other hand, probably have more convenient grid power available for this purpose. Another section of this report considers the sailboat market and the recreational vehicle market for float charging by photovoltaics. No investigation of other segments of this market was made during this study because the total magnitude of this market is limited by the relatively small power rating associated with float chargers, which can accomplish their functions at ratings as low as 0.2 to 0.3 W. For example, as discussed in Section 3.2.3, 170,000 general aviation aircraft would produce a cumulative market of only about 20 kW_{pk} and an annual rate of production of about 5 kW_{pk}.

The market for full charging of batteries by photovoltaics has somewhat different dimensions from those of the float-charge market although quantitative data could not be developed for this study. Cordless consumer articles are not promising prospects since the vast majority of these devices are sold with inexpensive rechargers operating from house current. As discussed in the previous section, no appreciable market has been found in remote regions where grid power would not be available. Similarly, although secondary batteries provide motive power in rural and urban markets for electric forklifts, industrial trucks, and mining and industrial locomotives, almost all of this equipment is recharged from the utility grid and photovoltaic array prices of \$0.50 per peak watt or less are required to compete.

Gasoline or diesel generators are available to recharge in the more remote regions. However, as Figure 6 indicates, at array prices of from \$2 to \$1 per peak watt in the 1983 period, photovoltaic generators could displace diesel power for this application. Yet, in remote regions, pollution is not a driving force toward electric motive power as it is in urban areas and in enclosed spaces, except in mines which use battery-powered locomotives and other equipment underground. For other remote applications, poor availability of fuel, or the more difficult logistics of fuel supply, might provide incentives toward the higher initial investment of battery motive power associated with photovoltaic recharging equipment. This study did not obtain data to permit sizing of this motive power market segment. Electric passenger cars, although potentially a large battery recharger market, have not been evaluated as a photovoltaic market for the near-term for similar reasons.

The float charge applications not separately identified in other sections of this report may add another 10-20 kW to the total cumulative market by 1985, and may increase 1985 production by 3-5 kW_{pk}. These estimates are included with those of Section 3.2.5.

3.2.1.3 Engine Generators

The market for gasoline and diesel generator sets was investigated to determine potential areas of application for photovoltaic power generation, as well as to develop estimates of markets resulting from displacement of engine generators. Data sources consisted of direct contacts with the generator set industry, publications of the U.S. Census Bureau (Current Industrial Reports), and a private market research report.

Table 10 summarizes the application categories in which engine generator sets are finding their major use. Table 11 indicates that the largest number of gasoline engine generator sets sold are in the low-power range, with about 87% of those sold in 1975 at rated power levels less than 5 kW. Almost 99% of the sets sold were at rated power levels of less than 15 kW. This is in contrast to diesel generator sets in which only about 30% of the sets sold were at ratings less than 15 kW. The next two diesel size categories added together amount to about 60% of the total market. The diesel generator market, although smaller in number of units, is about eight times larger than the gasoline generator market in power displacement potential. The rated power summed over the gasoline generator sets sold in 1975 was about 750 MW while that of the diesel generators was 6000 MW. In spite of its smaller fossil fuel displacement potential, the small gasoline generator set market may be more promising for near-term photovoltaic displacement.

Based on the simplified assumptions underlying Table 5 previously discussed, substitution of photovoltaic power systems for diesel generators exceeding 15 kW in continuous load rating could take place when array costs drop to \$0.50/peak watt and when 1980 fuel prices rise to about double the current price and continue to escalate at 10% per year. Smaller loads permit photovoltaics to be competitive at lower fuel prices and lower escalation rates. Gasoline generators in the 0.5 kW to 3 kW range could be displaced in continuous duty applications at higher array prices than here indicated for diesel generators. This is due to the higher cost of fuel for

Table 10
GENERATOR SET MARKET CATEGORIES

- Agricultural
 - Baseload, peaking & emergency power
- Second Homes, Recreational Camps
 - Baseload, peaking & emergency power
- Public & Commercial Buildings, Multi-family Complexes
 - Emergency power, total energy systems
 - Modular Integrated Utility Systems (MIUS)
- Municipalities
 - Baseload, peaking, back-up, emergency power
(prime power and water and sewage systems
standby)
 - Total energy, MIUS
- Industrial
 - Baseload, peaking, back-up & emergency power
- Private Homes
 - Emergency power
- Miscellaneous Remote Power
 - Radio relays, highway maintenance stations,
construction sites, large nav aids (land,
marine), offshore platforms, mobile power
applications (such as for disaster relief),
military test sites, and tactical military
applications, etc.

Table 11
GROWTH OF ENGINE GENERATOR MARKETS

<u>Type of Engine Generator</u>	<u>No. of Units/Year</u>		
	<u>1975</u>	<u>1980</u>	<u>1985</u>
<u>Gasoline Engine Sets</u>	<u>225,000</u>	<u>250,000</u>	<u>275,000</u>
0-5 kW	195,000	215,000	240,000
5-15 kW	30,000	35,000	35,000
<u>Diesel Engine Sets</u>	<u>22,000</u>	<u>30,000</u>	<u>38,000</u>
0-15 kW	6,500	8,400	10,500
15-100 kW	6,900	9,000	11,400
100-500 kW	6,300	8,600	11,500
500-3000 kW	2,300	4,000	4,500

such generators, which produce electric energy at costs 1.5 to 2 times the cost of energy from diesel generators. However, most current gasoline generators are produced for standby and emergency duty, with shorter service lives than assumed for these calculations. Data on the segmentation of this market into baseload, peaking, and standby applications could not be obtained prior to termination of this study, making penetration estimates uncertain.

Because baseload and peaking loads appear to be more likely applications for photovoltaic power (with either engine generator or battery storage for backup) than do the standby and emergency loads, Figure 6 was based on the assumption of continuous duty, as stated earlier. Generally, backup applications require immediate load transfer, except for portable emergency power for disaster relief. Such instant availability would, in the case of photovoltaic power, require relatively large battery backup capacity, essentially capable of carrying the load for, at a minimum, one-half day

before recharge by solar arrays could be assumed to begin. At worst, battery storage capacity equivalent to several days of load demand would be required to allow for uncertainties in insolation at specific sites. At the 5 kW rating, such storage by itself (without the photovoltaic generation system), assuming continuous duty and full load backup, would cost \$6000 of initial investment per day of storage. The same backup capability could be provided by a gasoline or diesel generator at a first cost of about \$1800 and an operating cost of about \$50 per day.

Emergency generator applications, in which power is only produced infrequently during the year, are therefore unfavorable prospects for photovoltaic power generation systems. The considerably higher first cost of such systems predominates in life-cycle costing of infrequently used systems, and will make the present-value cost of the system considerably higher than that of either a gasoline or diesel generator power source.

Baseload or peaking load applications, on the other hand, with duty cycles ranging from 100% to 50%, approximate the conditions explored by Figure 6 which, as stated earlier, indicates that break-even array prices attainable prior to 1985 would permit some limited economic competition of photovoltaic power with engine generator power. However, the number of such applications in the low power regime could not be estimated. A limited-effort survey indicated some remote baseload applications which would be satisfied at levels of power between 1 and 5 kW. These include remote housing, remote radio relays or base stations not accessible to utility power, some air traffic navigation systems, a few irrigation applications, recreational facilities and others as discussed in other sections of this report. A much larger baseload and peaking market exists at power levels exceeding 15 kW in size but predicted array price break-even costs would not permit this market to be penetrated until after 1985. To the extent that total energy concepts could increase the break-even array price up to and beyond the \$2 per peak watt range, this market could be initiated prior to 1985. Total energy in this context encompasses utilization concepts in which by-product

thermal energy resulting from cooling of concentrator-type photovoltaic systems is sold to applications capable of benefitting from the relatively low (less than 180°C) temperature of the coolant. Space heating, absorption refrigeration cycles, and some industrial processes would be examples of such applications. As shown by Table 10, many of the engine generator applications already involve total energy concepts or are prospects for such systems. However, power levels for such installations would be in the megawatt range.

Foreign applications, particularly in developing countries, could have fuel economics considerably different from those assumed for the U.S. They probably would experience higher operating and maintenance costs because of lower labor skill levels and higher initial investment and replacement parts costs, and would therefore tend to favor earlier realization of array price break-even than would domestic applications. Investigation of these markets was excluded from this study but is recommended for the future.

3.2.2

Sensors/Data Processing and Transmission Markets (1.1.1 in Applications Tree)

The market segments under this general heading are shown in outline on Figure 8. Applications included in this grouping cover power for devices sensing a variety of natural phenomena or events, or physical and chemical conditions associated with man-made systems. Some of the applications merely record the sensed data, others process and record, still others will transmit the sensed data, or the processed analog, to collection stations via radio, using direct line-of-sight transmission, land-based relay or repeater stations, or satellite repeater systems (References 32-35). These applications exhibit common characteristics in that they are often remotely located, almost always require both low average as well as low peak power, and usually are required to operate in an automatic mode. Another common characteristic is the normally intermittent collection, processing, and transmission of the sensed information, with the highest power consumption occurring during transmission, but only over relatively short periods of time. The largest power level requirement appears to exist for meteor burst transmission systems, reaching a level as high as 350 W of transmitter power for periods of time measured in microseconds. Minimum power requirements for transmission appear to range in milliwatts when land-based repeaters are used for relay to the data collection station. Satellites can detect signals with radiated power of about 1 W, even at synchronous altitudes. In general, this application class is probably the most likely to see large use of photovoltaic power, and has already experienced sizable penetration. However, even though perhaps hundreds of thousands of individual sensing and transmission systems may eventually be powered by solar systems, the total array area required will cumulatively not exceed 2 MW peak. Table 12 summarizes the size of the market identified for this applications group.

Table 12
SUMMARY OF MARKET FORECASTS FOR SENSORS/
DATA PROCESSING/TRANSMIT

Application	Array Size, in peak watts (average)	Cumulative Power by 1985, in peak watts	Sales in 1985, in peak watts
Intrusion Detection	35-200 mW per ft of perimeter	1.3×10^6	120×10^3
Earthquake Observation	2 W per station	9×10^3	3×10^3
Environmental Observation	4 W per station	34×10^3	6×10^3
Total		1.35×10^6	130×10^3
<p style="text-align: center;"><u>Potential Markets for Which Forecasts Were Not Feasible</u></p> <p style="text-align: center;">Fire Detection Approach Sensors Pollution Monitoring Status Sensing for Water Utilities Location Sensors</p>			

3.2.2.1 Intrusion Detection Systems

3.2.2.1.1 General

A variety of sensing systems fall under this classification. Reference 36, although discussing military uses, provides an overview of systems similar to those required for civilian applications. Figure 9 lists the variety of sensing devices currently available to detect passage of people or objects over the perimeter boundaries of a variety of sites. In addition

to the land sites shown on this figure, marine applications would include offshore platforms. Military marine applications have special requirements which often prevent the use of solar power because of submergence of the sensors and their associated systems. They were not considered by this study for this and other reasons.

Intrusion sensor requirements were determined from contact with a number of industrial suppliers of such equipment.

These contacts included:

Honeywell
GTE Sylvania Security Systems Group
Kinometrics, Inc.
La Barge, Inc., Electronics Division
COHU, Inc., Electronics Division
Stellar Systems, Inc.
RCA Laboratories
Air Space Devices (Norton Co.)
Teledyne Geotech
General Dynamics Electronics Division

The following assumptions, used in the conceptual design of photovoltaic power supply systems, were based on industrial data. The units shown are those in which instrument power needs (continuous) are commonly quoted:

Pressure sensors — 150 microwatts per 300 feet of line
Vibration sensors — 4 W per 1000 feet of fence or wall
Capacitance (E-field) sensors — 4 W per 1000 feet of line
or fence
Infrared sensors — 0.5 W per 150 feet of line of sight
Video — 20 W per 500 feet of line of sight

In addition to the sensors, power is required for data transmission, and in some instances, for the receiver, monitor, and display associated with the

entire intrusion detection system. The latter, however, is more likely to be located near utility power supplies. Transmitter power generally varies from milliwatts for low data rate systems to perhaps up to 5 W for video signal transmission. This power is, of course, also a function of range, or of link distance if relay stations are used. From 15 to 20 W of power will be required for monitoring stations involving CRT displays.

3.2.2.1.2 Specific Markets

National Borders. Information on both currently emplaced and projected future installation of detection systems along our land borders was obtained during a visit with the Immigration and Naturalization Service. A number of such systems are already in place, and sensors are generally battery powered because the Service considers it necessary to provide covert emplacement for most of the sensors used and is not aware of means to utilize solar cells without compromising both the presence and location of the sensor. As a consequence, photovoltaic power has been considered by the Service only for the repeater stations which relay sensor signals to sector headquarters. Such repeaters are commonly operated by battery, although in February of 1976 one solar-powered repeater station was already in operation and three others had been authorized and were in process of procurement. Under the assumption that camouflaged solar cells, or other means for covert use of photovoltaic devices, could be developed, and estimating from data made available by the Service, the total market for arrays, under the assumption of about 5.3×10^6 feet of border utilizing sensor systems, is forecast not to exceed $200 \text{ kW}_{\text{pk}}$ for sensors and repeaters for both the northern and southern borders of the U. S. On the basis of expert judgment, a maximum of 50% penetration of this market can be expected, or $100 \text{ kW}_{\text{pk}}$, even though array break-even costs are about $\$200/\text{W}_{\text{pk}}$ when traded against primary batteries. Rate of penetration is expected to be slow. Funding constraints and the need for development of arrays capable of covert emplacement will probably constrain total emplacement to occur no earlier than 1985, with the annual rate of sales during that year not to exceed $20 \text{ kW}_{\text{pk}}$, including the power requirements of repeater stations.

Other Applications. Some of the other sites on which intrusion sensors are often used include remote storage depots such as for highway maintenance tools and supplies, test sites (both civilian and military) which require notification of human intrusion to prevent accidental injury due to test activities, nuclear generation and waste disposal areas, watershed areas and reservoirs where intrusion may relate to potential sabotage, prison farms and similar outlying facilities which may consist of large fenced-in areas, and so forth. For many of these sites, buried or otherwise covertly emplaced sensors are as applicable as to national borders in order to prevent deactivation of the intrusion warning system. In many others, however, the visible presence of perimeter protection devices is considered valuable as a deterrent. These latter systems have special potential for utilization of photovoltaic power sources, even within rural or urban areas. For example, sensors operating at power levels of milliwatts for detection, data processing and signal transmission are often powered by primary batteries, even though within the immediate vicinity of a utility grid, for either economic reasons or because of the added security of an independent power supply. As pointed out in Section 2.3.3, power line connection alone may cost as much as \$250 even without line extension. Minimum power charges per year often far exceed the cost of battery replacement. In addition, conductors from the power source to the sensor package may require burying, at costs ranging up to \$3 per foot for trenching, conduit, conductor, and backfilling, even for low voltage systems. Sabotage of the power line to the site would inactivate the detection system unless backup power, usually secondary battery standby, is provided at added cost. Photovoltaic power supplies in the milliwatt-to-watt range, complete with storage and RF signal transmitter, could be produced at costs between \$50 and \$100 for most of these applications. No attempt was made to estimate specific break-even costs for such applications because of the great extremes in power level, detection system sensitivity, range from sensor to control station, etc., which are encountered within this application group. Discussions with

representatives of the security industry tend to lead to the conclusion that break-even costs are equal in magnitude to those generally determined for primary battery powered devices, i. e., \$150 to \$200 per peak watt. There seems to be awareness of the potential of photovoltaics for application to such devices within the industry. A substantial market may be available when areas of uncertainty concerning reliability, environmental stability, resistance to vandalism or deliberate sabotage are clarified or removed through demonstration and actual field application experience.

Attempts to size this potential market met with difficulty because of lack of published secondary data sources concerning the number of sites, perimeter lengths, and special requirements associated with classes of applications. Trade associations in this field are not communicative concerning market data. Two such associations were contacted for data, the Security Distributors and Manufacturers Association headquartered in Los Angeles, and the National Burglar and Fire Alarm Association in Washington, D. C. Only the latter had a publication addressing this question (Reference 37) and it proved to be a nonquantitative discussion of this market.

Two of the industrial organizations contacted were willing to discuss results of private market surveys conducted for them by professional market research companies. Although this information is used here, it must be cautioned that the market is highly competitive and the reported data were purchased initially at private expense. Nevertheless, they were the only such data available to this study. On the basis of these data, and under the assumption of a 30% penetration by photovoltaics, a total of six million feet of perimeter could be protected by 1985, representing a cumulative market of about 1.2 MW_{pk} by 1985. Sales of about 100 kW_{pk} per year might be possible by 1985, with levels of 200 kW_{pk} reached in 1982, believed to be the peak year for security installations. Industry marketeers point out that the security market has greater potential overseas where sabotage and crime are more prevalent, and where, particularly in newly developing countries, the need for protecting newly established industries is greater.

In addition to perimeter protection, space protection sensors may also be used. However, such applications will be relatively rare in remote areas, and relevant market data were not available to this study. Space protection systems would apply to the interiors of warehouses, industrial complexes, schools, etc., and could use acoustic and microwave sensing systems as well as closed circuit television.

3.2.2.2 Fire Detection

Sensors for detection of incipient and actual fire conditions were considered to be candidates for photovoltaic power primarily in the remote and rural application domains. Two potential applications were found to be of interest on the basis of literature references and industrial contacts. Fixed automated fire detection systems in remote, forested areas appeared to offer advantages, regardless of power source, until contact with cognizant personnel in the U.S. Forest Service indicated that fire towers and other fixed observation stations, manned or automated, might be in process of being phased out. It appears that aircraft-based fire surveillance is considered more effective than are fixed ground-based systems by some service personnel (but not by all), not only because canyon-bottom fires are more easily detected by such means but also because the aircraft-based systems serve a dual function in providing tactical fire data during fire suppression activities. Some research on IR fire detection from fixed sites is still being carried out in a cooperative program between the Forest Service and the University of Pennsylvania, but exact information on future plans of the Service for remote, automated detection systems could not be obtained.

The Forest Service currently operates about 1500 lookout towers nation-wide. Information on the number currently on utility power would require contact with individual regions and districts of the Service. The power required for these lookouts is not for sensors but for housekeeping functions such as lighting, refrigeration and heating, and for the operation of a radio communications system. Demonstrations of the use of photovoltaic

power for this application have been designed and installed by NASA Lewis Research Center under sponsorship of the ERDA Photovoltaic Program at two such lookouts in California, and have been sized at 300 W_{pk}. They do not provide heating. Lewis Research Center also determined that array break-even costs of about \$7 per peak watt would be competitive with currently used engine generator or battery power sources. If it were assumed that 50% of these lookouts are not now on utility power, the total cumulative market for this application would therefore be about 230 kW_{pk}, assuming 100% penetration by photovoltaics of this fraction of the lookouts, a reasonable assumption only if the buy decision were to be made by a central authority within the service. As mentioned earlier, the possibility exists that the number of lookouts would be reduced in the future either through more extensive use of aircraft-based systems, or through the development of effective ground-based automatic fire detection and reporting systems.

Railroad engineering personnel indicated an interest in remote detection of hotboxes (overheated journal bearings) on rail cars. These commonly are detected by IR systems which are now emplaced only in locations where utility or in-house generated power (engine generators) is available. Power requirements of units currently in use appear to range up to 500 W continuous and, in some locations, 24-hour operation is required, making the use of primary batteries impractical. The use of photovoltaic power sources would permit remote location of such detectors. When coupled with train detector systems which would activate the IR detector only when needed, array sizes might be of economic proportions for the near term. No data on market size for this application were obtained. This potential application and a number of other railroad applications discussed under different headings in this report appear worthy of further investigation.

Other remote fire detection systems appear to have utility in oil and gas production fields and offshore platforms, where remote control operation is already in development. Similarly, remote storage facilities

such as highway maintenance depots or test site depots would find fire sensing as useful as intrusion sensing. No market data have been obtained for these applications.

3. 2. 2. 3 Earthquake Sensors

The data on sensor usage, both current and forecast, for earthquake detection was obtained in contacts with the California Institute of Technology Seismological Laboratory, the Seismological Measurements Branch of the United States Geological Survey (USGS), and instrument manufacturers.

Earthquake sensors are primarily accelerometer devices buried in concrete vaults at fault lines and in other areas of seismological interest. Instrument power averages about 50 mW on a continuous basis. Most of the currently used instruments transmit data over telephone lines, and thus only instrument power is required. When radio data transmission is used, about 200 mW of power is required during operation. Transmitters using photovoltaic power are already in use and are equipped with 2 W_{pk} array panels. Other transmitters are on battery power, using 1000 Ah capacity Zn-air cells, up to five units per installation, and requiring replacement on an annual basis. About 500 such seismic stations are currently in use in the U. S. , with about 50% of these utilizing radio transmission. If the Congress acts favorably on currently pending legislation, the total number of such stations eventually in place in the U. S. may range from 2500 to 5000, with annual installation rates ranging from 100 to 500 units. If data transmission via satellite link is instituted (currently under study), the power draw of each station would increase. Radio is preferred to telephone links in order to reduce the potential disruptive effects of earthquakes on data transmission. Laser ranging instrumentation is also in use but only to a limited extent, and then only for special research purposes not involving extended periods of unmanned operation.

On the basis of these data, the total market by 1985 is estimated at 5000 stations. Assuming a 90% penetration by photovoltaics, at

array break-even costs between \$150 to \$200 per peak watt, the cumulative array peak power installed by 1985 is estimated at 9 kW_{pk} with an annual rate of sales in 1985 reaching 2-4 kW_{pk} , for this market.

3.2.2.4 Approach Sensors

Remotely installed sensors for detection of moving objects are currently in use on railroads for activation of block signals and of grade crossing gates and signals. Research and development appears to be under way to develop sensors for highway applications where they would also activate warning signs and traffic control signals. Sensors can be used not only to detect the approach of a moving object and measure its speed but also to provide a cumulative count of the number of vehicles which pass a given point. Many railroad installations are in areas remote from utility power or there is a requirement for independence from external power supplies, and they are therefore powered by primary batteries.

When a railroad approach sensor is used merely to trip a block signal or to activate older types of grade crossing signals, simple shunt detectors are used on the rails. These are primary battery-powered and draw about 150 mA continuously at 1 V. Newer installations at busy grade crossings use motion detection systems which are also capable of determining the speed of the approaching train and thus will correlate the time of gate closing and opening more accurately with requirements. These systems require, on the average, a continuous supply of 5 A at 10 V. Approach systems used in conjunction with grade crossing systems are treated for market forecasting purposes as part of the gate and lights installation, and that market is sized in Section 3.2.4 of this report. Hundreds of thousands of trip switches are used for purposes such as block signalling on railroads, however, and could constitute a market of several kW_{pk} (cumulative). No information on likely penetration could be obtained, however.

Approach sensors associated with highway signals are counted as part of the market for such signals, as discussed in Section 3.2.4. No data could be obtained on the number of highway traffic counters which might become a market for photovoltaic power.

3.2.2.5 Environmental Sensors

Data on environmental sensor requirements were obtained in contacts with the Forest Service, the Environmental Protection Agency (EPA) in Washington and its laboratories in Las Vegas and Research Triangle Park, the Corps of Engineers, the Water Resources Division of the USGS, the Bureau of Land Management (BLM), the Soil Conservation Division of the U. S. Department of Agriculture, and the Basic Observations Branch and the Data Buoy Office of the National Oceanic and Atmospheric Administration (NOAA). In addition, contact was made with La Barge Electronics Division, a manufacturer of data platforms and radio transmission systems, and the Comsat General Corporation, currently testing satellite data transmission systems tailored to remote instrumentation applications. The Lawrence Berkeley Radiation Laboratory was contacted for data on pollution instrumentation. The Electronics Division of General Dynamics Corporation provided information on ocean data stations. References 39-45 contain information on various requirements for remote power supplies for land and ocean environmental sensing and data relay.

The remote land-based weather instrumentation sites controlled by NOAA utilize either the Remote Automatic Meteorological Observation System (RAMOS) or the Device for Automatic Remote Data Collection (DARDC) data platforms. Both use telephone, VHF radio, or UHF satellite data links, with about half of the currently emplaced stations employing telephone links. About 20 remote RAMOS stations are planned, with an advanced RAMOS system under consideration. If the latter should be developed, from 80 to 90 of these would be deployed in remote locations and would require independent power supplies. The DARDC system is smaller, measures only 2 or 3 parameters at a time, but will be emplaced in numbers approaching 4000. Most of these will be in remote locations and will be prime candidates for photovoltaic power. Advanced RAMOS will require about $10 W_{pk}$ panels, while DARDC requires $2 W_{pk}$ panels.

Photovoltaic power is already being demonstrated with RAMOS by NASA Lewis Research Center under ERDA funding, and DARDC is being sold with a photovoltaic option.

Ocean-based instrumented platforms are not yet in mass use, and planning data made available do not indicate future mass utilization. NOAA estimated that they will have no more than 20 data stations on stationary, moored platforms. Drifting buoys are also used by NOAA, but these are relatively simple, one-shot devices which are not recovered, and are therefore destined to remain battery-powered. Average power requirements for the moored platforms is about 11 W. At least one of these platforms has already been equipped with solar panels and is currently undergoing testing in the Gulf of Mexico.

A number of other ocean data platforms are being used by governments, both U.S. and foreign. These include the ESB (Environmental Service Buoy), the SODS series (Small Ocean Data Station), and the LNBY series (Large Navigational Buoy). The latter is primarily a light-ship replacement, although weather instrumentation is often included. The SODS can be used for inland water pollution sensing and for environmental data acquisition in coastal zones, as well as for open ocean operation. Of these, only the SODS stations are battery powered, with diesel engine generator sets powering the larger stations. Only a small number of these larger stations are in use, with only 6 ESBs built so far and another 36 projected over a 5-year period. There are only about 12 LNBYs planned for the U.S. Perhaps as many as 300 SODS may eventually be in use in the U.S. Foreign countries have, of course, existing installations, as well as plans for such marine environmental stations, but data on projected usage could not be obtained.

Hydrological data platforms are in use by the Soil Conservation Service of the Department of Agriculture, which has about 70 remote instruments already powered by solar cells. Some of these instruments report data via land radio links, others via satellite. New types of data

stations may soon be procured; about 1000 of these may be emplaced over a ten-year period. No data were available on the power requirements of these new systems. The currently used system uses 1 W panels for the instrument and 3 W for the repeaters in the land-link mode. Satellite transmission requires 2 W panels.

The USGS is currently operating about 10,000 hydrological instruments, but most of these record data in hard copy for periodic manual pickup. Only about 1000 stations telemeter their data via telephone lines, while very few utilize radio transmission. From 100 to 200 experimental data platforms designed for use with the Geodetic Earth Orbiting Satellite (GEOS) and Land Satellite (LANDSAT) satellite systems are planned to be installed, mostly solar cell powered. If successful, several thousand may eventually be used. However, power levels will average only about 200 mA at 12 V. Hydrological instrumentation is also used by the BLM and the Corps of Engineers. Together, their use is said to number in the thousands. An actual inventory would have required separate calls to the various district headquarters of these services, since no central data source could be found. It is understood that large numbers of these instruments already use solar cells, as do the radio repeaters associated with them. Absence of a central planning organization also made it impossible to obtain future market estimates for these agencies.

Attempts to find a central planning organization in the EPA for pollution monitoring instrumentation were unsuccessful. Remote nuclear radiation instrumentation is used on oceans, but these are disposable, one-shot devices for which batteries will be retained as power sources. Other remote area monitoring is done by aircraft and thus is not a prospective market for solar cells. Pollution monitoring in urban areas, the great majority of such work by the EPA, appears to utilize instrumentation designed for 115 VAC power supplies. A review of Reference 45 confirms that instrumentation for battery operation was not in use in 1972. Contact with the author of this reference indicated that this situation has not changed.

The EPA thus appears to offer no discernible market potential for photovoltaic devices, although this may well change.

The potential of solar cell power in air quality monitoring networks was investigated through contacts with the NOAA Air Research Laboratory in Boulder, Colorado. Although a number of such stations are being planned by NOAA and the World Meteorological Organization, only very few of these will be in locations remote from the utility net. No visible market is associated with this application.

Table 13 summarizes the total environmental sensor market.

Table 13
ENVIRONMENTAL SENSORS, TOTAL MARKET FORECAST

Organization	Number of Stations	Power/Station, in peak watts	Total Power, in peak watts
Corp of Engineers	1000	2	2000
Bureau of Land Management	1000	2	2000
U. S. Geodetic Survey	5000	4	20,000
Soil Conservation Service	1000	2	2000
Forest Service	250	6	1500
State Forestry Service	5000	6	30,000
NOAA	20 RAMOS	10	200
	4000 DARDC	2	8000
	300 Advanced RAMOS	4	<u>1200</u>
Total			66,900

At break-even costs of between \$150-200 per peak watt and at 50% penetration, a total cumulative market for photovoltaics by 1985 of 34 kW_{pk} results, with the rate of sales in 1985 estimated to be at about 6 kW_{pk} per year.

3.2.2.6 Sensors in Industrial Surveillance

This class of applications covers primarily status sensing at unmanned facilities such as oil and gas production and storage fields, water storage and pumping, offshore platforms, gas and oil pipelines, etc. Automated control of petroleum and natural gas fields is a growth area for which photovoltaics are being considered. This will be discussed in Section 3.2.3, "Communications."

Reference 46 represents the only statistical information which could be readily obtained on water utility systems in the U.S. It reports that in 1970 a total of 5200 water distribution storage systems were in active use in the U.S. These are reservoirs near use areas, not the lakes or dammed river storage systems from which the water supplies may originate. About 220,000 miles of distribution pipelines were in use. No information could be obtained from the American Water Works Association on remoteness of these systems from utility power, or on current and projected independently powered instrumentation associated with this vast system. The potential for a major photovoltaic market in sensor applications should exist, and further investigation through surveys of individual utilities is recommended.

3.2.2.7 Location Sensors

An existing applications group includes devices capable of sensing the presence of objects in general when they are moving along specified paths, or sensing a specific characteristic of an object, whether moving or stationary. The former have already been discussed under approach sensors and have application to highways and railroads, and rights of way in general. The latter is exemplified by railroad car identification systems which read the color line code applied to the exterior of cars as they pass by. It is not believed that the latter sensor systems offer a near-term market potential since they are high power consumers and are generally located where utility or engine generated power is available. No particular rationale exists for placing these locator/identification systems in remote areas.

Developments in law enforcement have been concerned with devices to detect hijacked trucks and cargo. These devices can be used in both urban and more remote environments and operate mostly in two major modes. In one of these modes, the device is merely a transponder and relays to the truck-mounted transmitter a coded signal which identifies the location of the device. The truck transmitter then relays this information to the central control watching over the movement of the truck. In the other mode currently under development, the locating device, which may be pole-mounted on the side of the road, interrogates a transponder hidden in the truck or in the cargo container and re-transmits the coded identification signal received, together with its own sensor identification number, to the central control. There are variations of these modes which involve location fixes through trilateration on local radio stations, with only occasional updating of the truck-mounted location computer from roadside transponders. Nevertheless, almost all of the systems being studied and test-deployed at this time use roadside devices which are generally battery powered because power drain is normally in microwatts.

Although such devices are currently being considered mainly in the context of law enforcement, future potential exists in other areas. For example, transportation system using surface buses, jitneys, or taxicabs can maintain better service through computerized dispatch control made possible by frequent automatic updating of location data.

Wildlife locators, consisting of small transmitters attached to an animal, have been used for years, and recent advances in micro-transmitter technology, as well as in satellite technology, may expand this use. References 35 and 38 discuss this specific application in more detail. Since wildlife research would not constitute a major market, it has not been further investigated by this study. However, mention has been made in the literature of health monitors attached to range cattle, which could alert ranch personnel to danger status concerning the animal and to its location. Technology has made this feasible but the economics of this application are

not known. Photovoltaic power could be utilized for the sensing and data transmit function as well as for the repeaters required to relay the data to a control station.

Quantitative market data for these sensor application have not been developed. Since required power levels range from micro to milliwatts per unit, this market will not likely reach major proportions.

3.2.3 Communications Market (1.1.2 in Applications Tree)

The applications under this general heading are outlined on Figure 10 of the applications tree and range in equivalent continuous power consumption from microwatts, in the instance of radio call boxes, to kilowatts for microwave repeaters. Peak power demand occurs during periods of transmission and will range from the 1 W level to several kilowatts. There is less commonality in operating characteristics for this class of application than for the sensor class of applications previously discussed. For example, duty cycles could range from very low for emergency transmitters, which may be activated only for test several times during the year to 100% for busy communications repeaters.

Photovoltaic penetration of this market is strongly dependent upon the equivalent continuous power level of the application. If this level is in the microwatt to milliwatt range, photovoltaics will be economic even in urban areas, except where 115 VAC is already available in the immediate vicinity. Power levels in the order of 10 kW and up will find diesel generator power more economic during the near term even in remote areas, except where special situations prevail.

In general, transmitters or repeaters carried by an independently powered vehicle are not viable candidates for photovoltaic power, whereas stationary remote systems are attractive candidates, except at higher power demand levels. One exception to this generalization is railroad caboose communication systems powered by car-axle-driven generators, which are inoperative while stationary.

For the near term, sales of photovoltaic power systems for this market should increase by several orders of magnitude. However, the increased use of satellite communication relays will reduce the number of land-based relays and repeater stations and will thus provide a technological limit to what is probably the largest segment of the communications market to be reached during the 1980's.

Table 14 summarizes the size of individual communications market segments surveyed by this study. Table 15 lists the organizations contacted during the review of the communications market. Either published data from these sources, or telephone contact with their marketing or engineering personnel form the basis of the market forecasts provided in Table 14.

3.2.3.1 Emergency Radio

3.2.3.1.1 General

The classification of emergency radio includes a variety of communications applications all of which provide means for summoning assistance in an emergency situation. The devices used for this purpose generally fall into two categories, "local transmit only" and "local receive and transmit." The familiar fire box which, when the handle is pulled, transmits a coded signal indicating its location, is an example of the "local transmit only" device. Two varieties of "local receive and transmit" have been used in this country. One operates like a telephone, allowing voice communication with a central control; the other is equipped with a number of buttons, one each for a likely emergency need, such as fire, police, medical aid, etc. When the appropriate button is pushed, a coded signal is read at a central control and the requisite response is dispatched. At the same time, the sending station is notified by an audio or visual signal that the message has been received and acted upon. The great majority of these devices operate via telephone lines at this time, but may be a potential for conversion to photovoltaic systems using a radio link because of economic considerations. New systems may also be installed in large numbers.

The class of "local transmit only" emergency devices also includes the emergency location transmitters (ELTs) prescribed by regulation for civil aircraft to assist in locating crashed aircraft. A similar device has been in use on a voluntary basis by recreational boating, although mandatory for commercial shipping. Consideration is currently being given by the Coast Guard to requiring emergency position indicating radio beacons (EPIRBs) on

Table 14
SUMMARY OF MARKET FORECASTS FOR COMMUNICATIONS

Application	Individual Array Size, in peak watts, (average)	Cumulative Power by 1985, in peak watts	Sales in 1985, in peak watts
Highway Call Boxes	0.5	250×10^3	10×10^3
ELT's	5	65×10^3	15×10^3
EPIRB's	5	50×10^3	20×10^3
Radio Control	7	700×10^3	100×10^3
Repeaters			
Common Carrier	14×10^3	4.3×10^6	600×10^3
Private Microwave	1.5×10^3	3.5×10^6	800×10^3
UHF/VHF	3.3×10^3	3.2×10^6	550×10^3
Totals		1.2×10^7	2.1×10^6
<u>Potential Markets for Which Quantitative Forecasts Were Not Feasible</u>			
Community Call Boxes			
Air Traffic Beacons and Radio Landing Aids			
Railroad Block Signal Controls			
Highway Signal Controls			
Fixed and Mobile Radio Base Stations			
Rural Telephone Systems			
Locators			
Radio and TV Receivers			
Utility Meter Reading			

Table 15
ORGANIZATIONS CONTACTED

Governmental

Federal Aviation Administration (FAA),
Washington, D. C., Oklahoma City, Los Angeles, Atlantic City
Electronic Compatibility Analysis Center (ECAC), DoD
Federal Communication Commission (FCC)
Federal Highway Administration (FHWA)
Kern County (Calif.) Public Works Dept. Communications Dept
U. S. Coast Guard

Industrial

American Science & Engineering Co.
Sangamo Electric Co.
TCOM, Subsidiary of Westinghouse
Spectrum Analysis and Frequency Engineering Co.
Compucon
Industrial Communications,
Microwave Journal,
Motorola Electronics, Chicago, El Segundo, Phoenix
Union Pacific RR
Southern Pacific RR
Farinon Electric
Santa Fe RR
Shell Oil Co.
Amoco Oil Co., Denver
Econolite Div. of Altec Corp.
GTE Laboratories, Santa Monica
Pacific Telephone Co.
A. T. & T., Basking Ridge, N. J.
NARCO Avionics
Eagle Signal Co.
GTE Lenkurt

Others

Electronics Industry Association

pleasure boats as well. VHF radio telephones have, of course, been used for this purpose for many years, but also on a voluntary basis. EPIRBs would be suitable for use on life rafts, life boats, and emergency flotation devices and thus could supplement the VHF radio when abandonment of the vessel is required.

3.2.3.1.2 Highway Call Boxes

Solar-powered call boxes were originally marketed by Hoffman Electronics as "transmit only" systems for use on highways, and a number of them were installed, e. g., on the Beltway in the Washington area, about 10 to 15 years ago. One current manufacturer of solar-powered call box systems identified during this study is Motorola Electronics, which has a number of them installed in Arizona, Connecticut, and Florida, among others. These are full service, two-way radio telephone systems and operate via radio relays and/or telephone links, when needed, to reach a central control. These repeaters, of course, often are also solar-powered. Current units utilize arrays sized at about $0.65 W_{pk}$ but could probably function at lower power levels since the duty cycle is low, usually not exceeding one-half call/box/day. A number of other companies manufacture conventional boxes operating over radio or telephone lines.

The primary competition to solar cell power appears to be the local telephone company. Information on actual costs for such telephone service could not be obtained. Break-even cost computations would, in this instance, have to be based upon total system costs. These would include line connection, individual station, and central control telephone charges in the instance of a telephone connection; photovoltaic system for each station, repeater stations and interconnects, and central control transceiver equipment in the instance of a radio system. Based on break-even computations on other low-power level radio systems, there is little doubt that solar cell systems would be cost-competitive against battery-powered radio systems. At least two currently sold call box systems using batteries have been identified by this study (using secondary, lead-acid batteries). On many miles of

highway, call box service can only be provided through battery-powered devices or photovoltaic systems using radio links. For those cases, of course, break-even costs would range from \$150 to \$200 per peak watt.

Contact with cognizant personnel at the Federal Highway Administration disclosed that although this agency currently recommends that call boxes on the Interstate Highway System be placed no further than one-half mile apart, it does not require their installation nor specify the type of call box to be used. About 90% of the Interstate System passes through rural or remote areas where both utility power and telephone service is only intermittently close to the highway. No information was available on the actual number of call boxes already installed or planned to be installed, from either Federal agencies or industrial marketing personnel. Because of this, the estimate of the potential market can this time only be based on judgment, and further market research in this area is recommended.

Potential competition to highway call box systems also exists in the form of voluntary CB networks such as REACT (Radio Emergency Action Citizen Teams). Serious consideration of the organization of such networks is being given by both federal and state authorities.

The total potential market is, of course, related to the size of the highway system. There are about 3 million miles of surfaced roadway in the U.S., of which the interstate system will contribute 43,000 miles. If federal recommendations are followed and call boxes are installed every one-half mile on each side of the road, about $50 \text{ kW}_{\text{pk}}$ of array would be required, assuming 50% photovoltaic penetration of this market. It is doubtful, however, that more than 30% of the non-interstate road system would receive such service and then probably averaging no more than one every mile. The total cumulative market for the non-interstate system might therefore reach $180 \text{ kW}_{\text{pk}}$ for a total highway system market of about 230-250 kW_{pk} . This represents about 500,000 units to be installed. Potential sales per year could not be estimated with any degree of confidence on the basis of data at hand. For purposes of this forecast then, the cumulative market by 1985 is optimistically assumed to be $250 \text{ kW}_{\text{pk}}$, with the rate of installation in 1985 having declined to between 5 and 10 kW_{pk} from earlier peak rates.

3.2.3.1.3 Community Call Boxes

Radio call boxes photovoltaically or battery-powered for emergency services in urban or suburban communities appear to be economical when no hardwire system is presently in service. The city of Santa Rosa in California found it cost-effective to recently install a "transmit only" system manufactured by Econolite and powered by solar cells. It consists of about 250 unit installations. No national survey was attempted, and installations of similar type may exist elsewhere. Sales appear to have been inhibited by the general shortage of municipal funds for this purpose and by fear of vandalism associated with the solar array. Sales arguments are usually based on the high cost of copper lines and the cost of battery replacement in alternative systems. No forecast of potential markets for this application has been possible, but additional market research is recommended because of the apparent cost advantages which photovoltaic call boxes would have in new suburban communities, new towns, and recreational communities that are being formed at a high rate.

3.2.3.1.4 Emergency Locator Transmitters

The existence of 170,000 general aviation aircraft, about two-thirds of which are required to carry ELTs, made it desirable to investigate this market. The specifications covering this type of equipment require that the unit be operable over a 48-hour period at peak effective radiated power of 225 mW, with average radiated power over a 72-hour period no less than 75 mW. All currently manufactured equipments for this application are primary battery powered.

Contact was made with various FAA personnel, resulting in somewhat conflicting opinions concerning the need for power source substitution. Field personnel reported that batteries have not proven reliable power sources because of poor low temperature characteristics, outgassing problems which have caused explosions, and terminal corrosion which has prevented rated power output. FAA headquarters personnel, on the other hand, felt that outgassing and explosion problems had been solved by avoidance of lithium

batteries, and that the corrosion problem was in process of being solved. Malfunction of ELTs was said to be primarily traceable to acceleration switches which activate the transmitters on impact, and power supplies have, in general, been satisfactory. Field personnel were receptive to the idea of a new power source but could not comment on the applicability of solar cells. Headquarters personnel felt that the primary advantage of long signal life obtainable from photovoltaic systems was not important to the operation of the ELT since this device has value as a life-saving feature only during the first two or three days after crash. Human survivability after that time period drops too low to be significant. In addition, a method of mounting of the array to assure its survivability in crash situations has not been developed at this time. Comments could not be obtained on the feasibility or desirability of using wing or fuselage mounted arrays to float charge both a secondary battery in the ELT as well as the SLI battery of the aircraft which powers the ignition system and other aircraft systems. This latter scheme might not provide for longer ELT transmission life, but would assure full battery charge at all times and reduce the need for expensive replacement of primary ELT batteries on a periodic basis.

Contact with industry marketeers, as well as available statistical information (Reference 47), provided some data permitting gross market forecasts on the assumption that float-charged secondary batteries for ELT's will be permitted by the FAA and that 1 W_{pk} panels would be sufficient for this purpose and for floating the SLI batteries. It is also assumed that only new aircraft would incorporate this system, on the basis that retrofitting of panels into existing structures would not be attempted frequently enough to be important. Between 1970 and 1976, the total of general aviation aircraft has increased at about 4.3% per year. New aircraft shipments for domestic use amounted to about 10,000 units in 1976, or about 5.8% of the total fleet in 1976. The apparent low scrappage rate of 1.5% will undoubtedly increase in the 1980's as the proportion of older aircraft increases. The total growth in the general aviation fleet between 1980 and 1985 has been estimated at 40,000 units, with actual new deliveries, including scrappage replacement, to increase

this amount to at least 65,000 units. This is believed to be the primary market for aircraft-related photovoltaics. If only float charging is to be judged feasible and the penetration is assumed at 30%, this market would total only about 20 kW_{pk} with annual rate in 1985 reaching 5 kW_{pk}. If a feasible means for directly powering ELTs with solar panels were found, in order to provide much longer transmission periods, the array size required would be in the order of 5 W_{pk}. Assuming only a 20% penetration in this instance, the cumulative market in 1985 might reach 65 kW_{pk} with an annual rate of about 15 kW_{pk}.

3.2.3.1.5 Marine Emergency Position Indicating Radio Beacons (EPIRB)

Data on this market were derived through contact with the U. S. Coast Guard at Long Beach and in Washington, D. C., and manufacturers of emergency radio beacons.

Commercial vessels are required to carry EPIRBs broadcasting at the international marine emergency frequency of 2182 kHz. No such requirement exists for pleasure craft. However, many boat owners carry EPIRBs which are either conventional aircraft ELTs, or such units modified by the manufacturer for the marine environment. In both instances, however, transmission is either on the 121.5 and/or 243 MHz frequencies, the 2182 kHz frequency being unsuitable for small boat use because of the large antenna required. The Coast Guard, being aware of this practice, listens on these aircraft emergency frequencies. Many aircraft overflying ocean areas also listen on these frequencies. Some consideration has been given to mandating the use of EPIRBs on pleasure craft, at least on those used on the open sea. Some tests of foreign-made units have already been conducted by the Coast Guard to determine potential specification requirements (Reference 48). Full consideration by the RTCM (Radio Technical Committee, Marine) and their approval will be required before any regulations could be adopted, and time predictions for such action were not available from any of the sources contacted. If adopted, such units would probably be required to radiate at least

one watt of power, with a minimum on-time of 5 seconds out of 15 seconds, and with a desired on-time of one minute out of two. Here, as in the instance of aircraft rescue operations, Coast Guard personnel saw no particular virtue in long duration of transmission, believing that rescue within three days is necessary in order to accomplish a life-saving function. It was admitted, however, that cases have been recorded where persons in marine distress situations have survived far longer than that either in lifeboats or rafts, or even by clinging to flotsam. Because of this, it is believed that a better case for a self-renewing energy source can be made in the instance of marine emergencies than for air crash situations.

Accurate data on pleasure boat registration are difficult to get. Several marine and boating associations contacted for such data were unable to provide it. It appears that registration is a state function and totals would have to be collected from each cognizant state agency. Approximate numbers were obtained from the Southern California Marine Association. In 1975, the number of registered sailboats without inboard power was about 800,000, those with inboard power totalled 240,000, and about 550,000 inboard motor boats were registered in the U.S. No information could be obtained on the fraction of these boats used on the ocean and the Great Lakes, where the requirement for EPIRBs is most probable. An array size of no more than $5 W_{pk}$ appears to be required, even if the photovoltaic system is to provide primary transmission power. A life preserver could therefore be used to mount the array and provide the buoyancy required for the transmitter. A float-charging system could also be conceived, which would ensure a fully charged secondary battery at the time of emergency, and which probably could operate at a fractional watt output.

If EPIRBs were mandatory for certain classes of boats, perhaps as many as 50% of the pleasure boats registered in the U.S. would require them. Assuming a 50% penetration of this market, the cumulative market could range from $190 kW_{pk}$ for the float-charging system to about $1.9 MW_{pk}$ for the solar cell primary power source. However, it is unlikely that mandatory use of pleasure boat EPIRBs could be initiated prior to 1980.

An important market could probably not develop prior to 1983, so that the cumulative market by 1985 is estimated not to exceed 50 kW_{pk} under the most optimistic scenario, with annual sales in the order of 20 to 30 kW_{pk} under the same assumptions.

3.2.3.2 Air Traffic Applications

This study concentrated on Federal Aviation Administration operated air traffic systems, primarily because of the central information sources available in the Federal Government. Potential requirements associated with smaller, private fields lacking FAA facilities and personnel were not surveyed although applications may exist and should be further investigated.

FAA groups concerned with air traffic control, communications and navigational aids, and landing aids were contacted in Washington. An FAA study project concerned with new power sources at remote locations was contacted in Atlantic City, N.J. The major power-consuming equipments used by the FAA include the VOR and VORTAC navigational aids of which about 1000 are currently in use in the U.S., the 20 Air Traffic Control Centers distributed over the U.S., and the control towers associated with major airports, of which currently about 430 are in service. In addition to these, instrument landing system adjuncts such as outer markers (radio beacons) are in use on runway approaches and, of course, runway lights on those airports operated by the Federal government. The navigational aids generally operate 100% of the time, are heavy power consumers, and are currently on utility power backed by diesel generator sets.

The future of VOR/VORTAC systems is currently in doubt because of the strong possibility of their replacement by simpler and more effective systems. For example, the Omega navigational system is capable of covering the entire globe with only eight stations. In addition, satellite systems are under development which do not require ground station links with aircraft. The time scale for the replacement of current navigational systems is uncertain, and may range from 10 to 20 years. One of the difficulties in replacing current ground-based navigational aids with more advanced systems is that the latter appear to require more sophisticated and therefore more

costly onboard equipment, which may be out of reach of most general aviation aircraft operators.

The Air Traffic Control Centers are currently on utility power, as are the airfield control towers. Instrument landing systems are generally emplaced on airports with sufficient traffic to warrant these. Such airports are normally on the utility grid. Furthermore, the newer systems now being developed are heavy power consumers. For example, the MLS (microwave landing system) now being considered for implementation requires a minimum of 3 kW for electronics, from 4 to 14 kW for environmental control, and various miscellaneous power to a total of about 26 kW per installation in small airports. The system for large airports would consume up to 50 kW. Landing and approach lights on FAA serviced airports are also large power consumers and rely on utility power, with backing by engine generator sets in many cases.

It was learned that outer markers in Instrument Landing Systems (ILS) could become candidates for photovoltaic power in new installations where costs of providing power line extensions can be traded against array costs. Only about 25 W are required for each marker beacon, and the devices could be remotely actuated upon aircraft approach either by the tower or by the aircraft, and, of course, returned to standby upon aircraft passage. Apparently one ILS marker is already operating with solar power at Anchorage and has a satisfactory performance record. No market data could be developed during this study to permit a forecast for photovoltaic penetration.

It is recommended that smaller private airports and landing strips be investigated for applications involving landing aids and navigational beacons. Most such strips, except those used only for emergency landings, are within reach of the utility grid, so that this market is not likely to be sizable.

3.2.3.3 Radio Control

Under this heading are included those potential photovoltaic applications in which remote control is exercised over production functions, safety devices associated with automated operations, traffic control systems

on railroads and highways, and so forth. In some instances, control may be exercised by computer systems; in other instances, human operators are in the loop for the final control decision. In all instances, however, the information flow between functions to be controlled and the decision maker is over radio links because of a separation in distance between the function and the controller. In remote control situations, power will also be required to operate the functional controls as well as to send the actuating signal. Photovoltaics can provide such operating power when the power level is within the range which makes solar cell power competitive with alternate sources for the specific location. When hardwire data links are present, photovoltaics are not likely to play an important role, inasmuch as both power and information can be transmitted over the conductor. Several potential areas of remote control application have been identified by this study but quantitative market data could not be obtained prior to termination to the work.

Gas and oil production is an important new growth area for remote control, generally termed CPC for Computer Production Control. In such systems (Reference 49), sensors measure parameters such as temperature, pressure, flow rates, valve status, and liquid levels, and report these data to a minicomputer in a central facility which processes the data to provide a factual basis for operating decisions. Normally, control locations are provided with directional antennas to reduce transmission power requirements, with the central computer facility receiving (and sending) via an omni antenna from the control locations, scattered perhaps as much as 25 miles away. The control stations are the primary candidates for photovoltaic power because they are often distant from utility power, require only about 0.5 to 1 W for sensing and during standby, and will dump their collected data periodically upon interrogation into the central computer. Transmission might require from 5-20 W for periods up to one second. Translation of control commands into function operation, such as valve closing or opening, may require electric power of relatively low level, at least in those instances where gas well pressure, for example, is available for primary actuating power. Depending upon the duty cycle for such actuation functions and the required power level,

pressurized air reservoirs for pneumatic actuation could also be maintained by solar-powered compressors. Additional power requirements, which occur infrequently enough to permit consideration of photovoltaic power, include gas collector pipeline heating systems to prevent line plugging due to condensate freezing downstream from the separator unit. Alarm systems to protect remote installations are also in use and require power.

The competitors to photovoltaic power in remote control installations are, of course, diesel or gasoline engine generator sets, TEGs (thermoelectric generators) powered by gas being produced, gas-burning turbo-generators, gas-burning I.C. engine generators, and, for offshore fields, wind generators on the platforms. Oil production often involves diesel-powered pumping and thus makes available a relatively cheap source of electricity which would eliminate consideration of alternate power sources.

Sampling of two oil companies contacted in connection with CPC applications produced conflicting market opinions. In one instance, arrays had already been purchased from several manufacturers for test in an actual installation being made (in 1976). The attitude was receptive and consideration was being given to a variety of photovoltaic applications outside the CPC area. The personnel of the other company was skeptical with respect to future potential, pointing out that thermoelectric generators had been available to them for some time and had not found widespread use.

Remote-controlled block signalling has been in use by railroads for a long time and has required provision of power on remote tracks through use of engine generators or batteries. The possibility of providing solar power for such functions has only been briefly explored by this study and should receive further investigation. Railroads, in general, have been found receptive to concepts which offer power supplies independent of utility power, which, in remote areas, suffers higher incidences of interruption due to weather and vandalism. Similarly, remote-controlled highway traffic control systems are currently being considered to optimize existing road systems. Such systems would include electrically operated road signs, control surveillance, and communication systems. The utility of photovoltaic systems for

the control systems is, of course, dependent upon their ability also to provide economical power for the signal, whether lighted or mechanical, or for such surveillance devices as vehicle counters. The ability to place signs and signals on road segments remote from utility power may be an important aid to traffic control since it decouples traffic control requirements from utility power line locations, which are normally determined by entirely different considerations. Both railroad and highway applications appear to have considerable potential, and further quantitative exploration of these markets is recommended.

Some rough order-of-magnitude estimates concerning the radio controls market can be offered merely to scope the photovoltaic potential in this applications grouping. In 1974, about 150,000 gas wells, 500,000 oil wells, and 2000 offshore platforms were operational. Perhaps as many as 65,000 telemetry stations might be in use for such applications by 1985, using solar power. Railroads operate about 360,000 miles of track in the U.S., about 200,000 by class 1 roads, and may perhaps utilize as many as 100,000 block signal or other signal installations, of which up to 10,000 might be equipped with solar-powered telemetry by 1985. The approximately three million miles of highway in the U.S. might, under the assumption of a vigorous federal effort to introduce electronic traffic control and surveillance systems, require as many as 30,000 telemetry stations utilizing solar power by 1985.

Under the assumption of 1 W of continuous equivalent power to be required on the average per station, corresponding to a $7 W_{pk}$ panel for each, the cumulative market by 1985 for all of these uses might reach about $700 kW_{pk}$ with annual sales in the order of $100 kW_{pk}$. These estimates are, however, to be regarded as no more than educated guesses, and, of course, exclude the power required by the signal itself, to be discussed in another section of this report.

3.2.3.4 Radio Repeaters and Transponders

3.2.3.4.1 General

The radio repeater market appears to have one of the largest potentials for photovoltaic power generation, in the near-term, of any markets

examined by this study. It includes safety and special services and common carrier microwave systems, as well as VHF and UHF repeaters used in a variety of these and other services. Relay and repeater stations are generally placed on the highest point along the transmission path for maximum range, and multi-station paths normally must cross some remote areas if they are linking distant regions. Mountaintop locations often require the construction of special access roads if fuel supply and maintenance services are to be regularly provided. Access roads also require maintenance, more so on mountaintops than elsewhere because of their generally more severe environment. The alternative of helicopter supply at between \$200 and \$400 per flying hour is also expensive. The construction of power line extensions to mountaintop locations impose increased capital cost penalties, as discussed in Section 2 of this report. All of these added cost factors, plus the inconveniences and reliability questions associated with maintaining reciprocating or rotary equipment at remote sites, allow photovoltaics to compete with more conventional power sources at many station sites where low power levels permit higher array break-even costs. It will be recalled that Section 3.2.1 discussed array break-even cost in trades against diesel and gasoline generator power and concluded that photovoltaics could compete by 1981-1983 at power levels below 5 kW, particularly when fuel and maintenance costs are increased by remote location of the engine generator installation. Under special circumstances, photovoltaics can compete today, as in the example of a Kern County, California, installation on a mountaintop which would have to be reached by crossing private property, and where permission to build a power line extension over private property could not be obtained. In this instance, the high cost of fuel resupply favored a 3 kW photovoltaic application.

Market information for this applications group was obtained from industry marketeers, trade association publications (References 50 and 51), telephone contacts and private communications from the FCC (Reference 52), and similar contacts with the Electronic Compatibility Analysis Center (ECAC) of the DoD, (Reference 53). Although a number of conversations were held with telephone company personnel, definitive market

data could not be obtained for common carrier future expansion plans. It appears, however, that private microwave systems for use by railroads, pipeline systems, and other industrial users will grow much more rapidly than will the A. T. T. land-based long-lines system. A major competitor to land-based microwave repeater systems are satellite systems which will, most likely, act to inhibit further expansion of at least the common carrier portion of land-based microwave links. While the number of private system stations is expected to grow, technical advances are reducing the power requirements of transmitters so that, for equivalent communication capacity, unit power needs in the 1980's will be about one-half those of currently installed transmitters. This also will tend to favor the earlier introduction of photovoltaic power by increasing break-even array cost.

3.2.3.4.2 Common Carrier Microwave Relays

Direct contact with GT&E, Pacific Telephone, and AT&T did not produce quantitative information on potential station growth in the long-line segment of the common carrier business. Other companies, such as Western Union, MCI, Datran, etc., operate microwave systems as Special Common Carriers, but could not be contacted during the course of this study. Contact with the FCC also did not provide information on the potential growth of the common carrier market. ECAC provided information on the number of relay facilities currently maintained by AT&T, each of which operate with up to 7000 circuits. There were, in 1976, about 7100 such facilities. The growth rate of land-line microwave facilities is considered inhibited by the increased use of satellite communications circuits and has been estimated at only 5% per year up to 1980 and at 3% after 1980. AT&T appears to prefer utility power with diesel backup for its stations or facilities, regardless of remoteness of location. As a consequence, only 10% penetration by photovoltaic of the new stations after 1980 has been assumed. The Special Common Carriers have been assumed to develop a long-lines station total equal to 20% of that of AT&T, at about half the circuits per station. Also, the penetration of photovoltaics has been assumed to reach as high as 50% because of lower

power requirements, potentially less accessible sites, and institutional factors. The total cumulative common carrier microwave market for photovoltaics has been estimated at 4.3 MW_{pk} by 1985, with an annual rate of sales at about 600 kW_{pk} in 1985, and is based on cost break-even being reached in 1979 at \$6.00 per peak watt against 1 mile utility line extensions. Longer power line extensions will make earlier initiation of this market possible, but it is doubtful whether institutional factors will allow important penetration prior to 1979, even though in special instances, as on Indian reservations, innovative use of photovoltaics for microwave communications (Reference 54) had already begun in 1976.

3.2.3.4.3 Private Microwave Relays

This classification includes communication systems for rights-of-way companies such as railroads, pipelines, and utilities. It also includes a variety of users in the Safety and Special Radio Services categories as defined by the FCC. ECAC data (Reference 53) show about 9000 relay or repeater stations licensed for these services in 1976. This market has been growing at a rate of about 10%, according to Reference 50, and may show accelerated growth in future years. For example, one railroad expected to add to its network at a 30% rate over the next few years. Estimates from this and other railroads indicate a potential photovoltaic penetration varying from 30% to 60%, with eastern roads at the lower level, because of greater probability of being close to utility power. Satellite competition will be less severe for this market than for the long-line common carrier market because of the shorter distances between terminal points.

It was again assumed that important sales would not occur before 1979, and then primarily in competition against utility power, although this market is, because of institutional factors, more inclined toward engine-generated power than is the common carrier market. Initial penetration by photovoltaics was assumed at 10% by 1980 and to grow to 50% by 1985. The number of circuits per station is considerably less than in the previous market segment so that power requirements per facility will probably average no more

than $1.5 \text{ kW}_{\text{pk}}$. The total cumulative market by 1985 was estimated at $3.5 \text{ MW}_{\text{pk}}$ with the rate of sales in 1985 at $800 \text{ kW}_{\text{pk}}$.

3.2.3.4.4 UHF/VHF Relays

Reference 53 indicates that about 5000 frequency assignments for repeaters and relays have been made to the Public Safety and Special Radio Services in this frequency range. No information on the actual number of transmitter stations could be found although the assumption of one transmitter per frequency is not likely to introduce a major error in market estimates. Reference 50 indicates a growth rate of about 10% per year for all of the transmitters in this class, a rate which may double by the 1980's. It was therefore assumed that the number of repeaters and relays would grow at about the same rate. These facilities are also located at high points, similar to microwave relays, and are used in a variety of applications, ranging from police, fire and emergency medical services to industrial and commercial applications, as well as for land mobile, marine, utility, forestry, and highway maintenance purposes. All of these applications are likely to be found in the remote or rural areas of the nation. Many of these stations, however, will also be placed in heavily populated areas, where even mountaintop repeaters can be expected to have ready access to utility power. Furthermore, a number of these relays will be located on the roofs of tall buildings or will utilize tall antennas in order to remain within the urban or suburban region to be served. Thus, the potential for photovoltaics is less than for microwave applications.

Penetration by photovoltaics has been assumed to start in 1979 at a 10% rate and to increase to 50% by 1985. Station power levels are, on the average, higher than for microwave relays and have been assumed at the $4.5 \text{ kW}_{\text{pk}}$ level initially, with decrease to $2.2 \text{ kW}_{\text{pk}}$ by 1985, as a result of technological improvements. The total market to 1985 is estimated at $3.2 \text{ MW}_{\text{pk}}$, with annual rate of sales in 1985 at $550 \text{ kW}_{\text{pk}}$.

3. 2. 3. 5 Radio Base Stations

3. 2. 3. 5. 1 Fixed

A number of base stations are located in remote areas in fixed locations without access to either utility or engine generator power, and are therefore battery-powered. These may include amateurs and special public safety services such as forestry, local government, highway maintenance, etc. No information on the total number of such remote base stations could be obtained, although the total number of transmitters in the amateur service was set at about 260, 000 in 1975, and the total number in the public safety services was at 3, 300, 000 in the same year (Reference 50). Although only a small proportion of these transmitters are remote from utility power, and the individual power requirements are in the order of 5-50 W_{pk}, a market of several tens of kilowatts (peak) may exist in this segment. A quantitative estimate could not be made.

3. 2. 3. 5. 2 Mobile

Although experimentation with solar power for backpack radios such as used by forest rangers has been reported in the literature, this application has not taken hold, even though potentially providing cost savings over primary batteries at break-even costs between \$150-\$200 per peak watt. Reasons for this lack of success in penetrating this market were not identified during this study but may relate to considerations of weight, relative convenience of replacing batteries during frequent returns to a base station, and danger of damage to the array in a mobile application. This market could not be sized.

Another mobile application was identified through contact with railroad personnel who indicated that cabooses are powered by car axle-driven generators. When stationary for longer periods of time in marshalling yards, personnel living on-board during these periods lose use of their VHF communication system. There are 25, 000 cabooses in service in the U. S. today, constituting a sizable market. The requirements for radio power in this

service have been included in another section of this report dealing with the general subject of caboose power, including lighting and other needs.

3. 2. 3. 6 Telephone

The subject of microwave relays for long-line telephone service has already been discussed above. The potential for photovoltaically powered repeaters (amplifiers) for coaxial and surface telephone lines was investigated with several telephone companies. It was learned that current practice is to power line amplifiers through a separate conductor from the telephone central and that independently powered systems offer no advantage at this time. The possibility of powering rural, limited subscriber-type private telephone systems with photovoltaic generators does exist but information on this market and its requirements could not be obtained. Indian reservations and other areas mostly without utility service might offer market potential for this application.

3. 2. 3. 7 Locators

3. 2. 3. 8 Radio and TV Receivers

Considerable mention is made in the foreign literature of replacing primary battery power for television receivers, used for educational service in remote regions of underdeveloped countries, with photovoltaic generators which are undoubtedly already cost competitive at this time for this application. U.S. requirements for this market have not been estimated although it exists, potentially, on Indian reservations and recreational sites, as well as in other rural regions in the Western U.S.

3. 2. 3. 9 Others

3. 2. 3. 9. 1 Utility Meters

An interesting potential application for radio transponders exists in both rural and urban areas in systems for remote, automatic reading of utility meters. Electric meters are currently already being read remotely in some areas but utilize the utility line and power itself and are therefore not

a market for photovoltaics. Another system, which has received some experimentation (Reference 55), utilizes battery-powered transponders which report gas meter readings to periodically passing interrogator units mounted in vans. However, the power levels required are in the order of microwatts and thus do not constitute an important market even if every home were equipped with such devices.

3.2.3.9.2 Navigation

Contact with the Coast Guard concerning current usage of radio or radar beacons for navigational purposes disclosed only a small number of radar transponders in operation, and no plans for important increases in numbers of remotely located RF beacon systems. The subject of air traffic navigational devices has already been treated earlier. With the exception of outer marker beacons for ILS systems, air traffic systems appear to rely on utility power. The market for such ILS beacons has not been determined.

3.2.3.9.3 Miscellaneous

Sailboat power requirements, including those for radio systems, are being treated in another section of this report. An airborne application of radio relay was identified through contact with the TCOM Corp., a subsidiary of Westinghouse Electric. This company markets balloon-based microwave relay VHF, FM, and AM broadcast, as well as TV broadcast systems, used usually in lesser developed countries where roads to mountaintop locations do not exist and would be difficult to construct. Power draw ranges up to 25 kW_{pk} per balloon. Photovoltaic power generation has already been considered for this application, but current array weights do not permit its use. Thin-film arrays, when perfected, may have an interesting application in this market.

Photovoltaic power has already found use in low power, remotely located transponders used in the location of aircraft by trilateration (References 56 and 57) in military testing. Civilian applications for such systems are considerably handicapped by the relatively high cost of the

equipment on-board the aircraft, which will probably prevent its use in landing aids. The Air Force General Positioning Satellite (GPS) navigational system which allows precise position location for aircraft, ships, and land vehicles and which may also be used by ground troops, has similar cost difficulties facing its transfer to civilian applications.

3.2.4 Signals Markets (1.1.3 in Applications Tree)

This applications grouping has potential as an important market for photovoltaic power generation and may equal, or even surpass, the communications market in size. As in the instance of communications, the value of photovoltaics has already been recognized for remote, difficult-to-service applications in which primary batteries constitute the alternative power source. In addition to sales already being made for such applications as offshore platform navigational lights and horns, and a limited number of Coast Guard lighted navigational aids, planning for an extensive investment in photovoltaic power for navigational aids by the Coast Guard has been reported. Experimental use of solar cell power has been reported for a number of other applications and the excellent, trouble-free performance experienced so far will cause translation of these markets from experimental to operational use. However, the largest potential applications appear to be those for which photovoltaics have not yet been seriously considered but where they could make a significant contribution in public safety and in increasing efficiency of transportation systems. The primary advantage which accrues to photovoltaics in signals-related applications is the ability to decouple the need for a warning or informational signal from the availability of utility power. The complementary land transportation systems of the U. S. contain numerous sites on which placement of a powered signal, although highly desirable, has been inhibited by the high cost of conventional power.

The signal markets to be discussed in this report section are shown to the fifth level of the applications tree in Figures 7 and 13. Table 16 indicates the data sources contacted for basic marketing data and for judgments concerning potential photovoltaic market penetration. Table 17 summarizes the market estimates for this applications grouping.

Table 16
DATA SOURCES, SIGNALS

Government

Federal Highway Administration
Sacramento and Washington
State of California, Department of
Transportation
Federal Railroad Administration
U. S. Coast Guard
Groton, Conn., Washington, D. C.

Industrial

Automatic Power Co.
3M Company
Western Highway Products Co.
Federal Signal Corp. (Federal Sign Division)
Southern Pacific Railroad
Southern Railway
Nu Art Lighting & Manufacturing Co.

Others

American Association of Railroads
Transportation Research Board

3.2.4.1 Railroads

The recent actions by Congress in furtherance of grade-crossing safety projects through federal subsidy of signals and gate installations may provide as much as \$100 million per year for such installations. There are currently about 220,000 public at-grade highway crossings on rail lines in the U. S. Automatic signals exist at only 50,000 of these crossings or about 23% of them (Reference 58). Reference 59 indicates that 10% of the total of 220,000 public crossings are without commercial power. It is probable that a higher percentage of the currently unsignalled crossings are

Table 17
SUMMARY OF MARKET FORECASTS FOR SIGNALS

Application	Individual Array Size, in peak watts, (average)	Cumulative Power by 1985, in peak watts	Sales in 1985, in peak watts
RR Crossing Signals	400	1.4×10^6	160×10^3
Highway Signs	70	9×10^6 ($1.7-17 \times 10^6$)	3×10^6
Marine Navigation	30	400×10^3	$30-40 \times 10^3$
Totals		10.8×10^6	3.2×10^6
<u>Potential Markets for which Quantitative Forecasts were not Feasible</u> RR Block Signals Billboards Airway and Landing Strip Signals Offshore Platforms Obstruction Lights			

without commercial power because these tend to be in rural and often remote areas. There are, in addition, about 142,000 private grade crossings. No information on the availability of power or the need for signals could be found for these crossings, so private crossings are not included in the market estimates herein.

Power for automatic grade crossing signal systems is required for three major subsystems. Devices to actuate the signal on approach of a train vary from relatively simple shunt-type trip switches operating at milli-watt levels to sophisticated motion detector systems requiring about 70 W for

continuous duty. The signal light system may require up to 250 W, but only for the time of passage of a train. The gate, when present at a crossing, will require between 70 to 100 W during operation. Lead-acid batteries (12 V) will generally back up commercial or railroad-generated power at such crossings.

Experimental photovoltaic crossing signal installations, without gates, were identified at a Southern Railroad location near Atlanta. Another such installation exists in Canada. Both installations are said to be operating satisfactorily. At least one other railroad, the Southern Pacific, was found to have been sufficiently interested in solar power to have requested bids for installations on a new line which had recently been completed.

The criteria by which crossings will be selected for signals and/or gate protection have apparently not yet been determined. These criteria will include threshold values for the number of trains passing the crossing per day, the number of highway vehicles crossing the tracks per day, the average train speed approaching the crossing, and other factors. These criteria will be decisive in selecting currently unsignalled crossings for protection, rather than the mere availability of commercial power. Estimates of the number of crossing installations to be considered as candidates for photovoltaic application must therefore await the development of such criteria. Market estimates presented below are based on the optimistic assumption that 10% of the crossing protection systems to be added will be in unpowered locations. This is based on the previously given nationwide ratio of unpowered crossings to total public crossings and does not account for the possibility that powered crossings may be given early preference in any installation schedule, leaving unpowered ones for later in the 1980's because of their higher initial cost.

The passage of the Highway Safety Act of 1976 has made available sufficient funding for protecting about 9000 crossings in 1977 and 1978, if the average cost of a conventionally powered system is between \$15,000 and \$30,000. It is hoped that future extensions of this act will eventually provide for a total of 50,000 crossings. Current production capability allows

the installation of about 3000 units per year, but is expected to increase to 5000 per year. The average equivalent continuous load of a combined lights-and-gate crossing system was computed to be about 100 W, based on 24 activations per day. Array break-even costs against utility power were computed to equal about \$21.00 per peak watt for a 1-mile line extension, a price which would allow installations to begin now. On the basis of an 80% penetration by photovoltaics of the unpowered crossing installations, the cumulative market to 1985 would thus sum to about 1.4 MW, with the yearly rate of installation in 1985 equaling about 160 kW.

Other railroad signal applications involve block signals, perhaps radio controlled as discussed in the previous section. Perhaps as many as 10,000 such block signals might be considered candidates for photovoltaic power. This survey did not, however, obtain sufficient data concerning this application to permit market estimates. This area is recommended for further study.

3.2.4.2 Highway Signals and Signs

Two types of highway signs requiring power are illuminated signs and motorized signs. Examples of the latter include louvered signs in which the louvers open to reveal a message or to change the sign message. Actuation of these signs can be by mechanical timer, remote control, or by special sensors in the instance of hazard warning signs. Lighted signs can also be actuated by light sensors. Some highway signals are merely lights, such as traffic lights, or hazard flashers. Others involve a written or symbolic message which requires illumination at night.

The major competition to lighted signs comes from retro-reflective signs which utilize illumination from car headlights to make their message visible to the oncoming driver. Retroreflective signs are, however, highly directional inasmuch as most of the light is reflected back into the source. These signs must also be within the range of the headlights before their message can be read. Higher traffic volumes have increased the period of time that low beam settings are used on headlights, thus further reducing the distance at which the message is visible, and restricting the effectiveness

of reflective signs to road shoulder-mounted placement. Overhead signs are preferred when it is necessary to inform a driver over longer distances. Reflective signs also appear to lose visibility in rain, fog, or haze, and when dirtied by road dirt, snow slush, and exhaust products.

References were reviewed in which advantages of illuminated signs over reflective signs were analyzed (References 60, 61). Contacts with highway officials provided mixed opinions on the desirability of illumination for signs. It was generally agreed that special hazard warnings were more effective when illuminated at night. They are also more effective in daytime when special attention is called to them by flashing lights such as high intensity strobes. A number of states, however, do not permit the use of flashing lights on highways. Opinions are not unanimous that illumination is required for directional signs such as those identifying freeway exits. In general, it appears that the number of illuminated signs is being reduced because of energy conservation measures by state and local governments, and because funding is less ample than in previous years. The sign industry, aware of this trend, has been counteracting it by introduction of low voltage, high efficiency lighting systems. The low voltage reduces the frequency of bulb replacement and permits lower installation costs. High efficiency lamps such as high pressure sodium can offer a 25% improvement in energy efficiency over fluorescent sources, and as much as 300% over conventional incandescent lamps. These trends will aid the utilization of photovoltaics for signal and sign lights.

Another industry trend, perhaps stimulated by cognizant state and local government agencies and the Federal Highway Administration, has been toward use of need-activated illuminated and/or motorized signs. This operational mode requires that a special warning sign, such as an ice hazard sign, be actuated only when the ice condition actually exists. Another example would be rural intersectional signals or direction-indicating signals which switch on only upon approach of a vehicle. Research on effective and reliable sensors for such purposes is currently under way in a number of laboratories. One scheme for an ice hazard sign noted by this study involved a timing

system which activated the sign only at certain hours of the night, and only during certain months of the year, when the presence of ice was probable but was not sensed in actuality. This particular system used strobe lights and was powered by a set of primary batteries said to be sized for one season's operation. The only other signals found in use on highways, and commonly powered by batteries, were the barrier flashers and portable illuminated signs often indicating road disrepair or other hazards associated with road construction. It is to be stressed, however, that this study did not include a thorough survey of all of the highway sign systems currently in use.

In general, limited contact with traffic engineers indicated strong interest in economical power sources capable of providing sign or signal illumination in areas remote from utility power. There appears to be agreement that a large proportion of U.S. roads are sufficiently distant from a power line to have prevented installation of illuminated signals in locations where safety or traffic control considerations would otherwise have placed them. There is equally strong sentiment for roadway illumination, to be discussed in Section 3.2.5. It was found that some experimentation was conducted with lighted and moving signs which had no function other than to arouse driver interest in order to prevent drowsiness on lonely stretches of high speed, cross-country freeways. Such signs would have to be erected more often than not in regions in which utility power is not available. It must be stressed in this connection, as was pointed out in Section 2.3, that a commercial power connection to a conventional 12 kVAC line is quite costly for a low power installation such as a 100 W signal, even without the need for power line extension.

No statistics appear to be available from any central source, whether federal or state, concerning the number of miles of roadway which might be considered unpowered. There is also no information on the percentage of roads for which the power lines are any given distance away. There are no statistical data on the number of signs required, whether illuminated or not. Reference 62 does provide, however, data on the miles of road existing in the U.S. under various classifications.

The total mileage of rural roads, selected for this market estimate as the most likely to be remote from conventional power, is listed as 3,180,000 in the U.S. Of this number, 2,452,000 miles are shown as surfaced roads. Of that number, 827,000 miles are under federal aid programs of one type or another, and are therefore more likely to participate in safety programs involving illuminated signals and signs.

In order to gain some understanding of the potential market represented by this rural road mileage, a California highway district was chosen for study as an illustrative example. This district contains about 15,000 miles of rural road, of which about 10% or 1500 miles were stated to be totally without power in the sense that power line extensions would be so long as to be considered "impractical". A much larger percentage of mileage had power lines at distances from a few hundred feet to 1 mile away, distances considered practical for line extensions if the power need were important enough. A relatively small percentage of rural road mileage, in the order of perhaps 10%, had utility power adjacent to the roadway. This sample district is representative of the entire state in its distribution of urban-to-rural roads, and mountain-to-flat-valley terrain. Most of the power-remote mileage was in the mountainous portions of the district, reinforcing the "impracticability" of power line extensions, since these can be up to five times as expensive in mountains than on flat land. The minimum need for illuminated signs on this mountain mileage was believed to be about one sign every ten miles. These would be essentially special hazard signs, indicating ice, rockfall danger, bad curves, etc. If informational and directional signs were included, the number of required signs would, of course, increase considerably. The subjective, non-quantitative nature of the above statements is typical of the best information available in this applications area. To obtain anything more specific would require special surveys, the resources for which were not available to this study, and which also are not available to the state agency involved.

Break-even costs were based on strobe illuminated signs, assumed to require a minimum of 10 W of equivalent continuous power. Because of the likelihood that these types of hazard signs would be used more

often in regions subject to worse-than-average weather conditions, nine days of storage was assumed instead of the standard three days. A break-even cost of \$216 per peak watt of array was computed in a tradeoff with a power line extension of 1 mile, costed at \$15,000 per mile. Higher power requirements for the illumination would, of course, reduce this break-even cost, whereas allowance for higher line extension construction costs in mountainous regions would increase the cost. At current array prices of between \$15 and \$20 per peak watt, there is little doubt that photovoltaics could effectively price-compete today for low-powered signs, even those which require only a few hundred feet of line extension. Break-even costs against Zn-C battery-powered signs are in the \$200 to \$250 per peak watt regime. The total market was estimated for two limit assumptions: (1) that the 10% unpowered fraction of rural roads found for California applied nationwide, that illuminated signs would be required only every ten miles of this fraction, and that only low-power strobe lights would be used on special hazard signs; and (2) that the entire rural road system of the U.S. would have need for a specially powered illuminated and/or motorized sign every ten miles on the average. This latter may be a very conservative assumption in view of the fact that the Interstate Highway System finds it necessary to have illuminated signs every half mile, with 90% of its mileage considered rural, that many of these signs require much higher power levels than the 10 W (equivalent) assumed, and that a much higher fraction than 10% of rural roads are more than a few hundred feet from utility power.

On the basis of these arbitrary limits, and assuming 90% penetration because of the obvious cost effectiveness, the total photovoltaic market for highway signs might range from a conservative minimum of 1.7 MW to upwards of 17 MW. The uncertainties associated with the market make estimates of the annual rate of sales of 3 MW_{pk} in 1985, or the cumulative sales of 9 MW_{pk} by that date very soft. Customer acceptance factors are particularly important in sizing this market. For example, the value of illuminated signs versus reflector signs is in dispute, the likelihood of success in the development of sensors to activate signs on need only is

uncertain, as is that of other technical concepts which might contribute to lower power demand, and thus to photovoltaic acceptability, and the importance of the increased safety brought by sign illumination relative to other highway needs is in question. Nevertheless, the potential of this market in helping to meet ERDA production goals makes it highly desirable that demonstration projects be considered that would increase awareness of the contribution photovoltaic systems could make to highway safety and efficiency. In particular, the need for alternate power sources for intersectional controls and other traffic control signals should be investigated.

This market is a good example of the difficulty of market forecasting without primary research. Essentially new markets would be created by the emerging availability of a new, economical power source. There is no market substitution taking place because conventional power is so expensive for remote sign installations that it has not been considered a viable alternative. The customer acceptance factors referred to above cannot be quantified from secondary data sources. Break-even costs are totally dependent on distance from existing power lines but statistical data on this parameter do not exist.

Highway barricade flashers would be a substitution market if hazards of theft and vandalism could be overcome. However, no market estimates were attempted.

Highway billboard signs have been briefly considered for their market potential. However, required power levels appear to be upwards of 400 W and their locations can usually be coupled with available utility service. For this reason, detailed consideration was not given this application during this study. There appears to be a desire on the part of billboard companies to reduce power costs. This may lead to technical advances aimed at reducing required power levels. Such improvements may eventually make this market available to photovoltaic penetration, and further consideration of it is recommended, particularly since billboard companies seem to be actively shopping for alternative power systems.

3.2.4.3 Airways

Contacts with the FAA regarding air traffic control communications have already been described in the previous report section. The only signal application for which the contacted FAA personnel felt that photovoltaic power might be used were ILS outer markers, which are essentially radio beacons. Such a marker beacon might be activated only during aircraft approach in order to conserve power, since it requires about 25 W of power while in operation. No information on potential market size for such devices was obtained. Lighted signals such as landing strip lights may offer a market in the instance of small private landing fields. Factual data on the number of such strips that might be remote from utility power could not be obtained from the FAA, and a survey of individual states was not feasible. Airway systems under control of the Federal government were said to be always utility powered, with engine generator backup. These include marker beacons and flashing light beacons, as well as other navigational aids.

3.2.4.4 Marine Navigational Signals

This applications area was investigated primarily through contact with the U.S. Coast Guard at Groton, Connecticut, and in Washington, D. C. Early in 1976, the Coast Guard inventory of lighted navigational aids included 3884 buoys and 10,237 shore aids which were battery powered and therefore potentially convertible to photovoltaic power, subject to proof of reliability and to the availability of funding. At that time, long range planning called for the conversion of the bulk of these aids by 1980. It is understood that fiscal limitations have delayed implementation of these plans. Some photovoltaic buoy installations already exist near Boston, New London, St. Petersburg, and Ketchikan. However, additional trial installations were to be made in several of the Coast Guard districts, prior to a firm commitment for total replacement. Fifty such installations were planned off Florida in 1976. On the basis of an average array size of about $30 W_{pk}$ applied to a total of about 13,000 installations, the cumulative market by 1985 might reach $400 kW_{pk}$ with sales in 1985 for this application to total between 30 and $40 kW_{pk}$.

The break-even cost against the currently used Zn-air primary batteries was computed at $\sim$ \$40-60 per peak watt, allowing this market to be initiated at any time, presumably when funding becomes available and after doubts concerning reliability and resistance to environment and vandalism have been dissipated by continued testing.

Other signal applications exist on offshore platforms, where power for obstruction lights and fog horns is required. The primary competition to photovoltaic power for this application derives from the frequent presence of engine generator power, particularly for inhabited platforms or for those in oil field operation. Oil pumping requires considerable power, dwarfing the amounts required for signalling. Wind-powered generators also appear to find favor for this application because of high prevalence of winds over oceans. Buoys are also used for lighted navigational aids by private companies operating offshore platforms (References 63 and 64). The number of platforms not served by engine generator sets, out of the approximately 2000 total in U.S. waters, could not be determined at this time. Power demand for four lights and a one-half mile foghorn would not exceed about 25 W of equivalent continuous power. Thus a 200 W_{pk} array would suffice on the average, assuming 3-4 days of storage. In terms of array production volume, offshore platforms are apparently not of high potential.

3.2.4.5 Obstruction Lights

Lighted signals warning of obstructions to air traffic are found on high structures or on natural formations near airports, or under flight paths. Buildings, antenna towers, and water tanks are examples of such structures. Of these, the most likely to be remote from commercial power would be water towers. No information on the number of such obstructions requiring light signals could be found.

3.2.5

General Power and Lighting Markets

(1.1.4 in Applications Tree)

This grouping serves as a collection point for all of the applications not classifiable under the three major applications groupings previously discussed. It is shown to the 6th level of detail of the applications tree in Figure 11. Because of the diverse nature of the applications assigned to this grouping, little commonality in load requirements such as power level and duty cycle exists, except that power requirements are generally sufficiently high as to make engine-generated power and utility power the alternative power sources used in cost break-even calculations. Practically no primary battery usage exists in any of the application groups discussed below.

An important market in this grouping which has substantial potential for transference to foreign markets is that on Indian reservations, whose needs appear to parallel many of those found in developing countries. Because of this, American Indian markets appear to be desirable demonstration prospects as well as potentially productive markets in themselves. In addition, they can serve for field trials providing operational experience with photovoltaic equipment destined for the overseas market. Although the importance of this market was recognized early in the study, quantitative market data were extremely difficult to obtain, even with the aid of the Bureau of Indian Affairs. Requirements surveys, if at all performed on Indian lands, have not been published or made available to any central authority. An attempt at primary research through the use of a questionnaire circulated by the Bureau of Indian Affairs to all of the tribes in Arizona brought limited response. Follow-up to these questionnaires was made impossible by the decision to terminate this study.

The cathodic corrosion protection market also appears capable of providing considerable array production potential and its exploitation has already begun. Similarly, a number of farm and ranch applications appear promising, both for commercial and foreign markets.

Information concerning potential applications and estimates of photovoltaic penetration was derived through contact with a variety of sources. Table 18 lists the various organizations helpful as data sources. Table 19 summarizes the market estimates associated with the applications in this grouping.

3.2.5.1 Farm and Ranch Applications

A variety of food production and processing applications have been considered in the literature for solar energy utilization. A number of these use areas appear suitable for photovoltaic power because of power levels and duty cycles in which photovoltaics can compete with either engine-generated power or with utility power if line extensions are required.

Irrigation often involves large volume well-pumping, with subsequent distribution either through open canals or ditches, or via large sprinkling installations. Power requirements for this conventional irrigation mode reach into the hundreds of horsepower, making such irrigation systems unlikely prospects for near-term photovoltaic application. However, a new method of irrigation has been introduced in recent years. Since this method is conservative of power and water, it is particularly adaptable to arid regions with high insolation, and has exhibited both a high growth rate and some initial photovoltaic penetration by innovators. This irrigation method is termed trickle or drip irrigation because of its characteristic of releasing water to individual plants in very small quantities over a long period of time. Although currently operated systems may trickle-feed water up to 16 hours per day, no serious obstacles oppose watering only during the daytime, and it would appear feasible to suspend or reduce watering during cloudy periods. The need for secondary battery storage thus appears to be lessened, if not eliminated. Where this is not the case, storage of water in elevated tanks may be feasible rather than energy storage in batteries. Power requirements for this method of irrigation, when well pumping is excluded, stem primarily from the need to pump water through a series of small bore distribution

Table 18
DATA SOURCES,
GENERAL POWER AND LIGHTING

Government

Transportation Laboratory, State of California
Federal Highway Administration
Office of Pipeline Safety, Department of Transportation
U.S. Coast Guard
Bureau of Indian Affairs,
 Washington, Albuquerque, Phoenix, Santa Fe,
San Carlos Apache Tribe
Navajo Tribe
Papago Tribe
Havasupai Tribe
U.S. Forest Service
Federal Preparedness Agency
Federal Disaster Assistance Administration
Defense Electric Power Administration
Defense Civil Preparedness Agency
California Emergency Services Office
U.S. Bureau of the Census

Industry

General Corrosion Service
Southern California Gas Co.
Cathodic Protection Service
Arizona Public Service Co.
Farwest Corrosion Control Co.
Electric Rust Protection Co.
Cities Service Gas Co.
Amoco Oil Co.

Table 18
DATA SOURCES
(Continued)

Industry

Wayne Broyles Engineering Co.
Good-All Electric Co.
Harco Corp.
Texas Eastern Gas Transmission Co.
El Paso Natural Gas Co.
NARCO/KONEL
Marine Radio Service Co.
Fleetwood Enterprises
Explorer Division of Anthony Industries
RP Industries
Crane Co., Cochrane Environmental Systems
Subsidiary
Rainbird Sprinkler Manufacturing Corporation

Others

American Petroleum Institute
American Gas Association
American Waterworks Association
National Association of Corrosion Engineers
Southern California Marine Association
Manufactured Housing Institute
Recreation Vehicle Industry Association
University of Arizona, Tucson, Phoenix
University of California, San Diego

Table 19

**SUMMARY OF MARKET FORECASTS FOR GENERAL POWER AND
LIGHTING APPLICATIONS**

Application	Individual Array Size, in peak watts	Cumulative Power by 1985, in peak watts	Sales in 1985, in peak watts
Railroad Cabooses	175 per car	1×10^6	0.4×10^6
Drip Irrigation	60 per acre	22×10^6	5×10^6
Recreational	Various	1.7×10^6	0.35×10^6
Industrial Corrosion Protection	Various	8.3×10^6	2×10^6
Bridge Decking Corrosion Protection	150	4×10^6	0.15×10^6
Rest Areas (Highways)	700	0.5×10^6	100×10^3
Others	Various	$30-40 \times 10^3$	$8-10 \times 10^3$
Totals	-----	37.5×10^6	8×10^6
<u>Potential Markets for Which Quantitative Forecasts Were Not Feasible</u> Drinking Water Pumping Hybrid System Applications on Farms Water Well Corrosion Protection Water Utility Pipe Corrosion Protection Indian Reservation Needs Grade Crossing Illumination Campground Power Highway Illumination Highway Maintenance Depots Boat Battery Float Charging Water Purification Construction Sites			

pipes and tubing and range from 20 to 60 W per acre, depending on type of crop, type of terrain, and climatological considerations. This assumes that water is available from irrigation ditches, streams, or other surface sources. Arid regions are often sparsely populated, thus exhibiting a high probability, even in the U. S., that power lines will be distant and that fossil-fueled engine power would be required for pump operation. Additional power, although minor, is required to operate automatic controls, such as timers, valves, and the filters essential to prevent clogging of the small diameter tubing in the distribution system. Automatic moisture sensing instruments may also be used to detect soil moisture content and to start irrigation upon demand. Innovative use of solar cell power has already taken place for automatic controls for filter backflushing operations.

Reference 65 provides technical background on drip irrigation systems. References 66 and 67 provide information on application of this method of irrigation to various crops and estimates of growth in use of this method. Available data indicate that 133,000 acres under cultivation in the U. S. in 1975 used drip irrigation. A 30% per year growth rate has been predicted by experts on the basis of surveys, so that the number of acres drip-irrigated will grow to 500,000 by 1980 and about 1,800,000 in 1985 in the U. S. alone. On the basis of 60 W_{pk} per acre, the total cumulative market by 1985 could reach about 22 MW_{pk}, with the annual rate of sales during that year at the 5 MW_{pk} level if penetration by then reaches 50%. The foreign market may be larger.

Another application found to be of interest to personnel of the Bureau of Indian Affairs was shallow-well pumping to provide drinking water for people or ranch animals. This application also would require minimum energy storage, if any, since the pumped water could be stored to permit supply on cloudy days or at night. Up to a depth of 200 feet and at a flow rate of 5 gallons per minute, about 1/2 HP of power would suffice, or about 400 W. A number of such wells are currently being operated with wind power on Indian lands, at a cost of about \$6000 for windmill, generator, and structure.

It would appear that arrays at prices between \$2 and \$6 per peak watt would be competitive with wind power, based on local storage needs. Estimates of the total number of such pumping sites, either on Indian lands or in the U.S. in total, were not available to this study. About 120 such wind power installations were stated to exist within the territory of one New Mexico Indian Agency alone. On this basis, several thousands of shallow wells, either in place or potential, and remote from utility power, should be in use on Southwestern reservations, with many more in use on privately owned range land, making a cumulative market of several megawatts likely by 1985. A more quantitative estimate of this total was not attempted because of the lack of specific information available to this study. In addition to the cost advantage due to possibly lower initial cost, photovoltaics would offer reduced maintenance skill requirements and reduced operating costs, estimated at about \$100 per year currently for wind-powered wells.

Solar thermal energy appears to have application for crop drying, and possibly for heating process water in food-packing operations. Although not investigated by this study, requirements exist in such applications as power for air and water circulation. A potential market for hybrid solar systems may therefore exist and should receive further investigation.

As discussed in another section of this report, well-casing corrosion prevention by impressed current cathodic protection is already using photovoltaic power. The availability of electric pump power from photovoltaic devices would make corrosion protection available for range water wells as well. For artesian wells, smaller photovoltaic units, perhaps coupled with well control devices, might find application. The economics of water well operation has not been examined, and it is not known to what extent corrosion protection by impressed current would offer cost advantages over periodic replacement, or other methods of protection. This area is also recommended for further investigation.

3.2.5.2 Corrosion Protection and Other Industrial Applications

Under this classification have been found only a few applications, some of which are already being penetrated by photovoltaics. Industrial usage generally implies a high level of power demand and an urban location, neither of which permits economic application of photovoltaics by 1985 (unless in total energy concepts which were not investigated by this study). The selected industries which have relatively low-level power needs in remote areas include the oil and gas industries and, possibly, the water utilities. Among the low-power-level requirements of these industries are the remote communication and radio control applications already discussed in earlier report sections, and the impressed current cathodic protection (ICP) requirement to be discussed in this section. References 68, 69, and 70 provide basic technical data concerning the use of cathodic protection in the oil and gas industry.

A number of companies in the corrosion protection field are already selling essentially off-the-shelf systems utilizing photovoltaics. These ICP systems are off-the-shelf only to the extent that they are assembled from standard modules and other components. The systems themselves are sized for each specific application on the basis of a corrosion survey which determines the actual voltage and current required. Older well casings or pipelines tend to require a higher power level to prevent further corrosion than do new installations. In fact, in new installations, methods other than ICP may be used to prevent corrosion. Competing methods may involve special coatings designed to overcome local corrosive action, or galvanic anodes may prove more economical than ICP. The latter may be preferred even for some older installations.

Considerations entering into the choice of corrosion protection systems will include the chemistry of the soil at the specific site, the closeness of other sources of stray currents, the presence of high voltage alternating current transmission lines, the vicinity of other metal structures which might be unfavorably affected by the use of an ICP system, and so forth. In general,

ICP systems will be used when soil conditions and the corrosion survey indicate that the voltages required to overcome resistance in the soil and in the corrosion couple are higher than galvanic anodes can provide and when the repair and recoating of installed equipment would be uneconomical. ICP can arrest corrosion before it has progressed to a hazardous level, and can do so over greater depths, in the case of wells, and over longer distances in the case of pipelines, than can galvanic anodes. ICP can obviate the need to dig up buried pipelines, or the need to abandon existing wells because of impaired casings and to drill replacement wells at a still productive site.

Corrosion protection is also important to the economics of distribution pipelines in urban areas, but different factors will influence the choice of a preferred protective system. For example, gas and water lines buried in city streets often have other cables or pipelines as neighbors. If the cathodic current path crosses or travels along such other equipments foreign to the system to be protected, their corrosion could be enhanced. To prevent such damage to foreign systems, ICP systems need to be restricted to low voltage and low current, thus leading to a higher ratio of cathodic installations per unit length in, for example, a distribution pipeline. This increases the cost of the system and its complexity, and may make galvanic anodes more effective and economical than ICP in the absence of photovoltaic power. This is particularly true in conventional installations drawing power from the utility grid, and requiring a transformer, rectifier, and meter at every location at which power is tapped from the grid. The lower the power level permitted the ICP installation, the more such connections to the grid and the higher the consequent cost of the ICP system. An economic break-even is soon reached at which a photovoltaically driven ICP system becomes more economical, even in close vicinity of the utility grid.

The literature reports instances of successful application of ICP to urban distribution piping (Reference 71), as well as the utilization of photovoltaics to drive such a system (Reference 72). However, it is believed that considerable demonstration of the technical and economic value of photovoltaic ICP is necessary before current methods involving recoating and/or galvanic anodes can be displaced.

Less persuasion may be required in the instance of gas well casings and oil and gas pipelines. This study identified several hundred installations of photovoltaic-powered ICP systems that are in progress or already completed in the Hugoton, Kansas gas fields. Two solar installations were identified on an El Paso Natural Gas Co. pipeline, and one on a pipeline owned by the Southern California Gas Co. Verbal information indicates existence of other installations in this country and overseas.

Oil wells are not good candidates for photovoltaics since oil must usually be pumped and the internal combustion engines driving the pumps also provide electric power. Gas wells, on the other hand, do not normally require power since gas flows from naturally pressurized reservoirs. Thus, when commercial power or private company power is not near the gas well, photovoltaic systems make economic power sources for ICP installations. At current costs of arrays, only shallow wells requiring between 10 and 20 W of continuous power can be economically equipped with solar cell systems. Deep wells, which might require up to a few hundred watts, will not be protected with solar powered ICP until the array price drops considerably. The units currently being sold to the natural gas industry for this purpose cost about \$250 per continuous load watt, fully installed, and usually include a service contract for at least one year in that price. Verbal communications indicate that these units are guaranteed for 20 years. As discussed for other applications, the higher the power demand, the more competitive becomes utility power. In this instance, and at today's prices, a 100 watt continuous load unit for deep wells would cost between \$20,000 and \$25,000. This price permits consideration of a considerable power line extension, or of an engine generator set servicing several wells in a field over a private transmission line.

Pipeline installations, as in the instance of wells, have differing ICP power requirements depending upon the size and condition of the pipe. New pipelines properly wrapped and coated require less current than existing pipelines whose protective coatings have failed in spots. Power requirements

for the installations which were identified varied from 24 W to 173 W continuous, the latter on a 26-inch-diameter line with excellent coating in first class condition and providing protection for about 30 miles. When used on pipelines, the primary application of photovoltaic power would be in remote sections between pumping or compressor stations. The ICP systems near the pumping stations could use power generated at these stations. A strong factor increasing the use of ICP on pipelines has been the 1973 DOT regulations which increase safety requirements on all pipelines carrying hazardous materials and which specify cathodic protection under certain conditions. Such regulations do not exist for well casings where corrosion protection is primarily of economic advantage.

Contact with water utility personnel did not disclose any immediate application of photovoltaics to water mains or distribution piping. It was pointed out that power is generally available at the storage dam site, and that most of the pipeline system is within urban areas. Galvanic anodes are generally used at this time, with very little ICP reported. There appear to be a number of institutional factors which would delay acceptance of either ICP or photovoltaics (or both) in the water utility industry.

Market estimates for this segment of the corrosion protection market were based on statistics from References 73 to 76 and on expert judgement obtained from a number of industry personnel. The uncertainty of these estimates is high because of the unreliability of trendline projection in this industry because of factors relating to the energy crisis, the impact on domestic production of retaining price controls or removing them, the predicted decline in production of domestic oil and gas fields, and so on. For example, although the rate of drilling of producing gas wells in 1973 was about 8000 per year (Reference 73), this rate may well drop to a much lower number if price controls are maintained. It could also rise if decontrol were to occur. Pipeline construction is, of course, affected by new pool discoveries and the rate of new well construction. It also will be affected by future decisions on means of transport of Alaskan oil and natural gas.

Break-even costs for gas-well ICP protection, determined against utility power, range from \$9 per peak watt to above \$40, as a function of power level required, distance from utility power, and climatology of each site. The current sales of photovoltaic ICP systems in Kansas show that at certain sites current array prices are already competitive under 20-year life assumptions. Application to deep wells with their higher power requirements will probably have to await array prices of from \$1 to \$5 per peak watt, a range which may be entered by the end of this decade.

Market estimates for shallow wells are based on the assumption that about 10,000 wells will be protected by photovoltaic ICP by 1985, requiring a cumulative power of about $600 \text{ kW}_{\text{pk}}$ with the annual rate in 1985 at $100 \text{ kW}_{\text{pk}}$. About 6000 deep wells may have received ICP protection using photovoltaics by 1985, at a cumulative power level of about $4.5 \text{ MW}_{\text{pk}}$ and an annual rate in 1985 of $800 \text{ kW}_{\text{pk}}$.

The pipeline market estimates are based on the assumption that between 10,000 and 20,000 miles of pipeline will receive photovoltaic ICP protection by 1985 in the U.S., for a cumulative power level of between 1 and 2 MW_{pk} , with the annual rate in 1985 running at between 0.5 and 1 MW_{pk} . The lower break-even costs associated with the higher power levels required for pipeline installations, between \$2 and \$4 per/peak watt, will probably prevent a significant market from developing before 1980.

About 550,000 miles of gas distribution piping existed in the U.S. in 1974, of which about 54% was iron or steel, with about 8000 miles of steel piping being installed in 1974 either as replacement or for new distribution networks. This rate of installation has been fairly stable since 1963 and probably will not decline in the future. It may, in fact, increase as older city piping needs to be replaced, although much of the replacement piping may be plastic rather than steel. Based on a power requirement of about 1 mW_{pk} per foot of average diameter distribution piping, the total cumulative market by 1985, on the basis of 10% penetration by photovoltaic ICP, may reach about $260 \text{ kW}_{\text{pk}}$ with the annual rate at about 4 kW_{pk} . In water distribution,

a total of 220,000 miles of combined transmission and distribution pipelines were in service in 1970, the latest date for such statistics (Reference 46). Under the assumptions of about 165,000 miles of this total in urban distribution line service, an average requirement of about 10 mW per foot of pipe, and at 10% penetration by photovoltaics, the total cumulative market for this application could reach 900 kW_{pk} by 1985, with the annual rate running at 100 kW_{pk} during that year.

3.2.5.3 Indian Reservations

Reason for interest in Indian reservations as a market for photovoltaics is self-evident. Many of the habitations and communities on such reservations are remote from utility power; power line costs range from \$15,000 per mile and up; engine-generator power is used for many such communities; fuel transportation costs are higher; solar insolation is higher than average on many reservations, and trained manpower for efficient maintenance of engine generators is limited. In addition, it was hoped that the Bureau of Indian Affairs (BIA) would prove to be a centralized source of information. Further, the degree of development of tribal economies is similar to that of many developing countries, making Indian reservations of interest not only for the market they represent, but also as a means for modelling requirements of the export market, and for demonstration of devices capable of meeting these requirements.

Contacts were made with BIA and tribal personnel in the field, and with the BIA in Washington to ascertain where photovoltaics have already found use and where potential applications might be found. In practical terms, the only use for photovoltaic power to date has been for powering of 6 VHF radio repeaters in remote locations. A recent newspaper article indicates that solar power is also being used with a microwave repeater network associated with a Navajo telephone utility. Although no officially organized survey of alternative energy needs on reservations could be identified, BIA and tribal officials indicated interest in a large variety of energy applications in locations where power is not available today or where only engine-generated

power is available. Prior or current study effort by anyone to determine optimum power sources for these applications from the many candidates such as utility power, engine generators, solar thermoelectric, or photovoltaic, could not be identified, making it difficult to obtain quantitative estimates of potential markets. Many of the tribal officials would have preferred to have power system mission analyses performed but lack the resources to do it themselves. Apparently some surveys of solar thermal needs have been performed by local academic institutions under various government agency sponsorships, but these have not been paralleled by surveys of electric power needs.

Indian reservations have many applications similar to those discussed in other sections of this report. There is need for various types of remote sensors, for signals such as highway signs and airplane landing strip lights, for communication systems, emergency call boxes, and water pumps for range cattle and human drinking water, and for irrigation. In addition, requirements can be identified which are not common to other regions of the country. Many habitations have no electric power for lights, refrigeration, radio and TV reception. Schools must operate with engine-generator power to supply school building needs, and are often required to perform a power supply service for the family habitations which grow up in small communities around schools. Remote medical clinics require power for routine services such as X-ray examination, refrigeration of drugs and vaccines, residential needs of clinic personnel and the occasional patient requiring lying-in treatment until removal to a hospital facility. Recreational camps are operated on reservations which require power to attract tourist business.

In order to obtain specifics on load characteristics and on numbers of load points, the BIA agreed to circulate a questionnaire prepared by Aerospace among 19 tribes in Arizona on a trial basis. Should the response from this experiment prove productive, the Bureau planned to cooperate in expanding the data base to all Indian tribes. Although four responses to this

questionnaire were received, indicating interest in exploring solar energy utilization on the respective reservations, the data requested on the questionnaire were not supplied. Follow-up telephone calls to the respondents indicated that internal surveys to establish electrification needs have either not been performed or are currently still in progress. Only limited understanding of the technology, and of differences between different modes of solar energy utilization, was found at this time.

It appears that mere circulation of questionnaires will not suffice in determining reservation energy needs. Direct participation in physical surveys and in educational seminars is needed to develop a data base which would allow estimates of power needs and performance of economic tradeoffs to select an optimum power generation technology for each application. Demonstration projects are required not only to convince the local decision-makers that limited funding should be expended on the selected technology, but also to permit early training of personnel required for its subsequent utilization. Such activities should, however, not be constrained to photovoltaics but should encompass all of the potential alternative power generation modes.

There are not sufficient data to permit market estimates for Indian reservations. The limited sampling which was possible indicated a need to replace gasoline and wind-powered water pumps, and to add to the pumping capacity available. The San Carlos Apaches reported that some cattle were lost this past season because of lack of pumping capacity. The Papagos reported that about 30 villages on their reservation had no electric power of any type. The Navajoes indicated that cottage industry, specifically jewelry making, would be enhanced by the availability of residential power. The Havasupai would like to replace diesel generator power with a source requiring less maintenance, as would the Papagos for recreational camp sites. The Southern Pueblos wish to replace their wind-powered water pumps with a lower maintenance type system, and so on. Further market survey activity in this area is recommended.

3.2.5.4 Railroads

Two potential railroad applications for photovoltaic systems have not been included in previous report sections. One is to provide power for lighting of railroad caboose cars and for powering the VHF base station radios used by the crews for communications also while in yards. The other application involves illumination of grade crossings as a minimum safety measure when signals and gates are not provided.

There are about 25,000 caboosé cars in use on American railroads at this time. The general practice appears to be to provide power with car axle-driven generators which, consequently, cannot provide power during stationary periods. Short periods can be accommodated through use of a secondary storage battery. However, cabooses with live-in crews are often required to remain in marshalling yards for periods of weeks, for which battery capacity is inadequate. Load requirements include mainly about 120 W for lighting and 30 W for the VHF radio, with an average continuous load estimated at about 25 W, based on a relatively low duty cycle for both loads. The number of cabooses will probably remain about the same through 1985. Institutional considerations are likely to prevent too rapid a conversion to photovoltaic system power and the power level will permit competition from small gasoline-powered generators until the early 1980's when break-even costs in the order of \$2 to \$3 per peak watt are attained. This potential market is therefore estimated at a cumulative power of about 1 MW_{pk} by 1985, with the annual rate of sales in that year at about 400 kW_{pk}. Not enough information on crossing illumination requirements could be obtained so that estimates of this market are not feasible at this time.

3.2.5.5 Recreational Applications

3.2.5.5.1 Cabins

Second homes in resort locations appear to have potential for photovoltaic power. However, the average power levels of from 1 to 2 kW of equivalent continuous power for lighting, refrigeration, radio, and

other uses produce break-even costs against engine-generated power which will not be reached until 1985, and these uses are, therefore, outside the scope of this study. Reference 29, which offers 1967 data, contained the latest statistics available for the second-home market. Based on those data and other estimates, it is believed that by 1985 only about 7500 second homes per year will be constructed in the U.S. without connection to an electric utility of any type, and will be either totally without electric power or will be relying on a private engine generator set, most likely using gasoline. Even when photovoltaic cost break-even is reached, second homes will not be a major market on an individual power supply basis, but will have to wait for the time when it becomes cost-effective to provide small community power systems using photovoltaic arrays.

3.2.5.5.2 Camps

Based on Reference 77, there are about 320,000 campsites in about 5500 public parks, such as federally operated sites in National Forests and National Parks, and those operated by states and counties, etc. There are over 640,000 private campsites, the majority of these with available power; however, the majority of the public sites do not have power. One of the features of campgrounds is toilet facilities, which are often primitive and require frequent chemical control to assure sanitary conditions. In addition, leakage from septic tanks is an environmental danger and room for proper drainfields may not exist. Data are not available on the number of prospective sanitary facility sites, that is, the number of campgrounds having the number of campsites considered a minimum for toilet installation. One 8-fixture installation at Custer National Forest in Montana was reported (Reference 78) to be using a closed cycle, oil-flush sanitary system requiring a 360 W_{pk} panel. According to this reference, photovoltaics have nearly reached cost break-even with gasoline generators for this application. On the assumption that about 10,000 such facilities are required in the public parks, and that 50% may not be served by utility power or other locally generated power, 5000 sites averaging 4 fixtures each and requiring about

250 W_{pk} may be candidates for photovoltaic power. Since gasoline generators are the primary competitive power source for this application, required array break-even costs are low, in the order of \$2 to \$3 per peak watt, and economic installations may not take place until 1980 or later. A total cumulative market of between 0.6 and 1.0 MW_{pk} is therefore estimated by 1985, with annual sales at 250 kW_{pk} in 1985.

The unavailability of data concerning the power facilities existing at the 5500 public campgrounds made it equally difficult to size the market for other potential uses of photovoltaics, such as campground lighting, refrigeration, emergency medical facilities, visitors information centers, etc. Interest in some of these applications is indicated by responses to questionnaires sent out by NASA Lewis Research Center, which will result in the demonstration of photovoltaically powered camp refrigeration and visitor centers under ERDA sponsorship. Personnel of the Recreation Vehicle Association suggested the need for camp lighting on the basis of informal surveys performed by them. Assuming (for preliminary scoping) an eventual requirement for 500 visitor centers (about 10% of the total number of public campgrounds) at a minimum of 5 kW_{pk} each, camp lighting at 20% of the public campsites, or about 32,000 sites at 100 W_{pk} each, emergency medical facilities involving lights and refrigeration at 500 W_{pk} each, yields a cumulative power requirement of 6 MW_{pk}. To establish whether the public agencies would have sufficient funding to purchase these equipments, and the year when the total installations would be completed, would require contact with every one of the agencies involved. Economic break-even cost analysis is not adequate to determine penetration of this market since institutional factors appear to outweigh competitive economics in these buy decisions. These factors presumably have prevented the use of gasoline generators to supply these power needs up to now. The issue of whether to utilize photovoltaics is thus likely to be subservient to the basic issue of desirability of providing power for these services.

3.2.5.5.3 Recreational Vehicles

The recreational vehicle market has been briefly examined for potential photovoltaic applications. At least one manufacturer of high-priced motor homes has already offered battery float-charging by solar cell array as standard equipment on its higher priced models, and as an optional item for the lower priced models. These chargers are sized at about 3.5 W_{pk} and retail at about \$70 per peak watt. As discussed in Section 3.2.1, float charging appears to have good prospects for secondary batteries used in services where prolonged periods of stationary non-use are anticipated, removed from the convenience outlets of residences, commercial and industrial buildings.

The major electric power consuming appliances in motor homes and truck campers are refrigerators, air conditioners, and lights, and little need is seen by the manufacturers of such vehicles and their trade associations to provide alternate power generation for their operation. Most of these vehicles are operated sufficiently often to permit engine-coupled alternators to recharge the secondary batteries which power the appliances. Also, the most common models will not use refrigeration-type air conditioning and thus require only about 25 W for a small 12 V refrigerator, 5 W for the blower associated with an evaporative cooler, and perhaps a maximum of 150 W for interior lights. The more expensive motor homes or trailer homes do require more power for a more extensive complement of appliances and for refrigerated airconditioning. In those cases, built-in motor generator sets are provided which, in some few instances, produce up to 65 kW of power but, on the average, range from 2 to 5 kW. To replace a 2 kW power plant with photovoltaics under the assumption of 50% duty cycle and 1 day's energy storage might require up to 24,000 Wh of secondary battery storage, weighing about 2400 lb and costing at least \$1200 at current performance and cost characteristics. Since this is believed to be impractical for recreational vehicle applications, no attempt at sizing this market was made. Reference 79 indicates that the rate of sales of motor homes was 118,000 units

and that of truck campers was 46,000 in 1975. The 10% growth experienced in the past may not be sustainable in the future because of increased purchase and operating costs of such vehicles. Assuming an average 5% growth rate through 1985, a 10-year life, and an average 10% penetration by photovoltaic float-chargers, the cumulative market for float-charging in recreational vehicles only would reach 680 kW_{pk} by 1985, with an annual rate of about 100 kW_{pk} for this purpose in 1985.

Mobile homes for recreational use fall into the second-home category, which has already been discussed. Not only will the near-term market be very small, but mobile home manufacturers contacted do not appear to have any near-term planning interest in photovoltaics as a power source for residential applications. Very few mobile homes used for this purpose are sold for use in areas where utility power is not available. The industry also does not provide for this possibility by equipping homes with special low power-consuming or DC-using appliances. The primary current interest of the mobile home industry in solar energy appears to be centered on solar thermal space and water heating.

3.2.5.6 Highway Applications

3.2.5.6.1 Corrosion Protection

Highway signal and sign applications have already been discussed under Section 3.2.4. A substantial market should, with high probability, grow from current experimentation with cathodic protection of concrete bridge decking. Protection for the steel reinforcing rods (rebars) in the decking is required primarily because of chloride ion attack due to winter de-icing with salt. Salt corrosion is also experienced on roads near seashores, or on causeways connecting islands with the shore. Corrosion prevention is possible with proper coating of the rebars or of the road surface itself, with anodic protection using zinc or magnesium anodes, or with impressed current cathodic protection (ICP). The latter is the easiest to apply once corrosion has started when coatings have broken down. Papers on the subject are not definitive concerning the optimum system of protection. However,

galvanic anode systems have some drawbacks for the bridge decking application. These relate to the upper limit on voltage represented by the galvanic system potential and to the fact that current output is influenced by uncontrollable factors such as soil moisture and soil electrolyte concentration. Coating systems have an obvious disadvantage in that repair of imperfect coatings essentially requires replacement of the bridge decking. Information on cost comparisons between the various protective schemes was not found during this survey, except that waterproof membranes over the rebars to prevent migration of chloride ions to the steel can be effective, but appear to cost more than the ICP systems by a factor of 3 or 4.

Power requirements for bridge decking ICP systems are remarkably low, and thus make them of particular interest for photovoltaics. These requirements vary, of course, from location to location, and are a function of surface area to be protected, the density of the reinforcing steel mat, and the local corrosion potential. Reference 80 reports a current density requirement of about 0.7 mA per square foot of surface at 1.65 V for an experimental installation in the California mountains, while Reference 81 reports variations in current density from 0.15 to 1 mA per square foot at about 1 V for installations in Ontario, Canada. For average size highway bridges, power requirements would range from 12-20 W at between 1 and 3 VDC.

Break-even costs were computed for a 1-mile power line extension and a 20 W equivalent continuous load and resulted in a cost of \$100 per peak watt. When computed against the use of zinc-air primary batteries to be replaced once a year, break-even cost equals about \$70 per peak watt. Many of the bridges requiring protection are in mountainous terrain where both the distance from power and the cost of power line extensions are larger than the assumed values resulting in the above break-even costs. It is most probable, therefore, that the great majority of highway bridges requiring ICP protection would find photovoltaic power supplies more than cost-competitive against conventional power.

Secondary data sources are again inadequate in providing a firm data base for market estimates. Reference 82 provided information that there are about 560,000 highway bridges in the U.S., of which about 250,000 are in the Federal Aid System. About 90% of these bridges use Portland cement decking requiring steel reinforcement. However, the number of bridges utilizing salt de-icing is unknown, as is the availability of utility power to these bridges. Although figures were available for California, they represented only estimates by qualified personnel since a specific census of the desired bridges has not been performed. In California about 10% of the Federal Aid System bridges receive salt de-icing, and 30% of these are remote from utility lines. To project this total of 3% of candidate bridges to the nation as a whole is unjustifiable since the California climate, and thus the icing problem, is not representative of the country. The estimate of potential markets therefore assumes that 50% of all of the bridges nationwide require de-icing at some period during the year or are exposed to sea air, and that only 20% of them are more than one-half mile from utility power. Of this 20%, only 50% are prospects for ICP for a variety of institutional reasons, and an average draw of 20 W will be required. That leads to a total potential market for photo voltaic ICP on bridge deckings of about 4 MW_{pk} of which about 1 MW_{pk} may be in place by 1985, with the annual rate during 1985 equalling 150 kW_{pk} per year.

This market will see a rather slow rate of realization because of funding constraints on highway improvements in general, and the relatively slow rate of innovation in the highway construction field. Reference 83 indicates that a number of states are studying ICP application to this problem but that additional studies under way in other states are considering alternative methods of corrosion inhibition in bridge deckings. Completion of these studies will probably be necessary before important numbers of ICP installations can be realized. However, one experimental ICP system has already been installed during the summer of 1976 by the Federal Highway Administration on a bridge decking of the George Washington Parkway near Washington,

D. C. , which is being supplied by a photovoltaic power generation system as a demonstration of the cost effectiveness of such power systems.

3.2.5.6.2 Lighting

Lighting of rural highway intersections has been shown by accident statistics to be effective in increasing the safety of highway travel (References 84 and 85). California traffic engineers also report that illumination of rural freeway exits reduces accidents. As in the instance of highway signs and signals, neither intersections nor exits are guaranteed to have commercial power available, nor is funding necessarily available for the installation of a lighting system even if power were at the site. Institutional factors may again predominate in sizing this potential market; i. e. , the question of need for illumination must be argued in the face of increased competition for the tax dollar for a variety of public purposes. As in the instance of signs, roadway illumination can be more economically provided with photovoltaic power when power lines are more than a few hundred feet distant from the highway, even though power draw is higher. These factors, as well as the absence of statistics on the actual number of sites requiring illumination and on local power availability, have prevented an attempt at estimating this market. Further investigation is recommended.

3.2.5.6.3 Depots

Highway maintenance depots have only periodic utilization in many instances, such as in the case of snow removal equipment depots, or depots in regions where winter snows prevent any regular road maintenance and therefore obviate the need for sustaining a crew on location. Many such depots are also remote from commercial power. When such depots are fully utilized, engine-generator power is used for housekeeping functions. When crews are not present over longer periods of time and only limited inspection functions are performed at infrequent intervals, operation of engine generators is not only uneconomic but their startup problems, according to highway district engineers, may not match their usefulness. Alternate power sources,

such as photovoltaic power, could satisfy continuous but minor housekeeping needs associated with security functions already discussed in an earlier section, and could also provide lighting and other support functions during infrequent visitations. Data on numbers of such depots and average power needs could not be obtained, so that market estimates are not furnished.

3.2.5.6.4 Rest Areas

Reference 62 states that about 7600 rest areas were located on Federal-Aid highways in 1974. About 7200 of these were in rural areas and were probably located near power sources to operate lights and sanitary facilities, if such were provided. No information is available on the number of rest areas which do not provide facilities, nor can it be learned, without state-by-state surveys, where such facilities would be installed if power could be made available, or how many additional rest areas would be provided in such circumstances. Reference 86 provides some clues as to lighting requirements. Power needs of sanitary facilities have already been discussed and may not be required if septic tanks and drainfields can be provided at some of the locations. On the assumption that lights would be activated by sensors only when vehicles use the rest area, a total of about $700 W_{pk}$ of array would be required to power both lights and sanitary facilities, and only about $400 W_{pk}$ would be needed for lights only. On the assumption that only about 25% of the existing rest areas are in need of alternate power generation, the total cumulative market could reach $1.3 MW_{pk}$. Institutional considerations again predominate over economic competitiveness in determining when such sales might be initiated and how fast penetration might proceed. However, it is assumed that about $500 kW_{pk}$ will have been installed cumulatively by 1985 and that sales in that year will reach $100 kW_{pk}$.

3.2.5.7 Emergency Power

Emergency power applications were examined even though the use of engine-generated power for this purpose was shown in Section 2

to be more economical in most cases. The possibility exists that for certain applications the higher startup reliability of photovoltaic systems, when compared to engine generators, might compensate for their higher cost.

A number of state and federal agencies charged with emergency planning and action functions were contacted to identify government programs covering emergency power supplies. It was found that, of the federal agencies directly concerned with national emergencies, only the Defense Civil Preparedness Agency (DCPA) actually provides emergency power systems or provides incentives for the installation of such equipment. This agency had for many years maintained stockpiles of generators at various sites around the country for loan to state and local governments in times of local civil disasters such as floods, fires, etc. The DCPA has, however, begun to divest itself of such stocks by selling them as surplus or by turning them over to state governments. It plans to concern itself only with war-related emergencies in the future. The Federal Disaster Assistance Administration does not maintain stocks of generators but requests either the DCPA or the Corps of Engineers to make them available when required.

The DCPA is concerned with several programs utilizing emergency power systems (Reference 87). One program works with local governments to set up Emergency Operational Centers which have a primary local command-and-control function in the event of war-related emergencies but are also available for civil disasters. It provides financial assistance to such centers if certain requirements are met, among which is that of standby emergency power generation capability. Power levels of such generation equipment range from 30 kW upward. About 1000 of about 3000 planned centers are in existence. The DCPA could specify alternative power sources but has not done so as yet, and has no plans to depart from conventional diesel generator sets with a two-week fuel supply.

Another program, the Emergency Broadcast Protection Program, has provided about 600 radio stations in the U.S. with backup power in the form of diesel generators ranging from 50 kW to 750 kW in size to assure means of communication with the public in the event of national emergency.

The DCPA and the Federal Preparedness Agency also are concerned with a number of hardened relocation centers near the Nation's capital which will receive key government personnel in the event of nuclear war threat in order to maintain essential governmental functions. These centers are also equipped with baseload and backup power systems, presumably based on diesel generators. No personnel could be located during this survey who were able or willing to comment on the desirability of photovoltaic power for these applications. In some of these use categories, sufficient survivable surface area for the arrays would not be available. In others, sufficiently reliable backup systems, i. e. with adequate redundancy, are already installed. Engine generator reliability is assured by a program of periodic startup and maintenance, and concern over insufficient reliability was not noted in any of the contacts made during this phase of the survey.

Other governmentally mandated emergency standby power installations exist such as for hospital operating rooms and related facilities. This survey was unable to explore this applications area any further due to time and resource limitations. Further investigation of emergency standby power as a potential market for photovoltaics may not be warranted because of the generally poor economics of solar cell power in such applications.

3.2.5.8 Other Applications

3.2.5.8.1 Float Charging

Float charging or battery recharging has already been discussed in several sections of this report. The recharger market for consumer electronics and other miscellaneous float-charging applications was sized in Section 3.2.1 at between 10 and 20 kW_{pk} cumulative to 1985, with annual rates in the order of 3-5 kW_{pk} by that year. Section 3.2.3 discussed the potential for aircraft float-charging and estimated a maximum cumulative market of about 20 kW_{pk} by 1985 for this application, with annual rates of about 5 kW_{pk} at that time. Float charging for recreational vehicles was discussed earlier in this section. Another application which was thought

amenable to either battery recharge or float-charge by photovoltaics was recreational boating, since it was noted that some panels (total wattage unknown) were already being sold for that purpose by mail order houses such as Edmund Scientific, and, reportedly, by boating accessory dealers on the East Coast.

3.2.5.8.2 Boating

Contact was made with boating safety officers of the Coast Guard, with marine association personnel, with manufacturers of boating electronics, and with wholesale and retail merchants in the boat equipment field in the Los Angeles area for relevant data, as reported under Section 3.2.3. It is assumed that photovoltaic recharging would be unlikely for any boating application other than cruising sailboats, which now must run their engines for a period of time each day to maintain battery charge during prolonged cruising. Boats berthed dockside usually have utility power available for battery recharging or float charging. Trailered boats may have some difficulty in recharging, depending on their place of storage, but few of these are used in circumstances requiring substantial energy storage. Two classes of cruising sailboats were examined for potential power requirements. Once, considered in the luxury class, was equipped for this analysis with a variety of electronic gear, including HF/VHF radio, radar, Loran, RDF, depth sounder, and so on, plus conventional lights, pumps, heads, etc. A more modest equipment roster was sized for the second class of cruising sailboat examined. This modest complement included only speed and direction finder, depth sounder, and VHF radio in the electronics category, but equalled the luxury boat in electrical needs except for exclusion of a powered head and an electric fresh water pump. The equivalent continuous loads were computed to be 16.5 W for the modest boat and 55.7 W for the luxury boat.

For an average cruise duration of 7 days (7 days storage), the modest boat would require about $70 W_{pk}$ of array. The luxury boat would require a $240 W_{pk}$ array to permit a 14-day cruise without engine operation.

In both instances, it is, of course, assumed that engine operation for boat maneuvering-related operations would not be required. The question of providing 12 to 14 square feet of area on the topside of the modest sailboat, and 45-50 square feet of area on the luxury boat, where arrays could be safely installed with assurance of maximum insolation, was not addressed in detail by this study. It is, however, questionable that this area would be available for rigid panels, and it was concluded that sailboat applications would more likely be in the area of float charging which could be accomplished at about $0.3 W_{pk}$ or less.

As indicated earlier, only information on boat storage conditions in the Los Angeles harbor and adjacent marinas was available to this study. This indicated that over 95% of the boats requiring power and in relatively active use, i.e., no less than every second weekend, are berthed alongside docks with utility power. Most of the other boats are used in a very limited daytime operational mode which does not even require running lights, or are stored on residential property with plug-in power available for battery float-charging or periodic recharging before use.

Among the almost 800,000 sailboats without inboard power, the 240,000 sailboats with inboard power, and the 550,000 motorboats registered in 1975, there are undoubtedly many which would benefit from photovoltaic float charging for reasons related to both individual use and storage patterns. Unfortunately, no secondary data are available to allow estimates of their number.

3.2.5.8.3 Water Purification

Water purification by ozonation was briefly examined because of the relatively low power requirements of that technology and because it appears to be a growth market both in the U.S. and overseas. The obvious problem associated with the commonly used chlorination method of water purification, that of taste, may be increased in the future by concern about carcinogenic products from the chlorination of hydrocarbons in water supplies, and by the fact that chlorination appears to be of negligible effectiveness against viruses in water.

Ozone is a disinfectant and deodorizer but cannot provide for solids removal. Its application to drinking water purification must therefore be coupled to coagulation and filtration processes in locations where water supplies have an intolerably high solids content. It offers advantages over chlorination from an operational point of view since ozone can be generated on site from the oxygen in the air, and thus eliminates a material supply problem of importance in some regions of the world. On the other hand, electric power is required for the production of ozone but the power levels are sufficiently low to permit consideration of photovoltaics. For example, villages requiring purified water only for personal hygiene, drinking and cooking may require about 20,000 gallons of water per day per 1000 persons. Ozonation of this quantity of water could be accomplished at about 150 to 200 W of power.

Two methods of generating ozone are available, the conventional corona discharge process requiring about 10 mW of power per gallon/day and a new technique using electron irradiation by electron beam accelerators, and requiring about 7-8 mW per gallon/day of water. Additional power is required for ancillary functions such as airblowers, dryers, and water pumping, where required, and, of course, filtration when needed.

This application may be primarily of interest for overseas markets although a number of sites in the U.S. may exist at which bacterial contamination would require too high a chlorine content and where lack of utility power has, up to now, not permitted any other purification methodology. This applications area is recommended for further investigation.

3.2.5.8.4 Construction Sites

Reference 4 includes construction sites among potential applications of photovoltaic power but provides no specifics on such applications. The use of float charging of construction equipment standing idle for periods of several days has already been mentioned in earlier sections of this report. Another possible application exists in portable sanitary facilities,

where servicing costs and periodicity could be reduced by a variety of powered toilet designs, ranging from the already-described oil flush system to incinerator systems, or perhaps devices in which electric heating is used to promote more rapid bacterial conversion of waste materials. The obvious disadvantage in applying photovoltaic power to such uses is the naturally hazardous environment of construction sites and the potential for vandalism and theft which might increase operational costs. Cost break-even calculations were not performed since data on the economics of this sanitary service were not available.

Security applications appear also to exist at construction sites for powering intrusion detection systems and alarm bells, or silent alarms using radio relay systems, limited lighting, and possibly high voltage defensive fence systems. Road construction sites would have requirements for barrier warning flashers already discussed earlier in this report. A number of hazard conditions generally exist on construction sites which could be reduced with photovoltaically powered warning devices such as flashers, horns, or semaphore signs. Annunciator systems also could be so powered. Market estimates could not be performed, however.

3.2.5.8.5 Minor Uses

Solar cells are being used on battery-powered watches, calculators, and similar consumer items. Although these products may be sold in millions of units per year, individual power levels are in microwatts, making a total market size measured in a few hundred watts.

In summary, those miscellaneous applications discussed above for which market estimates could be made, total to a cumulative market potential of 30-40 kW_{pk} with an annual rate in 1985 at 8-10 kW_{pk}.

Many potential markets for photovoltaic power generation exist and have some probability of exploitation during the near term, that is, between now and 1985. Although it is believed that the more important markets have been identified, only a few of this number could be examined in detail during this survey, and of these, only a fraction could be described with quantitative estimates of market size. Table 20 summarizes the estimates which resulted from this study. It also lists the other application areas of sufficient promise to receive some review by this study but about which insufficient data were available to permit market estimates. Among these unquantified markets are several that are likely to be quite sizeable, including a number of highway and railroad applications, farm applications, and applications on Indian reservations. Since the total number of promising application groups was more than twice as great as the number represented in Table 20, it is reasonable to estimate that the total market may also be at least twice as great; or more than 25 MW_{pk}/year in 1985.

Only U.S. civilian applications were considered in this study. Many of the applications reviewed in the study, however, are believed to have greater market potential in developing countries than in the U.S. Photovoltaic industry representatives, in fact, are agreed in estimating that such foreign markets may be two to three times larger than the U.S. market over the near term. Since the U.S. military market may also be very substantial, it is clear that the projected 25 MW_{pk}/year of U.S. civilian array sales in 1985 represents only a fraction of the probable sales of photovoltaic power generation equipment which the solar cell and related industries may enjoy on a global basis.

The impact on the projected market of a number of possible developments could not be evaluated by this study, primarily because of an insufficient data base associated with photovoltaic terrestrial applications.

Table 20
SUMMARY OF MARKET FORECASTS

Application	Cumulative Power by 1985, in kW _{pk}	Sales in 1985, in kW _{pk}
Battery Chargers for Consumer Products	15	3
Intrusion Detection	1,300	120
Earthquake Observation	9	3
Environmental Observations	34	6
Highway Call Boxes	250	10
Emergency Location Transmitters		
Aircraft	65	15
Marine	50	20
Radio Control	700	100
Repeaters		
Common Carrier	4,300	600
Private Microwave	3,500	800
UHF/VHF	3,200	550
RR Crossing Signals	1,400	160
Highway Signs	9,000	3,000
Marine Navigation Aids	400	35
Other RR Applications	1,000	400
Drip Irrigation	22,000	5,000
Recreational	1,700	350
Industrial Corrosion Protection	8,300	2,000
Bridge Decking Corrosion Protection	4,000	150
Highway Rest Areas	500	100
Miscellaneous	35	9
Total Forecast	62,000	13,300

(Table 20 Continued)

Potential Markets for Which Quantitative Forecasts Were Not Feasible

Fire Detection Sensors

Approach Sensors

Pollution Monitoring Instrumentation

Status Sensing Instrumentation for Water Utilities

Location Sensors

Community Call Boxes

Air Traffic Beacons and Radio and Lighted Landing Aids

Railroad Block Signals and Controls

Highway Traffic Signals and Controls

Fixed and Mobile Radio Stations

Rural Telephone Systems

Radio and TV Receivers (remote locations)

Utility Meter Reading Systems

Billboards and Lighted Annunciators

Offshore Platforms

Obstruction Lights

Drinking Water Well Pumping (ranches)

Miscellaneous Farm Applications

• Water Well Casing Corrosion Protection

Water Distribution Piping Corrosion Protection

Indian Reservation Needs

Grade Crossing Illumination

Campground Power

Highway Illumination

Highway Maintenance Depots

Boat Battery Float Charging

Water Purification

Construction Site Applications

These developments could include slower (or faster) than predicted solar cell array cost reduction, more rapid increases in the cost of fossil fuel, more rapid progress in the development of competing power sources suitable for the remote applications of primary interest in the near-term, and so on. Price elasticity effects also could not be estimated with the available data base. The effect of government incentives in increasing customer acceptance at an earlier date is not known, although it can be safely assumed that government spending in, for example, the highway program, if redirected into channels favorable to alternative energy systems such as for providing signs rather than for road construction, would have a major effect on solar cell markets. Federal subsidies to economic development programs such as on Indian reservations also could be redirected to result in increased utilization of solar energy.

When compared to the sales of about 100 KW_{pk} in 1975 for terrestrial application of photovoltaic power, the quantitative cumulative projections for 1985 in Table 20 indicate a very rapid growth of almost 70% per year in sales, on the average, between 1975 and 1985. In actuality, of course, because of the additional potential applications listed and because many of the markets will materialize after 1979, growth rates could be much higher than 70% in the 1980-1985 period.

Realization of the market forecasts presented in this report will depend to a major extent upon amelioration of several fears expressed by potential users of photovoltaic devices. A number of uncertainties exist in perception of the practicality of such devices, especially as related to their use in remote, unmanned locations. Arrays must be exposed to the sun, they must be angled to increase insolation efficiency, and they, therefore, become more visible and attractive to the type of individual who is also afflicted with a desire to use road signs for target practice or to irrationally damage property in general. Additionally, at least in the near future, arrays will be valued at from \$50 to \$100 per square foot (even more per unit area for smaller arrays) and will have associated with them other valuable equipment items such as power-conditioning systems and battery storage. An economic motive for theft will therefore exist. Applications for railroads and for highways will be particularly vulnerable to these dangers of vandalism and theft. Potential users in these industries have sufficient experience with such dangers to be particularly aware of the increased hazard to photovoltaic installations as compared to massively encased battery storage at present or to engine generator sets housed in resistant structures.

Other uncertainties relate to claims of long periods of operating life under harsh environmental conditions. The life of 20 years assumed by this study for applications on land, which is often exceeded in manufacturers' claims, is viewed with skepticism by most prospective users because of the lack of convincing life test data. Some of the larger industrial or governmental users contacted by this study have their own testing laboratories and could undertake accelerated life testing, if desired. Most other prospective customers, at this time, must accept such claims on faith alone and seem to find this difficult.

Another important concern relates to the inability to draw upon many years of operating experience in formulating purchase specifications meeting specific needs in specific geographic locations. Some of the personnel contacted during this survey reported receiving proposals for photovoltaic

power supplies with very high ratios of peak-array power to equivalent-continuous-demand, and with similarly excessive battery storage capacity. There was doubt whether such equipment might not be oversized for their needs, and thus much more costly than necessary. Lack of confidence in the warranties offered by suppliers of photovoltaic equipment is a frequently expressed concern by organizations without resources to do their own acceptance testing, and conscious of the relative youth and absence of performance record of the supplier organizations.

Some of these user concerns could be relieved by equipment suppliers themselves or by an industry association; others would benefit by government action. Among the latter could be product acceptance testing, the preparation of model purchase specifications and standards to cover as many potential applications as possible, the distribution of instructions in the sizing of photovoltaic power supplies for individual needs, and the provision of necessary insolation statistics. Demonstration programs designed to show operational reliability and resistance to environmental degradation are important governmental activities which would contribute to user confidence, as would coupling the demonstration of power generation capability with that of protective systems designed to reduce or eliminate vandalism and theft hazards.

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SECTION 4

RECOMMENDATIONS

4.1 MARKET STUDIES

As indicated earlier in the report, a number of potential markets for photovoltaic power systems were only cursorily investigated, while others received essentially no attention. In some instances, the lack of attention was due to insufficient study resources to cover so large a number of potential applications; in others it was due to lack of available data. Sellers of photovoltaic devices will no doubt have an interest in exploring all potential markets to the fullest extent possible. Government, in its role of furthering the use of photovoltaics as an alternate energy source, might wish to sponsor studies which would increase understanding of the possible fossil fuel displacement and of the factors leading to public acceptance of this new technology. It is believed that the market survey reported herein has made a good beginning in accomplishing these governmental goals, and that it has provided a better understanding of the remaining tasks to be completed in meeting these goals. Probable near-term markets have been roughly sized, and attention has been drawn to promising market areas which should now receive additional industry marketing attention. The ERDA-sponsored market studies initiated in early 1977 with InterTechnology Corp. and with the BDM Corp. will add valuable data to these results, particularly with respect to foreign markets which were not covered by this study.

It is believed that this study, together with the two studies mentioned above and the survey of military requirements being performed by the Mobility Equipment Research and Development Command, is sufficient to provide an order-of-magnitude estimate of near-term markets for photovoltaic devices in the U.S. Further refinements of this estimate are not required to

draw the conclusion that the specialized, and consequently limited, applications which represent markets at array costs down to \$1 per peak watt will probably not, by themselves, support the production of 500 MW/yr of arrays in 1985. Important fossil fuel displacement will more probably evolve from application of photovoltaics to mass markets which may be widely penetrated when either lower array and/or concentrator prices are achieved or power costs are lowered by utilization of waste heat, such as in total energy concepts.

Since the realization of substantially lower array prices, or of novel power generation and marketing concepts producing lower power costs, is more likely to take place beyond 1985, it is recommended that future market studies concern themselves with the definition of applications in the mid-term and far term, that is, when cost of power generated by photovoltaic means can compete with diesel generator and utility power at the 1.0 MW level as a minimum. Such studies would consequently concern themselves with community power systems, on-site power generation for larger residential, commercial, and industrial complexes, and with the investigation of total energy, hybrid, and integrated utility concepts for such applications.

When the information in this report is combined with that generated by concurrent military and other studies and with the results of earlier efforts, there should be sufficient data available to plan test and demonstration programs. These programs would be designed to acquaint the public with operational characteristics and advantages of photovoltaic power for near-term applications, and thus to promote an increased production base to cope with the more important uses expected to materialize later with lower array costs. Future market studies should therefore concentrate on defining promising application areas which require longer lead time for test and demonstration planning and effectuation, and should be concerned with motivational and institutional, as well as purely economic factors, since all are important in assuring realization of the goal of commercializing the use of photovoltaics to reduce reliance on imported oil and gas.

As indicated above, early demonstration programs should have the twin goals of calling attention to photovoltaics as a convenient and economic alternative power source in applications areas where a near-term large market potential exists, and in proving claims about photovoltaic characteristics about which there is user concern.

Demonstrations are believed to be of particular value in increasing market potential when they address applications which may be created by the availability of alternative power sources. For example, many highway needs in the field of signalling have never been met because of the absence of economic power suitable for remote application. The demonstration of photovoltaic power as a practical and economic power source may thus create a new market in which no existing power source is being displaced and for which, therefore, the usual economic competition criteria are less critical. For another example, the development of Indian tribal economies will eventually require electrification of large territories which at this time know no other power than an occasional engine generator. Although this is a market in which photovoltaics must compete with other possible power sources, the economic and institutional disadvantage of displacing an existing power source is not present, and early demonstration may thus assure a market when array prices become competitive. Another promising area for demonstration includes drip irrigation because of its large market potential and its power needs which appear to match photovoltaic capabilities particularly well.

The other area in which demonstrations are important is in overcoming skepticism concerning practicality under normal operating conditions. Examples would involve demonstration under severe climatological conditions, and in situations where hybrid systems are required to meet all of the power needs of a particular site. Combined solar thermal and photovoltaic system applications, such as for mountaintop microwave repeater stations where the equipment housing might require space heating or cooling,

would make desirable demonstrations. Another characteristic to be demonstrated in overcoming user skepticism would be the ability to protect photovoltaics against vandalism and theft, perhaps using its self-powering characteristic in accomplishing this goal. Highway signals and railroad applications would be useful candidates for demonstration of such capabilities, as would construction site applications.

Although the objectives of the ERDA Photovoltaic Program in achieving high volume array production early in the 1980's may only be partially advanced by the potential markets surveyed by this study, demonstrating selected applications from this early market will help in establishing an industrial base, and in building public awareness of the contributions which photovoltaics can make in addressing future national energy needs. The many interviews with potential users conducted during this study lead to the conclusion that demonstrations will be of great value in diffusing this new technology and in aiding its commercialization.

4.3 DEVELOPMENT ACTIVITIES

Interviews with prospective users of photovoltaic power generation devices have allowed the formulation of some recommendations concerning development program emphasis in order to increase the saleability of such devices and to increase their scope of application.

The need for reduction in cost is obvious and needs no further discussion. The need for design concepts offering greater assurance of protection against vandalism and theft has already been mentioned. Government sponsorship of the development of such protective system concepts and of their demonstration would be useful in reducing user concerns.

Charge and discharge control and other power-conditioning devices, suitable for the low power range of interest to near-term applications, should be developed under competent standards with specific attention to the design needs of photovoltaic systems. Model purchase specifications for photovoltaic systems should be developed and should include sections concerned with power-conditioning devices as well as with energy storage

systems. Storage battery standards and specifications should be developed to cover the range of near-term applications in terms of required charge and discharge characteristics.

General guidelines should be developed for regions of the country with similar insolation characteristics, which will permit the purchaser to at least preliminarily size his power generation and storage system prior to the detailed system design provided by the equipment supplier.

Specifications and standards are also required for encapsulation systems and other components affected by the climatological conditions under which the photovoltaic system is intended to operate. The purchaser usually desires to tailor such environmental protection to fit his needs, both in terms of assuring reliable operation, and in order not to be cost-penalized by designs intended for more severe environments than his application. The development of such specifications is recommended.

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APPENDIX

EXAMPLES OF COST BREAK-EVEN CALCULATIONS

A. 1 INTRODUCTION

The purpose of this Appendix is to provide examples of the simplified cost break-even calculation method used during this study to determine photovoltaic array break-even costs. These costs were used to determine whether photovoltaic power would be competitive with alternative power sources during the near term up to 1985, by relating the break-even cost with the array price goals postulated by ERDA. Both the cost assumptions and system conceptual designs were deliberately simplified to allow rapid screening of applications groups. These examples are therefore not intended to show how particular installation cost estimates would be prepared in order to make a purchase decision, but illustrate a way to determine a rough range of costs leading to a decision as to whether or not more detailed cost estimating is warranted for a specific application.

A. 2 COST BREAK-EVEN FOR PHOTOVOLTAIC ARRAYS AGAINST PRIMARY BATTERIES

For the general case, designed to exemplify the power levels at which it would be cost-effective to replace primary batteries with photovoltaic power generation systems, a variety of loads in the microwatt to tens-of-watt power range were examined. Since zinc-air primary batteries were used for all applications requiring a total energy discharge exceeding 150 Wh in all of the battery break-even calculations performed during this study, this battery system was used for this comparison. Lead-acid secondary batteries were used for energy storage associated with the photovoltaic system. These batteries were costed as follows:

Lead-acid storage	\$50/kWh (Investment Cost)
Zn-air primary battery	\$15/kWh (Energy Cost)

The primary battery is an expendable item, with its cost, therefore, charged as a recurring cost in life cycle costing, while the secondary storage battery is treated as a capital investment. The array was assumed to have a 20-year life, and the secondary battery a 5-year life. A blocking diode was the only charge control device assumed for the photovoltaic case. Power conditioning was assumed to be part of the power consuming system, and thus was not costed. In the power range examined, the end use applications would generally be remote instrumentation and radio relays. This power range also, however, included most of the marine navigational lighted aids now in use. The latter case is examined independently in this Appendix because of the special backup provisions it requires.

For primary batteries, the assumption of yearly replacement was made. In view of its remote location, a charge for at least one man-day per year for service would normally have to be added to the cost of the batteries. In view of the fact that the photovoltaic system should receive at least one visit per year at equivalent cost to service the secondary battery and to clean the array surface, such maintenance costs were assumed to balance and were not costed. Because of the low power levels assumed for this sample calculation, no costs were charged for array support (otherwise to be costed at \$15.00 per m²), site preparation, and other installation-related cost items.

The present value equation reduced therefore to the following terms, using the terminology of Section 2:

$$(CI_{\text{array}})_{\text{pv}} + (CI_{\text{storage}})_{\text{pv}} = (RC_{\text{battery energy}})_{\text{pv}} \quad (\text{A-1})$$

The present value factor for the photovoltaic array is, of course, equal to 1 since it is installed at the beginning of the first year of operation and is not replaced during the 20-year life used for this cost comparison. On the other hand, the secondary batteries are replaced every five years, so that, using Eq. (1) of Section 2.3, the present value factor becomes the sum of four factors, those for the initial year, the 5th year, the 10th year, and the 15th year, or:

$$1 + 0.82 + 0.68 + 0.57 = 3.07$$

The present value cost of the primary batteries was estimated on the basis of the assumption that annual replacement is required. In this case, Eq. (2) of Section 2.3 is used, with $g = 0.05$, $k = 0.09$, $N = 20$, so that the present value factor is

$$\frac{1.05}{0.04} \left[1 - \left(\frac{1.05}{1.09} \right)^{20} \right] = 13.8$$

Since the price year and operational year were assumed the same, the factor (p) in Eqs. (1) and (2) is set equal to zero.

Rearranging, substituting, and solving Eq. (A-1) results in:

$$\text{Break-even Array Cost} = \frac{1.81(10^6)}{7.2} = 2.5(10^5)(\$/\text{kW}_{\text{pk}})$$

The factor 7.2 in this equation relates the load demand to the peak watt rating of the array as discussed in Section 2.2. Array break-even prices can be computed on the basis of this equation and several of the primary battery prices of Table 2 and Section 2.3 of this report. If it is assumed that effective battery prices vary with system load, as a result of price reductions associated with quantity purchase, then the break-even array prices also vary with load as indicated in Figure A-1. It can be seen from this figure that current array prices are well below break-even. Photovoltaic systems have thus been cost effective in comparison to battery systems for some time. Because of the small variation of break-even price with load level, however, all of the battery calculations performed in this study have been based on the assumption of non-sensitivity of battery price to demand level.

A.3 COST BREAK-EVEN FOR PHOTOVOLTAIC ARRAYS AGAINST UTILITY POWER

For the general case, it was of interest to explore the effect of length of power line extension on the array break-even cost; with particular emphasis on determining at what power level photovoltaics might be competitive

Figure A-1
ARRAY BREAK-EVEN COST AGAINST PRIMARY BATTERY
POWER AS A FUNCTION OF LOAD DEMAND
OVER A ONE-YEAR PERIOD

with utility power even when situated adjacent to the power line. For this example, it was assumed that the power company would impose a one-time charge for the connection, for the transformer required to reduce voltage from distribution line voltage of 12 kV to that required by the application, or at a minimum, to 115 VAC, and for the power line extension. The utility would charge for service and energy on a monthly basis. The customer has to purchase a rectifier if his application requires DC power.

As in the previous example, all equipment, except for secondary batteries, was assumed to have a 20-year life, with batteries costed on the basis of a 5-year life. Although it is likely that a power line extension would have residual value after that period in terms of reusable copper and poles, no credit was allowed for this.

The photovoltaic system was assumed to require 3 days storage capacity, sized by the equivalent continuous load determined for the application. The utility power was backed up by 1 day of storage. In both instances, lead-acid secondary batteries were costed. A blocking diode was the only charge control assumed for the photovoltaic system. As in the previous example, service calls were not costed, the assumption being that these would be required for both systems to a similar degree.

The following cost assumptions were used:

Power line cost	= \$15,000 per mile (proportional for fractions of a mile)
Utility connection charge	= \$250 (fuse box, meter holder, electrical fittings and hardware, installation)
Transformer cost	= \$150
Rectifier cost	= \$20 for 1 W of load \$40 for 10 W of load \$200 for 100 W of load
Secondary Battery cost	= \$50 per kWh (investment cost)
Energy charge	= Variable (see Table 3 of Section 2.3)

The break-even cost equation, using present value costs, becomes:

$$\begin{aligned}
 CI_{\text{array}} = & CI_{\text{power line+connection+transformer+rectifier}} \\
 & + CI_{\text{battery backup (utility)}} - CI_{\text{battery storage(PV)}} \quad (\text{A-2}) \\
 & + RC_{\text{energy charge}}
 \end{aligned}$$

As in the previous example, the present value factors are 3.07 for the secondary batteries and 13.8 for the annual recurring energy charges over a 20-year period. The same escalation and interest charges were used. This equation reduces to:

$$CI_{\text{array}} = 15,000 (D) + 400 + CI_{\text{rectifier}} - 7370 (P) + 13.8 RC_{\text{energy}}$$

where D = power line length, in miles, and P = load, in kW.

Figure A-2 shows the results of solving this equation for three power levels ranging from 1 to 100 W, and for power line extensions out to one mile. It is evident that for low power levels such as between 1 and 10 W, photovoltaic systems would be cost-competitive at current array prices with utility power even at the power pole. As the power level increases, cost break-even requires longer power line extensions. Practically all of the remote instrumentation applications, and many of the radio repeater installations, are, however, in a load-and-remote-location regime which makes photovoltaics more than competitive with utility power, even on the basis of simplified costing as used for this example. Many signals applications also fall into this competitive power regime between 10 and 100 W of continuous equivalent power.

A.4 COST COMPARISON OF ENGINE-GENERATED POWER WITH PHOTOVOLTAIC SYSTEM POWER

This analysis was aimed at exploration of the effects of several cost and design assumptions on the comparative costs of energy from diesel

Figure A-2

ARRAY BREAK-EVEN PRICE AGAINST UTILITY POWER AS A FUNCTION OF POWER LINE EXTENSION

generator sets and from photovoltaic systems. Since one of the parameters to be varied was the price of photovoltaic arrays, generalized conclusions concerning competitive array prices as a function of size of electrical load and diesel fuel price could be derived.

Cost assumptions for engine-generated power were based on specific fuel consumption values and generator set prices obtained from engine manufacturers and shown in Table A-1 and Table 4 of Section 2.3 of the main report. Other costs and operating assumptions for this analysis are shown in Table A-2. This table also shows the assumptions underlying the photovoltaic system costs.

Life cycle costing using the methodology of Doane et al.^{*} was used to arrive at present value costs for the comparison. 1975 costs were

^{*}J. W. Doane, et al., "The Cost of Energy from Utility-Owned Solar Electric Systems," ERDA/JPL 1012-76/3.

Table A-1
DIESEL GENERATOR FUEL CONSUMPTION (SFC)

Rating in kW	100% Load, in gal/kWh	
	Aerospace	Army
1	0.122	NA
3	0.112	NA
5	0.105	0.13
10	0.094	0.11
15	0.090	0.11
60	0.074	0.09

Aerospace data based on manufacturers' input.
Army data from Refs. 30 and 31.

Note: The Army data are presumably based on actual experience with older machines and consequently lower levels of operating efficiency.

used in all instances except for diesel fuel for which two differing 1980 prices were assumed. Because of this, all costs were escalated to 1980, and the levelized energy costs for the two alternative systems were compared for 1980 as the initial operating year by determining present value costs over a 20-year life, multiplying these by the Capital Recovery Factor to annualize them, and dividing these by the total energy produced over one year. It was of interest to explore the effect of varying fuel price escalation on the energy cost comparison. As a consequence, fuel price was allowed to escalate at 5 and 10%, while all other costs were kept at a 5% escalation rate.

The present value equation for this comparison is shown in Table A-2. Equations (1) and (2) of Section 2.3 were used to determine present values of all of the cost streams, with operating cost, maintenance cost, and overhaul cost treated as recurring costs. The operating, maintenance, and overhaul cost factors shown in the table are based on manufacturers' data. These may be optimistic for applications such as those military ones in which the generators are operated and stored outdoors under inimical environmental

Table A-2
OVERALL COST ASSUMPTIONS

$$\text{Present Value Costs: } X_{pv} = CI_{pv} + CO_{pv} + CM_{pv} + COV_{pv}$$

$$\text{Capital Recovery Factor} = \frac{k}{1 - (1 + k)^{-N}}$$

	Engine Generator	Photovoltaic System
Capital Investment = CI	Equipment Cost Plus Installation Cost	Same as for engine generator, including battery replacements
Annual Operating Cost = CO	$F_f \times P \times 8760 \text{ hr/yr}$ where F_f = (Fuel Price) (SFC) P = continuous load in kW	NA
Annual Maintenance Cost = CM	$0.05 (CI) + 0.05 (CO)$	\$400/yr
Annual Overhaul Cost = COV	$0.25[CI(\text{Overhaul Factor})]^*$	NA
Year of Initial Operation	1980	1980
Inflation, %	5	5
Interest, %	9	9
Fuel Cost Escalation, %	5, 10	NA
Life of Installation, years (other than Batteries)	20	20
1980 Fuel Cost, \$/gal	0.50, 1.00	NA
Storage Battery Cost, \$/kWh	NA	50
Battery Storage Capacity, days	NA (Starting only)	3
Battery Service Life, years	5	5
Backup	1 on 1 with generator	Storage
Power Conditioning	AC/DC Converter	None
Equipment Housing, \$/ft ²	30	5 (Battery only)
Array Support Structure Cost, \$/m ²	NA	15

* Where Overhaul Factor is determined from:	<u>Size of Generator in kW</u>	<u>Overhaul Factor</u>
	0-5	3
	5-10	1.5
	10-15	1

- Notes: (1) Operating cost consists of only the fuel cost. Fueling operations, oil servicing, etc., are charged as maintenance cost, together with routine mechanical maintenance. Major maintenance involving parts repair or replacement are included in overhaul cost.
- (2) The overhaul factor represents the need to replace worn parts on a regularly scheduled basis and is a function of both operating time and engine size. Smaller engines exhibit shorter operating lives with consequently higher overhaul factors per unit time.
- (3) Maintenance cost for photovoltaic arrays represents 2 visits per year to a remote site for array cleaning and battery maintenance.
- (4) NA = Not Applicable

conditions, and where, as a consequence, maintenance and overhaul costs may be higher. Additionally, the cost differentials which exist as a result of differences in operational modes, such as between baseload and peaking load operation versus standby operation, have not been investigated in detail by this study and are therefore not reflected in the reported costs.

For the purpose of this cost comparison, a remote, unmanned installation such as a radio relay station was postulated in which the load required a 24 VDC supply. This required the use of a converter in the instance of the engine generator, while no power conditioning was assumed for the photovoltaic system. This type of installation also required a backup for the engine generator which was postulated to consist of an identical engine generator set. Other methods of backup exist, including enough battery storage to permit repair or replacement of the generator set in the event of failure. No tradeoffs to determine optimum backup concepts were made. The battery storage associated with the photovoltaic system was considered to serve also as its backup, an optimistic assumption. As for the other break-even cost calculations performed for this study, the location was assumed to be in the Southwest, and only a 3-day storage requirement was postulated. This assumption also probably favors the photovoltaic system. A continuous duty requirement was assumed. The engine generator and associated equipment was assumed to be housed in a structure capable of providing environmental protection, as well as protection against vandalism, in order to permit unattended operation. In the case of the photovoltaic system, only the storage batteries could be so protected.

Figure A-3 shows the results of the analysis performed for this study. Displayed are 1980 costs for electric energy from diesel generators for two different basic fuel prices and two different fuel cost escalation rates. Also shown in the figure are the costs of energy from photovoltaic power generators at three different array price assumptions overlaid on the generator-based cost curves. This graph suggests that photovoltaic systems could begin to compete with engine generator power at array prices of \$2.00/ W_{pk} under continuous duty assumptions. The lower the array price, the higher the load for which photovoltaics are competitive. When a price of

Figure A-3
ENGINE GENERATOR ENERGY COSTS COMPARED TO
PHOTOVOLTAIC ENERGY COSTS

\$0.50/W_{pk} is reached, a fuel price of \$1.00/gal and fuel price escalation of 10% in the post-1980 time period would permit photovoltaics to compete in baseload applications requiring power up to at least 15 kW.

A.5 LIGHTED NAVIGATIONAL AIDS

Information received from the Coast Guard indicates that power levels and duty cycles of lighted navigational aids vary from 8 W at a 50% duty cycle to as much as 86 W at a 5% duty cycle. For this example, the 8 W load was selected. Two operational concepts were examined. In the first, the photovoltaic system is backed with primary battery power equivalent to the secondary battery storage capacity on the theory that the failure of the photovoltaic system would be telemetered to a control which could initiate replacement or service within the several days operation allowed by both storage and backup. In the other operational concept it is assumed that telemetry is not possible, and that a backup system would have to provide all of the power for a maximum of one year, the normal buoy service interval, or 35 kWh. This is a very conservative assumption since reports of failed lights would presumably reach the Coast Guard from other interested parties in a shorter period of time. For both concepts, the alternate power source is the currently used Zn-air primary battery, costed at \$15.00 per kWh of capacity.

Life cycle costing assumed that the severe marine environment will reduce photovoltaic array life to only 5 years, the same operating life as for secondary storage batteries, and that the shelf life of the primary Zn-air batteries also is five years.

Battery costs are as indicated in the earlier examples. The equivalent continuous load is 4 W, leading to an array size of 40 W since the more severe climatic environment of a marine buoy caused the assumption of a 10:1 ratio of array peak power to load power. Because of the same environment, a 7-day storage requirement of 672 Wh was assumed instead of the usual 3-day storage for the Southwestern land region of the U.S. Service periods for photovoltaics and primary battery replacement were assumed the

same, obviating a charge for service in the break-even calculations. The same rationale applies to the omission of a charge for power-conditioning equipment. The break-even cost equation in present value terms then becomes:

$$CI_{\text{array}} + CI_{\text{storage}} + CI_{\text{backup battery}} = RC_{\text{primary batteries}} \quad (\text{A-3})$$

where the backup battery is also a Zn-air battery, and where a present value factor applies only to the RC and computes to 4.48 for a 5-year period.

Under these cost and life assumptions, the break-even cost of the photovoltaic array is \$58 per peak watt when the backup primary battery is sized for only 7 days, and is \$45 per peak watt, when the backup consists of a full year's supply of primary batteries.

A. 6 RAILROAD CROSSING SIGNALS

For this example, a single track, remote location was assumed which requires two motion detectors to activate the single set of lights and gate.

The power requirement for the motion detectors is 50 W each at 100% duty cycle. The lights are assumed to require 22 W, with the gate requiring 75 W, but both operating only for a 2-minute period per activation. Twenty-four trains per day are assumed to pass this crossing. The duty cycle for lights and gate is therefore only 3.3%. The equivalent continuous load was computed to be 103 W, leading to an array size of 740 W, based on assumption of a Southwestern site. Three days' storage requires 7.42 kWh of capacity for the photovoltaic array, while 1 day's backup storage for the utility power, the competing alternative power source, requires 2.5 kWh of storage capacity. Annual energy consumption is 904 kWh.

Lifetime assumptions are 20 years for all components except the secondary batteries which are assigned a 5-year operating life and shelf life. The break-even cost equation in present value costs becomes:

$$CI_{\text{array}} + CI_{\text{storage}} = CI_{\text{power line+backup+connection+rectifier+transformer}} + RC_{\text{energy/service}} \quad (\text{A-4})$$

where

$$CI_{\text{storage and backup}} = \$50/\text{kWh} \times \text{kWh of storage required}$$

$$CI_{\text{powerline}} = \$15,000 \text{ (example is for one mile extension)}$$

$$CI_{\text{connection+rectifier+transformer}} = \$250 + 100 + 150 = \$500$$

$$RC_{\text{energy}} = 6.2 \text{ cents per kWh} \times \text{annual energy consumption}$$

Although a blocking diode is included in the cost, the remaining power-conditioning equipments are assumed essentially equal in cost for both alternative power systems and have not been charged. The present value factors are 3.07 for the storage batteries and 13.8 for the energy charge. Using these values and operating assumptions, the break-even cost of the array is computed at \$21 per peak watt.