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Photovoltaic Power Systems Market Identification and Analysis

Final Report
For Period January 1977-February 1978

Published May 1979

Prepared for:
U.S. Department of Energy
Assistant Secretary for Energy Technology
Division of Distributed Solar Technology

Under Contract No. EG-77-C-01-4022

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**Prepared for:
U.S. Department of Energy
Assistant Secretary for Energy Technology
Division of Distributed Solar Technology
Washington, D.C. 20585**

**Prepared by:
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Under Contract No. EG-77-C-01-4022

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EXECUTIVE SUMMARY

This report summarizes the work done by InterTechnology/Solar Corporation, its consultants, Mobil Tyco Solar Energy Corporation and the University of Delaware Institute for Energy Conversion, and its consultants, during the marketing analysis of near and intermediate term photovoltaic power applications.

To obtain estimates of the domestic and foreign market potential for photovoltaically powered devices two approaches were used. First, the team aimed at identifying, then screening all possible photovoltaic power supply applications. This approach encompassed the first two tasks of the study:

- (1) a survey of the current uses of photovoltaic systems, both domestic and international, and a projection of the usage of those systems into the future; and
- (2) a new idea generation task which attempted to come up with new ways of using photovoltaic power.

Second, the study required in-depth analysis of key near-term and intermediate-term photovoltaic applications identified during the first phase to obtain reasonable estimates of photovoltaic market potential. This process encompassed the third and fourth tasks of the analysis:

- (3) refinement of ideas generated in Task 2 so that certain products/applications could be identified, the product defined and a market survey carried out; and
- (4) development of a detailed product scenario which forecasts sales, barriers to market acceptance, and technical innovations required for proper introduction of the products.

Highlights of the work performed and findings of each task are presented in the following sections of this summary.

A. Task 1--Characterization of Photovoltaic Power Systems' Near and Intermediate Term Worldwide Market

To characterize photovoltaic power systems' near and intermediate term worldwide market, two separate analyses were carried out simultaneously for the current domestic and foreign markets. For the domestic analysis, this task required an identification of current photovoltaic applications, function, nature of customers, prices and numbers of units sold. In addition, price elasticity and market versus time, incorporating the DOE price goals were determined. For the foreign analysis, national economic plans were taken to identify possible uses of photovoltaic power supplies in the future.

The current U.S. market was strictly defined as those commercial applications for which one or more photovoltaic power supplies had been sold, excluding government demonstration projects. The foreign market for photovoltaics was surveyed in a much broader sense. The major foreseen markets have not yet developed and therefore, of necessity, included non-commercial as well as commercial applications.

1. U.S. Photovoltaic Outlook

The study of the current U.S. photovoltaic market examined 1976 shipments of photovoltaic power supplies for the following commercial applications: communication repeaters (common carrier and private); portable radio transmitters and receivers; corrosion protection equipment; railroad crossing gates and signal systems; emergency call boxes; consumer novelty items; recreational applications; environmental observation instruments and power supplies for offshore oil platforms.

Due to the economics, several of the original applications considered were eliminated from further study since their future markets were seen as negligible or nonexistent. An in-depth study of four selected candidate applications was pursued: communications, corrosion protection, navigation aids, and consumer/recreation applications.

For each of the four selected markets, the study investigated size, composition and growth rate of the U.S. market for photovoltaic power supplies as of 1976. It also identified the characteristics of those markets in which photovoltaic power supplies are already in use, studied the future outlook for photovoltaic power in these applications and, assuming the DOE price goals are achieved, predicted how fast these markets will develop. Finally, the study examined the resulting business outlook for near and intermediate term photovoltaic power and its implications for energy consumption in the U.S.

During its investigation of these issues, the team interviewed many individuals employed by original equipment manufacturers or large users who have specified, purchased, and/or operated solar generating systems to obtain data about the 1976 market. In addition, supplementary interviews were conducted with manufacturers of photovoltaics and with officials of government agencies and scientific laboratories.

While some of the responses were treated as "speculative" in that they constituted opinions, certain factual information was gleaned to provide data to support the findings presented below.

a) The 1976 U.S. Market

Examination of the economics surrounding the decision to buy or use photovoltaics revealed that the total cost of ownership is a primary

consideration. Attitudes toward photovoltaics based on first cost and operating costs at current solar module prices, compared with alternative power source costs, showed that photovoltaics are preferred in cases where wattage requirements are small but power supply is continuous.

The investigation also showed that prices in 1976 varied widely depending upon the type of product, wattage, quantity, and time of year. Commonly quoted prices are as follows:

Solar module	\$15 - \$30 per peak watt
Solar array	\$30 - \$50 per peak watt
Complete system	\$35 - \$100 per peak watt

Principal factors were identified which hamper the use of photovoltaic power applications: economics (first cost), function (reliability and climate/insolation), and psychological reaction to appearance and novelty.

The total U.S. and foreign photovoltaic industry was then segmented according to consumption in terms of peak kilowatt capacity and 1976 dollars. The export, government and aerospace markets were included here to arrive at totals for all photovoltaic equipment produced which could then be compared with figures published in other sources.

In 1976, total commercial shipments amounted to 168.6 kilowatts (\$6.6 million), versus a total of government and aerospace shipments of 277.1 kilowatts (\$16.7 million). Inclusion of Japanese and European shipments brought the global total to 381.7 kilowatts (\$21.6 million). In the commercial U.S. market, communication applications dominated, with 67.6 kilowatts (\$3.0 million).

b. Findings

Sales forecasts, based on delivered peak kilowatts, were projected for each of the four selected applications through 1985. Figure I-1 shows sales forecasts for each of the identified applications of photovoltaic equipment through 1985. The total value of shipments in dollars for each year shown was arrived at mathematically by multiplying the projected shipments for each application in peak megawatts with the projected price goals for photovoltaic modules.

Overall, the study projects an increase of total value of shipments for the four selected applications from \$3.3 million in 1977 to \$7.3 million in 1981, then a decrease to \$2.8 million in 1985. The projected dollar decrease in 1985 arises from the rapid drop in projected module prices compared with the expected increase in product demand.

This contrasts with an increase in volume of installations to more than 2.9 peak megawatts in 1985 for the four selected applications.

This portion of the Task 1 report concludes with several statements about the 1976 market:

(1) Although the total of U.S. shipments are estimated at \$16.7 million, only about \$5.0 million were used in domestic commercial markets. The U.S. government remained the single largest customer, buying about \$7.3 million.

(2) The best applications, in light of the high initial cost, are those that combine remoteness, low wattage demand, long operating time and need for service-free operation.

FIGURE I-1
FORECASTED SALES OF PHOTOVOLTAIC EQUIPMENT
FOR THE FOUR SELECTED APPLICATIONS WITHIN SCOPE OF STUDY

(3) Three applications make up 90% of the commercial market (communications repeaters, corrosion protection for gas wells, and power for off-shore navigational aids).

(4) Assuming DOE's price goals, 2.9 peak megawatts are predicted for commercial applications selected for study in 1985, compared with 128 kilowatts in 1976, three-fourths of which are provided by communications.

(5) The total installed wattage of solar power is expected to be no more than 0.01% of that operating in fossil fueled utility power plants.

2. Near and Intermediate Term Foreign Market Outlook

The analysis of photovoltaic potential in foreign markets was performed for certain economic segments in which photovoltaic applications would have appeal: oil-rich developing nations, and developing nations. The study relied heavily upon published accounts of the level of spending in these nations. The uncertain level of funding in these two types of nations made it necessary to determine which potential photovoltaic applications would be cost-effective; an economic analysis was performed to make this determination.

The scope of this study permitted five countries with economies representative of each of these foreign market segments to be selected. Three OPEC nations--Saudi Arabia, Nigeria and Iran--were selected to represent developing nations with oil exports; and India and Pakistan were chosen to represent developing nations without oil exports. The results of market surveys in these countries then were used to make a crude extrapolation to find the world markets for photovoltaics based on gross domestic product (GDP) and the fraction of the GDP that goes into gross capital formation.

Two methods for determining the market potential for photovoltaics were used:

(1) a review of planned or possible ventures that could employ photovoltaics; and

(2) analysis of funds available for a project in which photovoltaics could play a role. National economic plans and U.S. Department of Commerce information were used as data sources.

For example, the second method was used to make projections for water pumping in Saudi Arabia. After first establishing the economics of photovoltaic irrigation systems, the amount that might be budgeted for photovoltaics could be determined. The Saudis have budgeted money for water resources but not specified in detail how the funds should be allocated. Of the \$430 million budgeted for FY '79, 0.07% is assumed to go to photovoltaics. At a cost of \$7.30 per watt, sales of 41 kilowatts could be realized. Similar estimates were made for subsequent years and for market potential of near and intermediate term photovoltaic applications in the other countries studied.

The data derived from these analyses were then presented for each country considered, focusing on the principal markets within each country, such as lighting, rural electrification, communications, irrigation, and corrosion protection. An extrapolation of the data was then performed to arrive at estimates characterizing the world market.

To determine the availability of funds for purchasing photovoltaics, a ratio of estimated market to GNP times the percentage of GNP that

goes into fixed capital formation was used. This ratio, based on statistics from the United Nations, provides a relatively constant figure for each country studied.

$$k = \frac{\text{Market (kW)}}{\text{GNP (millions of \$U.S.)} \cdot \text{Fixed Capital Formation (\%)}}$$

For OPEC nations, the k value was taken as 0.015; for developing nations, a k value of 0.057 was used; and for the U.S., the k value was .0006. Admittedly, there is also large room for error here, as shown by a few variations from the average k value as high as 25% for each group studied. However, a rough knowledge of the k value, plus knowledge of the GNP and the gross fixed capital formation permits a gross estimate of market potential for photovoltaics for each country.

Using this ratio, estimates were made for all the world's countries for which relevant data could be obtained. FIGURE I-2 gives a cumulative picture of these estimates. Data indicate that a cumulative world market of 521 megawatts for near and intermediate term can be expected by 1985.

As is pointed out in the text (Section II.C.), several caveats should be noted in reading these estimates. First they are based on a representative sample of six countries. Second, there is a degree of uncertainty regarding the k values used. Third, no factor accounting for the attitude of individual national leadership was included. Fourth, alternate sources of energy for countries analyzed were not examined. Finally, the study did not take into account the effects of weather (in Europe, for example) upon the sales of photovoltaics. In addition, it can be expected that some trade barriers will have to be overcome in selling photovoltaic products abroad. These estimates are based on the best available information.

Estimated Annual Photovoltaic Sales (MW)

FIGURE 1-12
ESTIMATED ANNUAL WORLD PHOTOVOLTAIC SALES

Estimated Annual Photovoltaic Sale ($\times 10^{-6}$)

B. Task 2--Generation of New Photovoltaic Applications

The main objective of Task 2 was to develop a list of approximately 100 photovoltaic applications most likely to generate substantial near and intermediate term markets as the price drops from \$20 to 50¢ per peak watt over the next ten years. The list was to expand upon previous work to arrive at a thorough identification of the 100 best potential applications of photovoltaic power supplies.

1. Generating Ideas

The method used to generate new ideas for photovoltaics was that of brainstorming, using as participants in the project the three team members and their staffs, as well as representatives of foreign countries and other groups. In all, 894 ideas were generated during these brainstorming sessions. (This figure includes some overlapping and repetitive ideas.) While some applications can be found that are not included in this list, steps were taken to minimize the number that might be omitted. Also, applications generated under this contract were compared with listings from other groups' previous work.

The generic nature of many applications made it possible to group them by category, which gave rise, subsequently, to more new ideas. In many cases, however, these new applications or products were simply refined versions of concepts already identified. The applications were grouped under the following headings:

- a) Developing nations;
- b) Consumer products;
- c) Industrial products;
- d) Institutional/Government; and
- e) Agribusiness.

Of the applications identified, the following are those not reported in previous studies: insect killer; bird chaser; power for snail (type of plow); crop monitor; frost prevention; bugkiller; antenna-mounted television power supply; garden tools; window vents; corrosion protection for solar thermal; and construction trailer.

2. Evaluating Ideas

Each of the three team members and members of their staffs conducted polls to identify the 100 leading applications of the entire list. These polls were combined to provide a master list of the 100 most attractive concepts. Factors accounted for in this ranking include price of first application, market size and price elasticity. From this list, the applications were again ranked for highest potential by each team and then merged into a final list of applications.

An analysis of these applications was then performed to obtain quantitative near and intermediate term market estimates (U.S. and world). Scenarios for each application were developed to determine total potential market in terms of array area required for the application. The array area required in most cases was calculated by determining the energy requirements in kilowatt-hours per day from the power requirement and the duty cycle of the device. Multiplication of the energy requirement per unit by an estimated number of units yielded total electrical requirements. An array output of 48 watt-hours/day-ft² was used to translate the energy figure to array size for photovoltaic cells. A 1985 figure of 12 peak watts per gross square foot of finished panels was used to estimate the photovoltaic power potential.

In other cases, a second method of calculation was made to obtain a more reliable extrapolation from U.S. to world figures, based upon the ratio of U.S. GNP to world gross national product.

$$\frac{\text{Market}_{\text{World}}}{\text{Market}_{\text{U.S.}}} = \frac{\text{Fixed Capital Formation}_{\text{World}}}{\text{Fixed Capital Formation}_{\text{U.S.}}} \frac{\text{GNP}_{\text{World}}}{\text{GNP}_{\text{U.S.}}} \frac{k_{\text{World}}}{k_{\text{U.S.}}}$$

This rationale was used in determining the gross panel areas required to supply 100% of the market. The percentage of market share was estimated by ITC/Solar staff. These calculations then permitted calculation of estimated 1985 capture potential for the applications of photovoltaics in the U.S. and world markets and which are studied in further detail in the subsequent tasks (see TABLE I-1).

TABLE I-1
ESTIMATED 1985 CAPTURE POTENTIAL OF PV APPLICATIONS

APPLICATION	PV PEAK POWER* (MW _p)		APPLICATION	PV PEAK POWER** (MW _p)	
	U.S.	World		U.S.	World
1. Irrigation pumps	8060	23500	34. Police station	1.4	4.1
2. Refrigeration of food	700	2050	35. Railroad station	1.3	3.8
3. Food preservation (drying)	360	1050	36. Hat communication equipment	1.1	3.2
4. Ventilating fans	320	930	37. Buoys	.67	2.0
5. Pumping potable water	260	760	38. Electronic air cleaning	.48	1.4
6. Rural television	170	500	39. Electric tractor	.40	1.2
7. Rural lighting	160	470	40. Educational devices	.36	1.1
8. Portable power pack	150	440	41. Calculators	.36	1.1
9. Water treatment	120	350	42. H ₂ production	.36	1.1
10. Air conditioning	100	290	43. Educational TV	.32	0.93
11. Corrosion control	70	200	44. Phonograph	.30	0.88
12. Outside lighting	64	180	45. Insolation meter	.24	0.70
13. Electric vehicles	63	180	46. Power skier's radio	.24	0.70
14. With solar thermal	50	150	47. DC battery charger	.17	0.50
15. Construction Trailers	43	125	48. Telephone systems	.17	0.50
16. Warning flashing lights	30	90	49. Surveying instruments	.12	0.35
17. Railroad signals/controls	24	70	50. Electric toys	.15	0.44
18. Pumped storage	22	60	51. Safety equipment	.14	0.41
19. Television	17	50	52. Powering CB radios	.14	0.41
20. Back-up to utility	16	45	53. Garden appliances	.13	0.38
21. Boats, sailboats	14	40	54. Remote alarms	.12	0.35
22. Remote repeaters	12	35	55. Remote telephones	.08	0.23
23. Pool pump	10.1	30	56. Intrusion defense	.08	0.23
24. Portable medical machines	9.6	30	57. Food sterilization	.07	0.20
25. National park power	8.6	25	58. Power for simple industries	.06	0.18
26. Emergency power	5.8	20	59. Intrusion detectors	.05	0.15
27. Military	13.6	40	60. Instrumentation	.05	0.15
28. Remote medical centers	4.9	15	61. Traffic signals	.04	0.12
29. Radio	4.9	15	62. Watches	.04	0.12
30. Closed water system	2.9	8.5	63. National alert network	.04	0.12
31. Lighting, general	2.4	7.0			
32. Detecting crop harvesting time	1.8	5.3			
33. Remote communications	1.6	4.7			

* Based 1985 Figure of 12.0 Wp per gross square foot of finished PV panels.

** Figure based on ratio of GNPs.

C. Task 3--Specification of Products Likely to Generate Significant Markets

The assignment of Task 3 was to develop useful conceptual designs for a limited number of near and intermediate term photovoltaic products and to assess the potential market acceptance for these products. Product descriptions were to be developed based upon the conceptual designs and would serve as the basis for constructing a survey instrument to obtain market acceptance data. Data from the survey would then provide a basis for refining product designs and constructing demand functions.

1. Selecting and Describing the Products

During Task 2, the 100 ideas generated in the brainstorming sessions were screened for overlap, repetition, and early market entry. In Task 3, these applications were subjected to engineering judgments as to market capture potential and grouped according to end-usage categories. A list of 32 photovoltaic products was developed and formed the basis for the market penetration analysis.

For each of these 32 products, technical descriptions and an artist's rendering were developed, based upon such factors as size, appearance, portability, level of insolation, electrical load, yearly usage patterns, price per peak watt, storage capacity, life-expectancy, and standard reference values and costs for alternative power supplies.

Then 12 of the 32 products were selected as having the highest near and intermediate term market potential and/or high engineering judgments and as those most usable for the market survey process. These 12 products are:

- (1) 6- and 12-volt battery chargers;
- (2) outdoor lighting;
- (3) 50-horsepower motors to power agricultural and irrigation equipment;
- (4) compact refrigerators;
- (5) remote repeater stations;
- (6) corrosion protection equipment;
- (7) construction trailers;
- (8) small motors to pump water;
- (9) security devices;
- (10) field agricultural devices;
- (11) battery chargers for battery packs and small electric vehicles; and
- (12) radio transceivers.

2. Surveying the Market

With the aid of marketing consultants, either a personal interview survey or a mail survey or both were designed to solicit key information about each of the 12 photovoltaic products. The personal interview surveys covered four of the twelve prime photovoltaic products (battery chargers, outside lighting, irrigation pumps and compact refrigerators); the mail survey covered the remaining eight applications.

The surveys were directed to key decision-makers in manufacturing and operating companies with experience relevant to the suggested photovoltaic markets. These companies were chosen primarily from companies listed in the Thomas Register of American Manufacturers, the bulk of which had assets of over \$1 million.

The surveys solicited information and opinions on the following:

- (1) market penetration of solar-powered products under varying economic conditions;
- (2) barriers to market acceptance;

- (3) incentives for purchasing photovoltaic products;
- (4) market size; and
- (5) level of respondent's expertise.

The marketing survey was pretested in the Washington, D.C. area by personal interviews with representatives of sample product market areas. Eighty-three survey interviews, conducted by a national interviewing company, were held in five major U.S. cities.

3. Analyzing the Survey Results

Data obtained from the four interview surveys and the eight mail surveys were tabulated and analyzed in two ways: quantitative information was analyzed by computer and responses to open-ended questions were analyzed subjectively.

The answers to the interview surveys provided a basis for developing market demand functions for the four prime products and, thus, proceeding with Task 4, the development of market penetration projections and product/market scenarios as discussed in the next section of this summary.

a. Interview Surveys

Several sets of data were obtained from the interview surveys on battery chargers, outside lighting, irrigation equipment and compact refrigerators. The data provided information about the best uses of the given photovoltaic application, barriers to acceptance, and tax incentives. Subjective responses gave information about reasons why the products would be marketable, information needed prior to purchasing photovoltaic products, and the role of government in the development of the photovoltaic industry. Table I-2 summarizes the significant information obtained from the interview surveys on the four prime products.

TABLE I-2
INTERVIEW SURVEYS: SUMMARY OF RESPONSES

	<u>Battery Chargers</u>	<u>Outside Lighting</u>	<u>Irrigation</u>	<u>Refrigerator</u>
Most promising application	Temporary lighting for construction and industrial sites; two-way communications equipment; portable tools	Navigational aids; outdoor advertising and security lighting at remote industrial sites	Factory farm managerial staff and corp. ownership	Remote cabins; Medical uses.
Barriers to Market Acceptance	High initial cost Space used by arrays (Possible)	High initial cost Unreliability (Possible)	High initial cost Unreliability (Possible)	High initial cost Unreliability (Possible)
Tax Incentives	Purchasers, but not manufacturers, should receive tax incentives to reduce add-on cost of solar.	Purchasers and manufacturers should receive tax incentives to reduce add-on cost of solar.	Purchasers and manufacturers should receive tax incentives to reduce add-on cost of solar.	Purchasers and manufacturers should receive tax incentives to reduce add-on cost of solar.

FOR ALL APPLICATIONS*

Information needed by prospective consumers	Costs, cost-savings, performance characteristics, size of market, technical specifications, life-expectancy, guarantees. Public awareness.
Reasons why prospective consumers would buy PV products	Profit, longevity, cost savings, novelty, improvement of product over conventional counterpart, availability of power where needed.
Respondents' view of role of government in developing PV industry	Government financing of demonstration projects; R&D efforts, tax incentives for manufacturers and buyers.

* Listed in order of importance

b. Mail Surveys

Mail surveys were designed to obtain market acceptance data on the remaining eight of the twelve key photovoltaic products. Responses were received as follows: corrosion protection--9; remote repeaters--9; small water pumps--2; electric vehicles--5; agricultural field devices--4; construction trailers--4; security equipment--2; and tranceivers--0. Only the corrosion protection and remote repeater surveys elicited the number of response required to develop viable market acceptance and penetration estimates; however, responses to five of the other six sets of mail surveys did allow rough analysis. Responses to the mail surveys are presented in Table I-3.

4. Refining the Product Designs

a. Sizing and Optimization Analysis

While the survey results were being tabulated and analyzed, the University of Delaware's Institute for Energy Conversion proceeded with the task of a computer analysis of six photovoltaic products to analyze the problem of sizing and cost optimization of each system with respect to array/battery size and reliability.

This analysis was performed for the battery charger, outside lighting system, 50-horsepower irrigation pump, compact refrigerator, corrosion protection and remote repeaters. The computer program, incorporating ITC/Solar routines, generated data on randomized weather, insolation, electrical output, battery size, photovoltaic array area and daily losses. Reliability vs. array area and battery size were calculated, and system cost trade-offs were examined. Since system size is dependent upon location and climate, various locations in the U.S. and Canada were selected as probable system sites for the sake of analysis.

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TABLE 1-3 MAIL SURVEY:

SUMMARY OF RESPONSES

Application	Most Promising Applications	Probable Buyers	Reasons to Buy	Barriers to Acceptance	Tax Incentives	Market Penetration	Info Needed
<u>Corrosion Protection</u>	Pipeline protection.	DFC:\$2000 (20) gov't DFC:\$0.0 (4) ind. & gov't	Availability of power in remote locations; increasing cost of electric power & elimination of power lines.	High initial cost; vandalism; weather damage.	Some tax incentives could be granted to manufacturers and/or non-gov't purchasers.	Added first cost \$0.00 & savings \$100 = 58.9% Added first cost \$0.00 & savings \$50 = 39.4%.	Break-even cost of conventional equipment; reliability; maintenance performance histories.
<u>Remote Repeaters</u>	Radio telephone relay station for mobile telephones along highways and, in foreign countries, inter-city microwave stations in rural areas.	DFC:\$4000 (25) no buyers DFC:\$200 (4) ind. & gov't	Availability of power in remote locations and minimal maintenance & outage costs.	High initial cost; Reliability; novelty.	General tax incentives and capital invest. tax incentives.	Added first cost \$0.00 & savings \$100 = 71.7% Added first cost \$0.00 & savings \$50 = 66.7%.	Assurance of availability of cells and back up systems; reliability; demonstrate performance
<u>Small Water Pump</u>	Watering live-stock; drinking water.	DFC:\$1000 (12) devel. nation DFC:\$200 (4) devel. nation	Availability in remote locations; portability.	Lack of guarantee; maintenance problems.	NA	NA	Reliable market info and performance characteristics.
<u>Electric Vehicles and Battery Packs</u>	Delivery and amusement parks.	DFC:\$5500 (15) no buyers DFC:\$2000 (6) no buyers	Reduce power bills; use in remote areas.	High initial cost and reliability; night-time charging; return on investment.	NA	NA	Proof of feasibility; info on cost savings, reliability, maintenance and serviceability.
<u>Ag. Field Devices</u>	Moisture monitors; frost warning.	DFC:\$150 (10) priv./corp farms DFC:\$50 (3) all farms	Reduce power bills; use in remote areas.	Reliability & vandalism; unproven reliability, maintenance problems novelty.	NA	NA	Cost info., life expectancy, packaging, availability of original & replacement parts; assurance against freezing.
<u>Construction Trailers</u>	Remote locations emergency and disaster relief.	DFC:\$3800 (15) gov't DFC:\$1800 (8) gov't	Use in remote areas; petroleum shortages; dependability.	High cost and lack of guarantee.	NA	NA	Customer specs including solar power; proof of reliability of service, cost savings, customer interest; legislation limiting use of fossil fuel gen. equipment.
<u>Security Equipment</u>	Industrial sites in remote locations.	DFC:\$250 (12) ind/gov't tossup DFC:\$50 (5) trans.co.&gov't	System is large enough to provide power for other equipment.	High initial cost.	NA	NA	
<u>Transceiver</u>	No responses to this survey were received.						

* NA = Responses to questionnaire not acceptable.

DFC = First Cost Difference
 Number in parentheses = payback period
 ind. = industry and operating companies
 gov't = government agency
 trans. co. = transportation company

b. Refinement of Product Design

At the same time that optimization and sizing analyses were being conducted, specific design features were developed for the four prime photovoltaic applications: battery charger, outside lighting, irrigation system and compact refrigerator.

The final product designs used information or design criteria and marketability gathered from the market surveys. The designs were not only meant to provide for proper characterization of solar arrays, storage and circuitry, but also to provide innovations in styling, flexibility and portability to increase buyer appeal and decrease the first cost of each product.

Figures I-3 through I-6 show the four final product designs. Key factors in the final designs are:

(1) Modularity: gives the buyer the option of adding on to the system as his needs and financial capability increase. As in the irrigation system, modularity increases system flexibility by permitting the use of variously sized motors for such purposes as watering, drying, crop handling. As in the outside lighting system, modularity allows more effective use of stored energy by permitting the use of several smaller lights.

PHOTOVOLTAICALLY POWERED 12-VOLT BATTERY CHARGER

DESCRIPTION: A solar-powered, general-purpose battery-charger for 12-volt batteries will recharge a standard battery in one day. The device is simple, requires little maintenance, and has a long lifetime.

APPLICATIONS:

1. Small battery-assisted vehicles.
2. Lawn mowers and garden tractors.
3. Garage and service stations.

FIGURE I-3

PERFORMANCE AND SIZE: This battery charger consists of a photovoltaic panel, totaling 24 square feet, which may be mounted on a roof or in an open yard. The device is simple, has no moving parts and should last about 20 years. The panel provides approximately 600 kilowatt hours of electricity per year.

ALTERNATIVE ENERGY SOURCES: A battery charger can, of course, be powered either from the electrical grid, or by a small gasoline generator. In the case of the electrical grid it is not the cost of the electricity that is the important consideration but the cost of installing the electrical outlet. For a simple function such as charging a battery, only a modest expense for the initial installation would be appropriate. The cost of installing even a few hundred yards of electrical line, for example, out to a farm shed in which battery-powered tools were stored might equal the cost of the photovoltaically powered system. Once the electrical connection is installed, however, it could be used for other purposes such as lighting, in addition to the battery-charging function.

If a gasoline generator is used, it would cost initially about \$300 and would require about \$100 worth of fuel per year plus about \$30 in maintenance and oil. The device would last two or three years but would require considerable maintenance. The gasoline generator would be portable, however, and could be used for other tasks, such as operating power tools. The total cost for operating such a generator would be about \$250 per year.

The cost of the solar panels is currently quite high, but as usage and mass-production increase the cost will come down dramatically.

PHOTOVOLTAICALLY POWERED OUTSIDE LIGHTING

DESCRIPTION: A 175-watt mercury-vapor lamp powered by solar energy may be used out of doors. This system includes a light which may be pole-mounted or mounted on the side of a building, a photovoltaic panel, and a battery to allow night-time operation.

APPLICATIONS

1. Lighting farmyards.
2. Security lighting around remote buildings.
3. Lighting for signs.
4. Lighting for parking areas.

FIGURE I-4

PERFORMANCE AND POWER: A solar-powered 175-watt mercury lamp puts out the light of a 300-watt incandescent lamp, but requires only about half as much electrical power. The power comes from an array of photovoltaic cells totalling 48 square feet which may be mounted on the roof of the building or have their own separate structure. On sunny days the solar panels charge a battery which may be housed either inside a building or in a weatherproof box beneath the solar array. The light is turned on automatically as the light fades in the evening and turned off again in the morning. The battery stores enough power to operate the light at night for up to three nights during overcast periods. The panels will last about 20 years protected from mechanical damage. The batteries and light bulb will need replacement approximately every five years. The entire system is fully automatic and requires low maintenance.

ALTERNATIVE POWER SOURCES: Such a light can be powered by connection to the commercial power grid and is an inexpensive, low-maintenance source of power where it is available. The only problem is that the cost of extending the electrical wires out to the site where the light is needed can be more expensive than the cost of the light or energy it uses. The cost of the photovoltaic system can equal the installed cost of only a few hundred yards of power connection. If such a power line is installed, however, it can provide power for other uses as well as lighting.

The cost of solar cells is currently quite high but as usage and mass production increase the cost will come down dramatically.

PHOTOVOLTAICALLY POWERED HEAVY AGRICULTURAL UNITS

DESCRIPTION: A large but portable photovoltaic power source could provide power for driving a 50 horsepower irrigation pump. This same unit could be used during non-irrigation periods for a variety of uses such as crop handling and drying.

APPLICATIONS:

1. Agricultural irrigation, crop drying, crop handling.
2. Aquaculture.
3. Remote industries such as ore concentration.

FIGURE 1-5

PERFORMANCE AND SIZE: A solar powered agricultural unit may consist of 10 trailer-mounted photovoltaic panels totaling about 1500 square feet and a separate trailer containing a heavy battery bank and control circuits. If used in irrigation, the unit will power a 50-horsepower pump capable of providing 1000 gallons per minute against a 10 foot lift and 5 pounds per square inch outlet pressure for 2 1/2 hours per day. This is a total of approximately 144,000 gallons per day. The amount of electricity which can be provided by the panel is 38,000 kilowatt hours per year.

The batteries can store enough power to operate the pump at its rated capacity for 2 1/2 hours. The controls prevent the batteries from becoming overcharged and shut the motor off when the voltage level of the batteries is too low. Any number of photovoltaic panels may be connected to the control circuit depending upon the amount of power required for the job. During various seasons of the year, the power unit may be moved to different portions of the farm to provide power for such operations as blowing air for crop drying or running conveyor systems for loading produce.

If properly maintained, the photovoltaic panel should last in excess of 20 years. However, the battery pack would have to be replaced after 10 years.

ALTERNATE ENERGY SOURCES: Agricultural power of this magnitude could be provided either by connection with the electrical power grid or by installation of a diesel engine. If electrical power from the grid is to be used, the primary consideration is the cost of running the electrical subtransmission line out to the site where the power is needed. The cost of such subtransmission lines is about \$10,000 a mile for average terrain but can be much higher if the terrain is difficult. This often requires a substantial investment to obtain power at a single fixed location.

If a diesel engine is used, it will cost about \$10,000 initially, and require about \$2,000 worth of fuel a year. The cost of this fuel, however, is expected to rapidly increase and in some areas there may be restrictions on supply. The maintenance required for a diesel engine is much higher than for the photovoltaic system and the diesel motor can be expected to last about 10 years.

The cost of the photovoltaic panels is currently quite high, but with increased usage and mass production the cost will come down considerably.

PHOTOVOLTAICALLY POWERED REFRIGERATOR

DESCRIPTION: A small, five-cubic-foot refrigerator is powered by solar-cell panels which can be mounted on a roof and connected to the refrigerator by cable.

APPLICATIONS

1. Preserving food in campers, trailers, and tents.
2. Refrigeration for remote cabins and work camps.
3. Preserving food in developing nations
4. Preserving medicines in remote areas
5. Preserving medicines in emergency mobile clinics

FIGURE I-6

PERFORMANCE AND SIZE: Three 2 ft. by 4 ft. panels are mounted on a south-facing roof and tilted at an angle approximately equal to the latitude. On sunny days, in addition to keeping the contents of the refrigerator cold, the power from the panels charges a battery and freezes extra ice to carry the unit through the night and up to three overcast days. The solar cells will last up to 20 years and require little maintenance. The panels can provide about 500 kilowatt hours of electricity per year.

ALTERNATIVE POWER SOURCES: Other ways such a refrigerator might be run include running a small gasoline generator or extending utility power lines out to the site. If utility power is available, it is the cheapest way to run a refrigerator because the power needed is only about 400 kilowatt hours per year. However, if the electrical lines need to be extended more than a few hundred yards, the cost will exceed the cost of either a gasoline power plant or the solar panels.

A gasoline generator costs about \$300 and can run a few lights and small appliances in addition to the refrigerator. However, it requires daily attention, lasts only two to three years, and is a maintenance problem in remote areas. Typically, the cost of the fuel and oil for this generator would be about \$340 per year, including delivery.

Currently, the solar cells are expensive, but the price will be dramatically reduced by mass-production in the near future.

(3) Self-contained units: as demonstrated in the battery charger, panels are deployable to provide for portability, protection, and compactness for both the array and charging unit.

(4) Flexibility of End-Use: as in irrigation system and battery charger, the end-uses may vary, depending upon the number of batteries charged (and electrical output of batteries).

Other engineering improvements were made for each of the four products.

For the battery charger, a small-battery charging compartment was incorporated into the design to expand the system's charging capability.

D. Task 4--Product/Market Scenario

The objective of Task 4, the final phase of the photovoltaic marketing analysis, was to develop detailed product/market scenarios for each of four prime photovoltaic products studied in Task 3: the 12-volt battery charger, compact refrigerator, outside lighting system, and 50-horse-power pump for irrigation.

Using information obtained from the marketing survey conducted under Task 3, especially the consensus of experts' estimated demand for the products, the scenarios focused upon identification of near/and medium-term markets for the products, market penetration estimates, sales forecasts, probable barriers to market acceptance and marketing strategies.

1. Detailed Product Descriptions

Specifications for the four prime photovoltaic products were summarized as to solar cell panel size and weight for the six constant performance insolation regions of the U.S. Electrical specifications as to voltage, amperage, average continuous load, annual energy output and peak-watt ratings for the arrays, batteries and charger units were also summarized.

2. Segmentation of the Market

To obtain a reliable estimate of the major markets open to each of the selected photovoltaic products, it was necessary to ascertain which of the potential buyers would be willing to use photovoltaics. The scenarios were based upon reasonable assumptions about first cost of alternative power sources, including estimated distances from the utility grid.

Thus, it was assumed that, for the battery charger, for example, a likely market would be chargers for power tools (garden, carpentry and

automotive) and that, as opposed to running a \$300 gasoline generator, the use of a photovoltaic charger could produce savings of \$250 per year in operating costs.

Regional differences in system size had to be taken into consideration as well as several base costs to calculate the cost of the photovoltaic systems over time. In all cases the following parameters were used:

1. Structural cost per square foot = \$1.50/ft²
2. Battery Cost per kilowatt-hour = \$50/kwh
3. Dealer Markup = 20%
4. Power conditioning cost per watt = \$0.05/wp

Using these costs Figure I-8 shows as an example the annual costs for a photovoltaic battery charger system between 1977 and 1986 assuming the DOE cost goals are met.

3. Market Penetration Predictions

The consensus of interview responses obtained in Task 3 provided market demand functions which served, in Task 4, as the basis for making quantitative market penetration estimates. Values for initial solar cost (cost differences) over alternative power sources and operating cost savings were entered into the calculations at this point to obtain the quantitative market penetration estimates desired.

Then a mathematical model was constructed to merge the demand functions with the products' life-cycle development. Thus a model was developed which simulates, for example, the introductory period of the product life cycle in terms of time from introduction to the time when early maturity is reached. This displacement time was defined across a range from minimum to maximum so as to allow reasonable estimates of the products' life-cycle behavior.

FIGURE I-7
PV POWERED 12 VOLT BATTERY CHARGER SYSTEM COST
BY U.S. INSOLATION REGION

These market penetration predictions were then plotted for the United States and weighted by regional market size for the various applications. A representative curve is shown as Figure I-9. Regional weighting factors were based on relative proportions of total or urban population in the six constant performance insolation regions.

The saturation points vary for each application as well as for each region, with time to market saturation ranging from 4.2 years after 1976 for battery chargers in Region VI, to 9.4 years for irrigation pumps in Region I.

As Figure I-9 shows, the resulting market penetration projections indicate a sharp take-off at the point when breakeven cost is reached, which is primarily due to the projected rapid decrease in array costs.

Application One: Photovoltaics vs. Gasoline Generator

Application Two: Photovoltaics vs. Utility Grid

FIGURE I-8
MARKET PENETRATION PROJECTION FOR TOTAL U.S. MARKET
BATTERY CHARGERS

4. Sales Forecasts

For each of the scenarios identified, sales forecasts were developed for likely segments of the market based on information gathered about end-uses of each product and about product marketing decisions from manufacturers interviewed during the survey in Task 3.

These sales forecasts required making certain assumptions about the total annual sales for a given market segment, location and psychogenic characteristics of the intended purchaser. Also included in the forecasts were comparisons with competitive power sources.

The following table shows projected cumulative sales in MWp for two prime products for the years 1978, 1982 and 1986.

<u>Product</u>	<u>Cumulative Sales (MWp)</u>		
	<u>1978</u>	<u>1982</u>	<u>1986</u>
Compact Refrigerators	0.084	24.7	101
Security Lighting for Farms	0.046	8.5	163

It was not possible to arrive at estimates for cumulative sales of battery chargers and irrigation pumping systems since such estimates required more precise definitions of market segments than resources for this study permitted.

5. Barriers to Market Acceptance

The high initial cost of photovoltaic systems, followed by concerns about reliability, product guarantees, space consumed and vandalism, were shown during the market survey to be main factors that would impede market acceptance.

These concerns suggested that the lack of confidence in photovoltaics stems from the absence of data, which might be provided by field tests and demonstration programs.

Other barriers revealed included a generally negative or skeptical attitude about the "energy problem," energy conservation and the rising costs of conventional fuels. Also, some doubts about the projected DOE price goals for photovoltaics and overall DOE energy programs were expressed. Yet another barrier was seen to be the lack of investment capital and lack of appropriate channels within financial institutions and government for loan and other investment programs.

6. Marketing Strategies

To overcome these barriers, the study concluded with several suggestions, including the following:

(1) Mount demonstration programs and disseminate data provided by these programs to potential manufacturers and users. Information should cover such items as technical performance criteria, maintenance requirements, cost/benefits, life expectancy, availability of system components.

(2) Provide users and manufacturers with technical performance standards and quality control guidelines and provide instruction to maintenance and repair personnel.

(3) Explore the possibilities for expanding the basic product lines.

(4) Explore ways in which capital can be provided such as tax incentives, loans, and grants to the private sector.

(5) Consider establishing rental and leasing arrangements for users of photovoltaic systems.

(6) Consider production of both large-scale and small consumer items to sensitize the market place.

II. CHARACTERIZATION OF THE PHOTOVOLTAIC POWER SYSTEMS' WORLDWIDE MARKET

A. General Introduction

This section of the report comprises the Report of Mobil Tyco Solar Energy Corporation on the characterization of the worldwide photovoltaic market. It is divided into two sections: domestic markets and foreign markets. The analysis of the domestic market was made primarily by Technical Marketing Associates (TMA) of Concord, Mass., under the guidance of Mobil Tyco Solar Energy Corporation (MSEC). Mobil Tyco is responsible in full for the foreign market analysis.

Characterizing the photovoltaic power systems' worldwide market required the identification of current photovoltaic applications, functions, natureentification of current photovoltaic applications, functions, nature of customers, price, and number of units sold. Additionally, the price elasticity and market versus time have been developed assuming the objectives of the U.S. program are achieved. This task has been further divided into separate analyses of the United States market and the foreign market.

For the purpose of this study, the United States market has been strictly defined as those applications for which one or more photovoltaic power supplies have been commercially sold. Owing to funding limitations, government and private demonstration projects have not been examined in depth, although the current government market size has been identified. One effect of limiting the study in this manner has been the exclusion of several attractive future markets for photovoltaics. This limitation on the scope of the survey has also caused some significant differences between this study and previous studies. Major markets in previous studies, such as highway signs and intrusion detection devices, have not

been included since no commercial sales could be found. The price elasticity for each of the current commercial markets has been determined through interviews with the present users of photovoltaic power systems. Several conclusions regarding the domestic market can be found following the market analysis in Section II, pages 46-49.

The world market for photovoltaics has been surveyed in a much broader sense. Since the major foreign markets have not yet developed, it is necessary to survey non-commercial applications as well as current commercial applications. To limit an analysis of the foreign market to current commercial applications cannot do justice to the true nature and magnitude of the market. A simple extrapolation of the U.S. market is not satisfactory since it would yield a foreign market which is much smaller than is to be expected. Since this analysis is not limited to present applications, there is some overlap of this task with the study of "applications most likely to generate significant markets." These two tasks are complementary, especially in the realm of the foreign markets.

Appendix I to this report contains supporting information for the analysis. The economic analyses are elucidated for each of the major markets. Representative breakeven costs are given for a particular case of each application. This should aid in any further analysis which may be deemed necessary.

B. United States Photovoltaic Outlook

1. Introduction: Objectives and Methodology

a. Scope

i. The study covers 1976 shipments of photovoltaic power supplies, and components thereof, for end use within the United States, in the following "commercial" applications:

- (a) communication repeaters, both common carrier and private;
- (b) portable radio transmitters and receivers;
- (c) corrosion protection equipment;
- (d) railroad crossing gates and signal systems;
- (e) emergency call boxes;
- (f) consumer novelty items, such as wristwatches, calculators, electric razors, etc.;
- (g) recreational applications, such as battery chargers for yachts;
- (h) environmental observation instruments; and
- (i) power supplies for offshore oil platforms. (Data on U.S. Coast Guard purchases for marine navigational aids was provided to TMA by Mobil Tyco.)

ii. The following markets are excluded from the coverage of the United States study, although, in the interests of completeness, references to them appear in some of the exhibits:

- (a) photovoltaic equipment manufactured for export, or for end use outside the U.S.;
- (b) photovoltaic equipment for "extra-terrestrial" applications, including commercial communications satellites, NASA spacecraft, and Air Force satellites;
- (c) all military purchases;
- (d) purchases of DOE; and
- (e) any "commercial" applications, including new applications, not listed in the paragraph above.

b. Issues Investigated

i. Within the markets selected for study, the size, composition, and growth rate of the U.S. market for photovoltaic power supplies, as of 1976, were determined.

ii. The study also aimed at discovering the characteristics of those markets in which photovoltaic power supplies are already in use, such as:

- (a) technical requirements;
- (b) economics of the application;
- (c) practical alternative power sources;
- (d) prevailing prices;
- (e) factors leading to selection of photovoltaic equipment; and
- (f) attitudes of purchasers.

iii. The study was designed to determine the future outlook for photovoltaic power in these applications and, assuming that the array-price objectives of DOE are achieved, how fast these markets will develop.

iv. Finally, the study examined the resulting business outlook for photovoltaic power and its implications for energy consumption in the United States.

This section of the report (II.B) may be thought of as having two main segments: a "factual" segment, dealing with the photovoltaic market as it actually existed in 1976, and a "speculative" segment, in which the future of that market is forecasted through 1985.

In gathering information about the market of 1976, principal emphasis was placed on direct interviews with those individuals who were found to have had the greatest involvement with the market on a day-to-day basis. The great majority of the interviews were conducted with engineers employed by original equipment manufacturers (OEM) or large users, who specified, purchased, and/or operated solar generating systems. Supplementary interviews were conducted with manufacturers of photovoltaic equipment, and with officials of other organization, such as DOE, NASA, JPL and Lincoln Labs, who are actively involved in the field.

Interviewees were also queried about the future market, but their comments thereupon were treated as opinion rather than fact. Needless to say, it is difficult for an engineer to draw conclusions about his use of photovoltaics under unknown market conditions eight years hence, with the price of the photovoltaic equipment presumed to be at less than three percent of present levels. Hence, projections also make use of available published data interpreted, to the extent necessary, by the judgment of the writers.

Obviously, total cost of ownership is a primary consideration but not necessarily the only consideration in choosing between solar power supplies and supplies of other types.

At \$20 or more per peak watt, the first cost of a solar power supply is generally much higher than that for other types of power, but this is not invariably so. On a per-watt basis, the cost of photovoltaic power varies very little with the size of the power system. In contrast, the smallest engine-generator set which is practical to buy produces about 100 watts, and the utility will seldom install a power line extension with a capacity less than several kilowatts. Consequently, as wattage requirements become very small, the cost per watt of engine generator sets and of utility power extensions escalates sharply, while the cost of photovoltaic power remains stable. Batteries, of course, are also relatively uniform in cost per watt and are available on a practical basis down to the smallest power capacities.

After the first installation, on the other hand, the operating costs of the various types of power supply contrast on quite a different basis.

For example, the cost of using either engine-generator sets or batteries tends to go up almost directly in proportion to the amount that they are used. The generator sets, of course, require both fuel and service. Batteries involve the cost of replacement or recharging. The cost per watt for utility power, tends generally to decline as the system load factor is increased. In contrast, a solar power supply involves very little operating cost. Furthermore, this cost, which involves occasional service and battery replacement, depends only upon the size of the system and is little affected by how much it is used.

The end result of all this is that economics most favor photovoltaic power supplies in cases where the wattage requirements are relatively small and/or the power supply is in virtually continuous use.

2. The 1976 Photovoltaic Market

Prices paid for photovoltaic equipment in 1976 varied over a very wide range, depending upon the type of product purchased, the wattage, the quantity, and even the time of the year.

The most commonly quoted prices for photovoltaic equipment are prices for cells, which varied between \$15 and \$30 per peak watt in 1976.

Nevertheless, most commercial photovoltaic equipment was sold (OEM's and users) in the form of modules or arrays, so that prices actually paid ran in the range of \$30 to \$50 per peak watt.

When these products were assembled into complete power supplies, including supporting structures, interconnecting wiring, rectifiers, regulators, switches, and batteries, prices paid per peak watt ran in the range of \$30-\$100 per watt.

Figure II-1 shows the range of prices quoted for photovoltaic equipment in 1976.

FIGURE II-1
RANGE OF PRICES QUOTED
FOR PHOTOVOLTAIC EQUIPMENT IN 1976

a. Market Segments Found to be Negligible or Nonexistent

i. Portable radio transmitters and receivers. No solar-powered equipment is commercially available, even though demonstration models have been built.

ii. Railroad equipment. Only one solar-powered crossing signal is running in the U.S., and that one was provided by the government. At present prices, it is preferable to make use of utility power.

iii. Emergency call boxes. Although this appears to be a highly appropriate application, no commercial sales were uncovered for 1976. Fear of vandalism was cited as a major objection.

iv. Environmental observation instruments. Some installations may have been made in 1976 by state agencies in the West, but the market is extremely small.

b. Competitive Factors in the Commercial Market

i. General Observations

In commercial markets, photovoltaic power supplies may be thought of as "in competition" with power supplies of other types. The principal competitive types of power supplies will differ considerably, depending upon the type of application under consideration.

In the case of communications transmitters and repeaters, which are generally located on hilltops and are often in remote areas, the fundamental decision is whether or not to undergo the expense of extending the utility power line to the communications site. If the site is off-shore, or will have engines running at it for other purposes, an engine generator set will be considered, as will primary batteries.

Most corrosion protection applications deal with the protection of oil or gas wells or pipelines, or with structures such as bridges. Here again, the extension of the utility power may prove to be practical, especially if there are other electrical loads at the site. In the case of an oil well, an engine generator is likely to be considered, since other engines will be required at the site in order to pump the oil.

In the case of navigational aids on off-shore structures, utility power is seldom a practical alternative. In the past, the choice has often been to operate lights and horns by means of batteries which are replaced periodically. Another common alternative is to burn acetylene gas. Engine generators, because they are more expensive to service than batteries, will be used only when the power load is so high as to result in an appreciable difference in first cost. Wind mill generators are an interesting alternative to solar power in regions where the winds are reasonably stable.

So far as consumer and recreation applications are concerned, the choices are already familiar to us. In situations where it is possible to do so, we are likely to rely upon utility power to operate portable devices such as radios or calculators and to do without the convenient "self-charging" feature of solar power. If the device is to be used where no utility power is available, such as when camping or on board a boat, we will tend to rely upon batteries, with or without a recharging feature. Nevertheless, solar power supplies are finding increasing use in applications of this sort. Figure II-2 summarizes the proportionate use of alternate power supplies for various types of applications.

ii. Excerpts from Interviews: Factors Affecting Decisions Whether to Use Photovoltaic Power

The following excerpts are representative comments on using photovoltaic power, obtained in phone conversations with major users and suppliers.

FIGURE II-2
ALTERNATIVE SOURCES OF ELECTRIC POWER IN MAJOR SOLAR POWER APPLICATIONS

(a) Communications Applications

"AT&T Long Lines has mandated an experiment which is believed to be the only test of solar electric power within the AT&T and Western Electric complex. It is intended to produce a data point for the use of all other parties in the corporation. Cost is no object, the requirement being that a typical power installation be made and data taken under realistic conditions. Herb has decided to make an installation to provide 540 peak watts of power for some microwave equipment located in lower Manhattan near the World Trade Center." Mr. Herb Power, Area Transmission Engineer, AT&T Long Lines Division, New York, New York.

"Collins is not interested in getting into solar-powered repeaters, which they feel are viable only in remote areas with small requirements for channel capacity. Typically Collins manufactures communications equipment with 1800 channels, as opposed to 36 channels for a typical solar-powered repeater." Mr. Beckeridge, Engineer Microwave Communications, Collins Radio Company, Richardson Texas.

"The only location where DRGW has used solar power is on some governmental land where the government was unhappy about running a power line five to seven miles into their cross-over repeater. Therefore, they decided to go with a solar power supply. It turns out, quite by accident, however, that the solar power supply is competitive in first cost with the 5-to-7-mile power line." Mr. Bob Lehnertz, Communications Engineer, Denver and Rio Grande Western Railroad, Denver, Colorado.

"Mel figures there are probably five or six isolated mountaintop repeaters in New England, and perhaps 100 more in the western part of the country. About half the time, a power line can be run in economically, but for the other half they need solar power. About 50% of this market consists of state and local government repeaters, and the other half are private, used

by the forestry operations of large paper mills, or by groups of potato farmers who join together to install one repeater." Mr. Mel McIntyre, Application Engineer, New England Sales Office, Motorola Communications Division, Lexington, Mass.

"They do have some photovoltaic applications in two-way radio repeaters, but they have no solar-powered emergency highway callboxes. This would be a low priority item from a funding standpoint. They depend on federal funding for emergency callboxes, and foresee none at the moment." Mr. MacDonald, Communications Department, State of Nevada Highway Department, Carson, Nevada.

"They have installed about 250 solar power supplies in the last three years, largely for government and oil company installations, and mostly in the mid-east and Africa. On the other hand, they have made no solar power supply installations in the United States. The reason for this is that in the U.S., and in Europe for that matter, there are power lines just about everywhere, whereas in the third world there are very few power lines. Hence, over there, they generally put in diesel generators for the higher power requirements, and solar power supplies for the lower power requirements. The fact that skilled maintenance costs are very high in the third world favors the use of solar supplies." Mr. John Von Bergen, Engineer, Page Communications Engineering, Inc., Vienna, Virginia.

"They have installed only one solar power supply, and that was for a transceiver located on a mountaintop in Idaho. It was installed three years ago, because there appeared to be no way to run a power line up to this particular location. Approximately 15% of their 210 microwave repeaters required a special power line to be constructed. Most of these were less than one-mile long, however, and the longest was twelve miles long. At all 210 sites, they have propane-gas-generating units as power backup." Mr. John Kelly, Communications Engineer, Union Pacific Railroad, Omaha, Nebraska.

(b) Corrosion Protection Application

"Broyles manufactures a complete line of protection equipment for pipelines. They have installed three solar power systems to date, all in 1976. All three installations, however, were of a test or demonstration nature, because the costs of photovoltaic power are not competitive yet." Mr. Stan Potchernick, Application Engineer, Wayne Broyles Engineering Corporation, Houston, Texas.

"Farwest has the market cornered in the gas well casing business. Compared to oil wells, gas well casings usually require less corrosion protection power, and are also remote from power sources. In 1976, Farwest made approximately 600 solar power installations with an average peak power of 40 watts." Mr. Gordon Rankin, President, Farwest Corrosion Controls Company, Gardena, California.

"They have a couple of test units with 4'x 5' solar arrays, which are working fine, but they have no present plans to extend the use of solar power. Two factors are holding them back. They typically are quite a large pipe, roughly 16" in diameter, and it requires rather a high voltage and quite a bit of current to protect this. This leads to the other problem, which is the size of the arrays. He couldn't emphasize enough the amount of static and resistance they have been receiving concerning the appearance of these arrays. The resistance comes from land owners and even from conservation groups and environmentalists. There is also a related problem with vandalism." Mr. Dick Scroggin, Pipeline Engineering Supervisor, Tenneco, Inc., Houston, Texas.

(c) Navigational Aids

"From 1974 up to the present, Automatic Power has installed 40-50 peak kilowatts of solar power, half of it being installed during 1976. On unmanned offshore platforms, they formerly used air-polarized carbon-zinc batteries. The total cost of photovoltaic arrays is now competitive with

these batteries, so that today they tend to choose between solar power or a wind power supply, depending on geographic location, power load requirements, maintenance requirements, and the caliber of technical personnel available. In the Gulf of Mexico, where most of these installations have been made, photovoltaic power is preferred." Mr. Ernie Tindel, Project Engineer, Automatic Power Company, Houston, Texas.

"They used to use zinc-air primary batteries before photovoltaic power supplies became competitive in cost. The important costs are the service costs. To install or repair a power supply on a navigational aid requires about a day and a half on station. The rate for a service launch is approximately \$800 per day, and that of a serviceman is about \$40 per hour. While photovoltaic supplies appear to be more reliable, they are insisting on a 10-year service life." Carl Kotila, Project Engineer, Tideland Signal Corporation, Houston, Texas.

(d) Consumer, Recreational, and Miscellaneous Applications

"Yachts need a way to trickle-charge their batteries when at the mooring, especially if they run an automatic bilge pump. He bought 400 charging arrays from Solar Power Corporation in late 1975, and has sold 358 of them. All were domestic sales except for 55 units which were sold to a company in the Philippine Islands. Nevertheless, they are planning to phase out this product because it doesn't fit in with their overall company product mix." Mr. Fred Gerdes, Director of Sales, Yardney Electronics Company, Pawcatuck, Connecticut.

"The Outdoor Advertising Association of America has decided that it might be economical in some cases, and politically wise in a lot more, to use photovoltaic power for outdoor advertising signs. Hence they are going to try out two such applications in 1977." Mr. Marshall Dietrich, Regional Manager for Solar Energy Development, NASA-Lewis Research Center, Cleveland, Ohio.

"The Hayes Fluid Controls Division of Zurn Industries manufactures water meters. During 1976, they sold between 4,000 and 5,000 meters with solar-powered remote readouts. These instruments consume 10 milliamps at 6 volts. Zurn is the only one in the industry using a solar-powered readout; they are getting a very good reception in spite of the fact that their price is a little higher than for the older type of generator, which uses a water wheel generator within the pipe. The features of solar power are that people are interested in solar energy, the solar device does not introduce any constriction into the water line, and it is much more reliable," Mr. Sy Colson, Manager of Marketing, Zurn Industries, Erie, Pennsylvania.

"They have sold photovoltaic devices for portable radios, consumer novelty items, and recreational vehicles. They have sold quite a few for prime power for people who live in the wild areas of Mexico." Mr. Ron Ignatius, President, M-7 International, Arlington Heights, Illinois.

Table II-1 summarizes the interview findings on the principal factors that favor or oppose the use of photovoltaic power.

c. Total 1976 U.S. Market (Peak Wattage)

In Figure II-3, the total 1976 U. S. photovoltaic market is estimated in terms of peak kilowatt capacity. The "commercial" side of this market is shown in the upper circle. With the exception of the segment in the lower right, labeled "Commercial (Export)" this circle corresponds to the markets covered by the scope of this study.

The export, government, and aerospace markets are included here so as to arrive at totals for all photovoltaic equipment produced, which can then be compared against figures published by other sources.

TABLE II-1
PRINCIPAL FACTORS WHICH FAVOR OR OPPOSE USE OF
PHOTOVOLTAIC POWER

	<u>Communi-</u> <u>cations</u>	<u>Corrosion</u> <u>Protection</u>	<u>Navigation</u> <u>Aids</u>	<u>Consumer</u> <u>& Recreation</u>
A. <u>Economics</u>				
1. First Cost	XXXXX	XXXXX	XX	XXXX
2. Operating Cost	X	XX	XXXXX	
B. <u>Functional Factors</u>				
1. Reliability	XX		XXX	XX
2. Climate/Insolation	XX	XX	X	
C. <u>Emotional Factors</u>				
1. Appearance	XXX	X		
2. Novelty	XX			XXXX

Key

XXXXXX = Critical

XXXX = Very Important

XXX = Important

XX = Moderate Concern

X = Minor

d. Total 1976 U.S. Market (Dollars)

Comparison of Figure II-5, which shows the composition of the 1976 photovoltaic market in dollars, with Figure II-3 which shows it in kilowatts, offers some insight into the nature of the industry.

The segmentation of the upper circular chart on Figure II-5 is very similar to that on the preceding page because the average price per kilowatt for photovoltaic equipment does not differ greatly from one area of commercial application to another. On the other hand, the lower circles representing Government/Aerospace purchases differ considerably. The lower circle in Figure II-5 is much larger relative to the upper circle than in the preceding figure because photovoltaic equipment made to military and aerospace specifications is far more expensive than that made to commercial specifications. By the same token, the equipment purchased by DOE was manufactured essentially to commercial specifications whereas that made for satellites and for the Department of Defense was not. Thus, DOE which was the largest government buyer on a kilowatt basis, was a minor factor in the market on a dollar basis.

e. Structure of Photovoltaic Industry in 1976

Figure II-6 depicts the flow of photovoltaic goods from cell manufacturer to end user within the commercial market in 1976. As the products are gradually transformed from cells to arrays to power supplies to end-use products, they move down the chart, with value being added at each level.

To take the communications market segment as an example, the cell manufacturers sold their products for communications use in two forms. \$400,000 worth were sold directly to end users as complete power supplies. On the other hand, \$2.6 million worth were sold as arrays to manufacturers of radio equipment, who added the additional components necessary to convert the arrays into complete power supplies. These supplies were then resold to private users for \$3.9 million.

FIGURE II-3
ESTIMATED COMPOSITION BY PEAK WATTAGE
OF 1976 U.S. SHIPMENTS OF PHOTOVOLTAIC EQUIPMENT

TABLE II-2
ESTIMATED COMPOSITION, BY MAJOR MARKET SEGMENT,
OF U.S. PHOTOVOLTAIC INDUSTRY IN 1976
 (Shipment in Kilowatts)

<u>Markets</u>	<u>Total</u>
<u>Commercial (U.S.)</u>	
Communications	67.6
Corrosion Protection	28.1
Navigation Aids	20.3
Recreation	4.5
Other Consumer	7.0
Miscellaneous	<u>1.1</u>
Subtotal	128.6
<u>Commercial (Export)</u>	<u>40.0</u>
Total Commercial	168.6
<u>Government and Aerospace</u>	
Commercial Satellite	14.3
USCG	3.0
DOD	26.0
NASA	5.2
DOE	<u>60.0</u>
Subtotal	<u>108.5</u>
Total	277.1
Japan (Commercial and Government)	75
Europe (Commercial and Government)	<u>35</u>
Grand Total	387.1

Japanese and European markets were estimated from information in Electronics, January 6, 1977.

FIGURE II-4.
ESTIMATED COMPOSITION BY DOLLAR VALUE
OF 1976 U.S. SHIPMENTS OF PHOTOVOLTAIC EQUIPMENT

TABLE II-3
ESTIMATED COMPOSITION, BY MAJOR MARKET SEGMENT,
OF U.S. PHOTOVOLTAIC INDUSTRY IN 1976
(Value of Shipments in \$ Thousands)

<u>Markets</u>	<u>Total</u>
<u>Commercial (U.S.)</u>	
Communications	\$ 3,043
Corrosion Protection	823
Navigation Aids	710
Recreation	135
Other Consumer	300
Miscellaneous	<u>10</u>
Subtotal	5,021
<u>Commercial (Export)</u>	<u>1,600</u>
Total Commercial	6,621
<u>Government and Aerospace</u>	
Commercial Satellite	2,860
USCG	105
DOD	5,200
NASA	1,040
DOE	<u>900</u>
Subtotal	10,105
Total	\$16,726
Japan	3,300
Europe	<u>1,600</u>
Grand Total	\$21,626

FIGURE II-15*

ESTIMATED STRUCTURE OF U.S. PHOTOVOLTAIC INDUSTRY IN 1976

(Figures indicate value of products transferred in \$ thousands)

* Based on quoted prices and array price equal to 67% of the total costs.

i. Excerpts from Interviews: Comments on the Selection of Suppliers For Solar Power Arrays

The following comments are representative opinions of major suppliers regarding the potential of photovoltaic panel applications:

(a) Communications Applications

"Personal contacts in his lab identified Spectrolab and Solar Power Corporation as potential suppliers. Herb proceeded to deal with Spectrolab, since all prices were about equal and Spectrolab's sample equipment appeared to be better." Mr. Herb Power, AT&T.

"He has no vendor preferences at this point. He finds solar cell suppliers to be a mysterious lot of people and has difficulty getting adequate information from any of them." Mr. Bob Lehnertz, Denver and Rio Grande Western Railroad.

"When asked which supplier Farinon prefers, he expressed no preference. It appears they have been working with Spectrolab, primarily because they are nearby." Mr. Ken Hall, Sales Department, Farinon Electric Company, San Carlos, California.

"He says that they selected Solarex on the basis of cost effectiveness, but it is also obvious that they are located nearer to Solarex than to any of the other major suppliers." Mr. Rob Farmer, Applications Engineer, General Electric Communications Systems Division, Lynchburg, Virginia.

"They purchased their first and only unit from Solar Power Corporation. Because of Solar Power's big name, they felt they would have little worry about reliability." Mr. John Oades, Systems Engineer, GTE-Lenkurt Company, San Carlos, California.

"They bought most of their larger panels from Spectrolab because Spectrolab approached them first, and they have been quite satisfied with the reliability of Spectrolab's equipment. They have also purchased a few panels from Solar Power Corporation, as a sort of second source." Mr. Frank Weed, United States National Park Service.

(b) Corrosion Protection Equipment

"They chose Spectrolab because, at the time they first started looking, Spectrolab was the only manufacturer with a finished power supply that was actively selling in the corrosion protection field." Mr. Stan Potchernick, Wayne Broyles Engineering Corporation.

"Gordon purchases all of his arrays from Spectrolab, and feels he has a close relationship with the president of that company. Of course, Spectrolab is nearby compared to Solar Power Corporation, which was their other candidate. He observes, however, that Goodall Electric Company, which is one of their potential competitors in Nebraska, recently switched to Solar Power Corporation." Mr. Gordon Rankin, Farwest Corrosion Controls Company.

(c) Navigational Aids

"In 1976, about 50% of their purchases came from Solar Power Corporation, 20% from Spectrolab, 25% from Sensor Technology, and about 5% from Solar Technology. Although their purchases were in the form of modules made to their specifications, cell prices were a small factor in their overall selection. In 1977, they expect to get a large portion of their cells from OCLI. The reason for this is that OCLI has attacked their severe ocean environment problems head-on, and accomplished the desired results the hard way. Although it is expensive, OCLI is putting its cells in a metal can, with a complete glass-plate front, and hermetic feed-throughs for the leads. This approach really turns on Automatic Power." Mr. Bernie Tindle, Automatic Power Company.

"Originally, they purchased strip modules of cells from Solar Power Corporation, but nowadays they have decided to build their own arrays from bare cells purchased from the suppliers. They profess to have no preference for any particular supplier. Their basic building block will be a 10" x 10" array, which includes 16 cells of 2.5" diameter. Their specifications will be like military specifications, and they have even purchased a few cells to this specification from a little company in India." Mr. Carl Kotila, Project Engineer, Tideland Signal Corporation, Houston, Texas.

(d) Consumer, Recreational, and Miscellaneous Applications •

"A problem with photovoltaic arrays is that the "weekend warriors" shoot them up. They are working with Solar Energy Systems and with Spectrolab to develop Lexan covers which will stop a .22 bullet shot at the array at a perpendicular." Mr. Glen Wilson, Project Engineer, Southern Pacific Railway Company, San Francisco, California.

Table II-4 summarizes the interview findings on factors influencing the selection of suppliers of solar power supplies.

3. The Potential Domestic Market for Photovoltaic Power

a. Introduction

In Figure II-6 the curve depicts DOE's goals for selling prices of solar arrays, year by year, from 1976 through 1986. These prices, as measured in the scale on the left hand side of the page, are in 1975 dollars and are as described by John Bountendyk of Jet Propulsion Laboratory in the Proceedings of the Electrochemical Society.

In order to apply DOE's price decline goals to photovoltaic products which had a variety of prices in 1976, the scale on the righthand side of the page was used. The use of this scale carries with it TMA's assumption that, in the years to come, the prices of all photovoltaic products, such as complete power systems, will decline precisely in proportion to the prices of arrays. Therefore, if a power supply sold for \$100 per peak watt in 1976, it is assumed that the same power

TABLE II-4
FACTORS IN SELECTION OF SUPPLIERS OF SOLAR POWER SUPPLIES

	<u>Communi-</u> <u>cations</u>	<u>Corrosion</u> <u>Protection</u>	<u>Navigation</u> <u>Aids</u>	<u>Consumer</u> <u>& Recreation</u>
1. Specs/Form of Package	X	X	X	XXX
2. Market Coverage	XXXX	X	X	X
3. Service/Appl. Assistance	XXXX	X	X	XX
4. Reputation/Record in Field	XXX	XXXX	XXXX	
5. Price	XXX	XXX	XX	XXXXX

Key

XXXXX = Critical

XXXX = Very Important

XXX = Important

XX = Moderate Concern

X = Minor

supply would sell for about \$4.50 per peak watt in 1982. While it is doubtful that the prices of all photovoltaic products will actually decline precisely in proportion to one another, and to array price, this assumption was made owing to funding and time limitations of the project.

b. Excerpts from Interviews: Comments Concerning the Potential Market For Photovoltaic Power

The following excerpts are from interviews representative of comments received concerning the potential domestic market for photovoltaic power:

i. Communications Applications

"At today's prices, he feels there may be a maximum market of 15 potential common-carrier repeater applications within the USA. If solar cell prices were to drop by 50%, that market might expand to 30 units; if the price were to be cut in half again, the potential market would double again to 60 units. This relationship would hold until a 100-to-1 price reduction had come about. An identical observation could also be made with respect to cell efficiency." Mr. Herb Power, AT&T.

"Charlie feels that users and suppliers are apprehensive about the reliability and cost tradeoffs of a solar-powered communications repeater. The manufacturers are waiting to see how successful GTE's 4-watt unit will be. If it proves to be successful, probably all of the microwave repeater suppliers will jump into that marketplace." Mr. Charles Cumalat, Telecommunications Marketing Department, Avantec, Incorporated, Santa Clara, California.

"He has discussed the use of solar power for crossing signal and field signal units, although there are only about 20 locations on their entire

system that do not have power lines nearby. Both types of signal units require 5 watts peak and operate at about 50% duty. He would consider solar power for these units if the power supply prices would come down to \$200 or less." Mr. Bob Lehnertz, Denver and Rio Grande Western Railroad.

"They feel that the marketplace for their 4-watt solar-powered microwave repeater will be approximately 100 units per year once they are in production. They also feel that this might go as high as 200 units per year if photovoltaic cell prices fall by as much as 25%. John also feels that solar-powered cable repeaters and fiberoptic repeaters would provide a new marketplace if the prices of these power supplies came down to \$1-2 per peak watt." Mr. John Oades, GTELenkurt Co.

ii. Corrosion Protection Applications

"They paid \$20 per watt for the 100-watt array they purchased in 1976, but DOE says they expect these prices to drop 50% within the next year. If that happens, photovoltaic power supplies could penetrate about 10% of the new pipeline corrosion protection installations. If prices were to drop to 25% of what they are today, penetration would go up to 25 or 35% of new installations, and some retrofitting of existing pipelines would begin to take place." Mr. Stan Potchernick, Wayne Broyles Engineering Corp.

"Gordon feels that volume of photovoltaic equipment used for gas wells will increase proportionately as cell prices decrease, but that the ultimate volume will level off at about 15 kilowatts peak in 1985. In addition, there may be three other potential applications, all to power telemetry equipment. These are for gas gauging, gas valve control, and sending monitors. He feels that the total market for all of these is roughly 2 kilowatts per year." Mr. Gordon Rankin, Farwest Corrosion Controls Company.

iii. Navigational Aids

"Photovoltaic power supplies are competitive at today's prices. The present rate of usage at this company alone is about 200 peak watts per month, but this is essentially a retrofit market. He anticipates that this rate of consumption will continue for another four years, but after that, the marketplace will be saturated." Mr. Carl Kotila, Tideland Signal Corporation.

iv. Consumer, Recreational, and Miscellaneous Applications

"They are investigating solar power supplies for power applications but the price tends to be too high. They feel solar power would be practical for comfort stations, provided they could get approximately one kilowatt of power at a price of about \$5 per peak watt. Another typical application would be power for ranger stations, where they would need about 10 kilowatts at around \$2 per peak watt." Mr. Addison Hulse, Electrical Engineer, United States National Park Service, Engineering Office, Denver, Colorado.

"Regarding the 7.2 watt trickle-chargers for yachts, Fred feels that if the retail price could be brought below \$200 each, and the wholesale below \$100, he could sell about 1,500 units per year." Mr. Fred Gerdes, Yardney Electronics Company.

c. Projected Installations of Photovoltaic Power

In the following two exhibits, future installations of photovoltaic equipment are projected, using the method of calculation explained (Exhibits II-1 and II-2).

i. Communication Applications

With respect to the private carrier repeater segments of the communications market, solar power is expected to compete with other power sources for a number of installations which will grow from 1435 in 1976 to 3950 in 1985, with annual growth rates changing between 10% and 15%. The average

FIGURE II-6

PUBLISHED DOE PRICE GOALS FOR PHOTOVOLTAIC ARRAYS

EXHIBIT II-1
SAMPLE CALCULATION

Area of Interest: Corrosion protection of new gas pipelines by cathodic impressed current.

Eight thousand miles of new pipe are being installed per year and this appears relatively constant for the future. Typical soil and pipe require 5 watts peak power per mile. The maximum U.S. market will be a flat 40 kW per year. Wayne Broyles Engineering Corporation estimates that there will be 10% penetration when the power supply prices get down to \$18/W-peak which is expected to occur in 1978. He also feels the penetration will increase to 30% when the power supplies cost \$11/W-peak which is expected to occur in 1979.

The power supply prices are determined by modifying the 1976 price of \$43-watt-peak for a power supply by the published DOE curve for future array, price reductions. Years prior to 1978 have 0 penetration. Years after 1979 have a constant 30% penetration because the remaining 70% are near utility power. There is now sufficient information to calculate sales for each year as shown below:

1978 sales = 40,000 (.10)* \$15* = \$ 60,000

1980 sales = 40,000 (.30)* \$ 9* = \$108,000

* See Exhibit II-2.

EXHIBIT II-2
SAMPLE WORKSHEET
CORROSION PROTECTION - GAS PIPELINES (NEW PIPE)

	<u>Predicted Unit Sales (Miles)</u>	<u>Peak- Watts/ Mile</u>	<u>Pene- tration</u>	<u>kW</u>	<u>DOE Price Factor</u>	<u>System Cost in Sale Form</u>	<u>Predicted Sales \$K</u>
1976	8000	5	0	0	1.0	43	0
1977	8000	5	0	0	.48	21	0
1978	8000	5	.10	4	.35	15	60
1979	8000	5	.30	12	.28	12	144
1980	8000	5	.30	12	.2	9	108
1981	8000	5	.30	12	.15	6	72
1982	8000	5	.30	12	.1	4	48
1983	8000	5	.30	12	.08	3	36
1984	8000	5	.30	12	.05	2	24
1985	8000	5	.30	12	.025	1.1	13

installation is assumed to require 335 peak watts, which, in 1976, would cost about \$32 per watt. As prices of solar power decline, photovoltaics' share of this market is expected to grow from 14% in 1976 to 75% in 1985.

Some offshore platform telemetry applications are included within the private carrier segment, but they provide only a trivial contribution to the available market.

So far as common carrier repeaters are concerned, the dominant user of photovoltaics will, of course, be AT&T. The number of installations available each year is expected to grow at 3% per year from a level of 1,300 in 1976. Each repeater is assumed to require a power supply rated at 2,000 peak watts, which, in 1976, would have cost \$44 per watt. No solar penetration of this market is expected until 1978. Thereafter, as prices decline, photovoltaics are expected to capture a gradually increasing share of this market, reaching 33% in 1985.

A summary of forecasted sales of photovoltaic equipment for communications applications is shown in Figure II-7.

ii. Corrosion Protection

At present, the only significant corrosion protection application for photovoltaic equipment in the U.S. is found on the casings of unattended gas wells. This, however, is essentially a retrofit market, which is expected to "dry up" in a few years, regardless of what happens to the price of photovoltaic equipment.

In the case of pipelines, some form of corrosion protection is generally required by law, and electrical cathodic protection is already a well-accepted means to meet this requirement. Photovoltaic power supplies are, as yet, seldom cost-effective for pipelines, but are expected to become so in some circumstances in the near future.

FIGURE II-7
FORECASTED SALES OF PHOTOVOLTAIC EQUIPMENT
FOR COMMUNICATIONS APPLICATIONS

The principal market opportunity in pipelines is not in new pipelines (such as were treated in the sample calculation), but in existing ones. In the case of gas, 8,000 miles of new pipe are expected to be installed per year, whereas over 500,000 miles of old pipe are already underground. Solar protection of such pipe is assumed to require 5 peak watts per mile and a power supply for this application would have cost about \$43 per watt in 1976. No sales for existing pipelines are predicted until 1979, when the cost of such a supply drops to \$13 per watt. Thereafter, further price declines are expected to increase solar penetration of this market, until existing piping is retrofitted at a rate of 2% per year, beginning in 1984.

The relative stringency of federal regulations regarding cathodic protection of oil and gas pipelines would tend to ensure a market for cathodic protection of gas pipelines. The opportunity for cathodic protection of oil pipelines would enlarge this segment of the market by about 15%.

The forecasted sales of photovoltaic equipment for corrosion protection is shown in Figure II-8.

iii. Navigational Aids

The principal non-Coast Guard application of solar power supplies for navigational aids takes place on wellheads and other unmanned ocean platforms owned by oil companies.

Photovoltaic power is already well-accepted in this application, and is used in most new installations as well as some retrofit work. Therefore, projected declines in the price of photovoltaic equipment are unlikely to do more than double the rate at which such installations are made. Furthermore, as more well-heads and platforms are retrofitted, the

FIGURE II- 8

FORECASTED SALES OF PHOTOVOLTAIC EQUIPMENT
FOR CORROSION PROTECTION APPLICATIONS

effects of market saturation will soon become noticeable, so that after 1979 the market will decline noticeably. Beginning in 1983, virtually no further business will be available; new well-heads will generally be equipped with power supplies taken from abandoned ones.

The Coast Guard has initiated a program to test photovoltaic power for buoys at sea. Provided that this program is successful, procurements will begin in 1978. The rate at which installations are made, however, will be little affected by the price levels of solar arrays. Instead, the rate of procurement will be determined by funds available for rebuilding of buoys and the Coast Guard's disposition to transfer buoy-tending personnel to other duties.

Figure II-9 summarizes the forecasted sales of photovoltaic equipment for navigational aids.

iv. Consumer Applications

Future applications on consumer products are relatively difficult to predict, since there is almost no experience with photovoltaic equipment in this market as yet.

In the recreational field, however, the Yardney Electric Company has sold a few hundred 7peak-watt solar supplies to trickle-charge batteries and operate automatic bilge pumps aboard yachts when at the mooring. Although Yardney has discontinued this product, it is their opinion that lower array prices would reopen the boat market, as well as a similar one with campers. Thus, as prices decline, it is predicted that this market segment may grow from 10 KW in 1977 to 350 KW in 1985.

In addition, a substantial market is foreseen in power supplies for portable radios, TVs, calculators, toys, shavers, and other light appliances. At present, no U.S. manufacturer offers a solar-powered product

FIGURE II-9
FORECASTED SALES OF PHOTOVOLTAIC EQUIPMENT
FOR NAVIGATIONAL AIDS

of this type, but such products are available in Europe and Japan, and, as prices decline, it seems inevitable that they will also be manufactured in the U.S. A market growing to 350 KW by 1985 has been projected, although, in an economy as large as that of the U.S., it could obviously become much larger.

Figure II-10 summarizes the forecasted sales of photovoltaic equipment for consumer applications.

v. All Applications

In Figure II-11, the projections of the four preceeding figures are combined.

Within the markets covered by this study, the communications market obviously dominates the business. Basically there are two reasons for this:

- (1) Among the non-consumer applications, only communication has enough potential wattage associated with it so that the reduction of array prices can create a large unit market.
- (2) Potentially, of course, the consumer market is even larger. Nevertheless, photovoltaics are not expected to make appreciable inroads into consumer products until array prices reach \$1/watt or less.

As for the dollar value of the market, this has been calculated strictly mechanically, using the price reduction factors derived from the DOE pricing goal curve. It should be noted, however, that the resulting prices are in 1975 dollars; effects of inflation, if any, are not taken into account.

FIGURE II-10
FORECASTED SALES OF PHOTOVOLTAIC EQUIPMENT
FOR CONSUMER APPLICATIONS

FIGURE II-11
FORECASTED SALES OF PHOTOVOLTAIC EQUIPMENT
FOR ALL APPLICATIONS WITHIN SCOPE OF STUDY

4. Summary and Conclusions

a. The U.S. commercial photovoltaic market is a typical immature high-technology industry, characterized by expanding volume, plummeting prices, fast-changing technology, many small optimistic competitors, and an uncertain future.

b. Although the total 1976 shipments of U.S. manufacturers of photovoltaic equipment are estimated at \$16.7 million, only about \$5.0 million of this was used in the domestic commercial market. The U.S. government, which has traditionally been the primary consumer of photovoltaic products in this country, remained by far the largest customer, buying about \$7.3 million worth in 1976.

c. The high first cost per watt of photovoltaic power continues to limit its commercial applications to those which combine: (a) remoteness from utility power lines; (b) low wattage demand; (c) long operating time; and (d) need for service-free operation. In practice, three types of applications constituted 90% of the commercial market in 1976: (1) communications repeater installations; (2) corrosion protection of gas wells; and (3) powering of offshore navigational aids.

d. Most decisions to use solar power appear to have been highly rational, in that solar power can be shown to meet the user's requirements at lower overall cost than any alternative power source. Nevertheless, other intangible factors have some effect on the total size of the commercial market:

i. Some "innovators" are buying photovoltaic equipment even though it is not economical, largely to gain familiarity with this new source of energy.

- ii. Some buyers are deliberately holding off their purchases, because they have been assured that prices will be dramatically lower in another year or two.
- iii. Other prospective users are repelled by fears of unreliability and consequent legal liability, concerns about the appearance of arrays, and fear of theft and vandalism.
- iv. Because the photovoltaic manufacturers are small, and their sales coverage is spotty at best, many prospective customers may go unsolicited.

e. Vendors of photovoltaic equipment are selected on the same basis as in many other immature high-technology markets. Reputation and demonstrable performance are the major factors in supplier choice, followed by price and quality/quantity of market coverage.

f. The longest-established firm in the industry continues to be the market leader and is believed to transact over half the total volume of the industry. In the commercial portion of the market, however, its share is only about 35%, and it is closely pursued by several other major manufacturers.

g. Looking to the future, the study projects an extraordinary growth in the rate of installation of photovoltaic equipment. Assuming the achievement of DOE's goals for photovoltaic pricing, it is predicted that 2.9 peak megawatts of commercial photovoltaic equipment will be installed in 1985 in the U.S., compared to only 128 kilowatts in 1976. About three-quarters of this gain will be provided by communications applications, with consumer products contributing most of the remainder.

h. Nevertheless, it should also be noted that use of solar power in these markets will contribute little to DOE's overall objective of decreasing U.S. dependence on petroleum-based fuels. By 1985, total installed wattage of solar power in the markets covered by the study is expected to be no more than 0.01% of that operating in fossil-fueled utility power plants in the U.S.

i. From the standpoint of the manufacturers of photovoltaic equipment, the future of the industry will be critically affected by prevailing array prices, which DOE is determined to reduce from \$20 per peak watt in 1976 to \$.50 per peak watt in 1986. If these goals are met (and industry representatives interviewed by TMA consider them to be "realistic"), it is obvious that there must be explosive growth in unit volume in order to sustain even the modest dollar volume which the industry enjoyed in 1976.

j. Unfortunately, even the twenty-fold increase in unit volume predicted in this study would not be enough to offset the effect of the price reductions proposed by DOE. As projected here for the current major markets, the domestic commercial sales volume of the industry would grow from its 1976 level of \$5 million to about \$7.5 million in 1981, but then, under the pressure of continuing price declines, would fall off to less than \$3 million in 1985.

k. Obviously, such an outlook would provide little incentive for investment in the photovoltaic industry, whereas the actions of companies like Motorola demonstrate that, in actual fact, substantial investments are presently being made. Hence, it seems more likely that the industry will develop along lines somewhat different from those described in this report.

C. Foreign Photovoltaic Market Outlook

1. Introduction

The foreign market for photovoltaics has sufficient potential to deserve a detailed quantitative analysis. It is obvious that the developing nations as well as the developed nations have many uses for photovoltaics. Photovoltaics are an excellent means to provide electric power in developing nations which do not have an adequate electric grid. Most often, however, those nations which do not have a well-developed utility grid are the nations which cannot afford the cost of installing the grid and do not have a sufficient electricity demand to support the operation of such a grid. This lack of funds and lack of demand must be carefully considered when forecasting the market in developing nations. The following analysis relies heavily upon published accounts of the level of spending in various sectors of the economies studied. Whenever possible the market estimates have been checked against expected funding levels.

The strong dependence of photovoltaics purchases upon the level of available funding indicates that the foreign market will be composed almost entirely of those applications which can be shown to be clearly cost-effective. In order to determine the cost-effectiveness, an economic analysis has been performed for each major market. The life of the arrays is assumed to be twenty years. The interest rate varies depending upon the application and the purchaser. Governments are assumed to be able to get low-interest loans while individuals secure a higher interest rate. Initial market penetration and the rate of penetration are based largely upon these analyses. For low-cost consumer items, such as transistor-radio battery chargers, first cost rather than life-cycle costing has been deemed more appropriate for determining the market. A distinction has been made in the text to show in which cases life-cycle costing has been used and in which cases first cost has been used.

The scope of this study did not permit an individual market analysis for each country, or even for a majority of the countries. In lieu of analyzing all of the world's countries, six representative countries were chosen to represent three different levels of economic development. The United States represents the developed market economies. The nations with developing economies not based upon exported oil are represented by India and Pakistan. The oil producing and exporting countries (OPEC) which are generally developing nations also are represented by Nigeria, Saudi Arabia, and Iran. Based upon the results of the market surveys in these countries, a crude extrapolation can be made to find the world markets for photovoltaics. These extrapolations are made on the basis of the gross domestic product (GDP) of the countries and on the fraction of the GDP which goes into gross capital formation.

One of the two methods used for determining the market potential for photovoltaics involved a review of the planned or possible ventures that could employ photovoltaics. National plans or U.S. Commerce Department information describe the capital formation which was to take place. This would include such items as the length of microwave repeater routes to be built or the amount of pipeline to be laid. From this information and an analysis of the economics of the situation, the requirements for photovoltaics could be determined. For an example of this type of analysis see the Indian microwave relay market analysis. This is the most precise, hence the most desirable, method of analyzing the data.

A second method of determining the market for photovoltaics is through an analysis of the funds available for a project in which photovoltaics could play a role. Again the first step is establishing the economics of photovoltaics. The economics then help to dictate the amount of the budgeted funds that could be expected to be spent for photovoltaics. An example of this method of market analysis is the market for photovoltaically-powered water pumps in Saudi Arabia. The Saudis have

budgeted large amounts of money for water resources but have specified very little about the projects for which the funds are allocated. In the Saudi fiscal year 1978-1979 \$430 million is budgeted. Of this amount 0.079% is assumed to go toward photovoltaics. At a system cost of \$8.30 per watt, sales of 41 kilowatts could be realized. Similar estimates are made for subsequent years. For further explanation see the Saudi desalination market analysis. The estimate of possible budget penetration is admittedly a subjective matter, but it provides reasonable estimates and has the advantages of limiting exceptionally high estimates. As a rule-of-thumb an upper limit of 5% budget penetration was set and in most cases, budget penetrations do not exceed 1%. Ideally, the two methods described would be used to check each other in estimating a given market, as was done for the potable water market in India. However, lack of data usually forces the use of one method or the other.

The data are presented on a country-by-country basis for the countries studied. The principal markets such as lighting, communications, etc., are broken down within each representative country. The final section of this portion of the report deals with the extrapolation of the data for the representative countries to the world market.

2. Saudi Arabia

Saudi Arabia is currently in the midst of a massive development program. The present Development Plan (1975-1980)⁽¹⁾ calls for economic and social development on many fronts. Under the plan, agricultural output is to be expanded in an attempt to make the kingdom self-sufficient in several types of crops. Expansion of agriculture will require an increase in the amount of irrigated land. Much of the brackish water pumped from the Saudi aquifers must be desalinated before it can be used for drinking or irrigation. Petroleum production, the main source of

revenue for the kingdom, will be expanded in the coming years. In an effort to diversify the economy, government assistance will be provided for electrification projects, new manufacturing, construction, and commerce. The educational program will be improved to reduce the dependence of Saudi Arabia on skilled foreign labor. There is also an extensive plan for the development of the physical infrastructure of the kingdom. Transportation via air, land, and sea is to be improved. This will require construction of new airports, roads, and ports. The telecommunication network is to be greatly expanded in both reach and capacity. Many of the proposed projects will not be completed during the current plan. Consequently, these projects will be extended into the subsequent development plan. It is estimated that the types of projects and rate of funding increase will remain constant during the 1980-1985 period.

Availability of funds is a topic which must be addressed when assessing the market for photovoltaics. Budgets have been proposed which present the amount of spending for various Saudi development projects. These budgeted amounts have been used in determining possible photovoltaics requirements and penetrations. While Saudi Arabia may have funds over the amount which has been budgeted, this should not be construed to mean that they will subsidize photovoltaics through applications which are not cost-effective. This market estimate assumes that photovoltaics will only be bought for cost-competitive applications.

The Saudis have shown a great interest in the use of many types of solar energy. Both personal contacts and published reports indicate a strong desire to invest in solar energy. The Saudis have invested in solar heating programs in both the United States and Saudi Arabia. They are also interested in alternative paths to solar electricity and have signed a joint accord with the French to procure a solar electric power tower. Saudi officials have also expressed an interest in procuring photovoltaic panels.

a. Water Pumping Applications

In the arid Mideast, water is a very important commodity. Water is mandatory for sustaining human life, agriculture, and industry. Due to the great need for water and its relative scarcity, the Saudi government is to make a large investment in providing water where it is needed.

The sources of water which the Saudis wish to exploit are surface water, ground water residing in aquifers, and sea water. Available surface water is capable of supplying only a small portion of the Saudi water requirements. Any sea water which is to be used must be desalinated. Such desalination is usually done for cities and industry in large, multistage flash-evaporation plants. Groundwater pumped from aquifers supplies the major portion of the Saudi water requirements. The aquifers of northeastern Saudi Arabia are numerous but often present difficulties due to their depth or salinity. The aquifer depth varies from about 200 feet, for the shallowest level aquifer in the east, to 3000 feet or more in the west.⁽²⁾ Electric or fossil-fuel-driven pumps are now being used to raise this water.

Total water use in 1975 was estimated to be 2,460 million cubic meters. About 77% of this water was used for agriculture irrigation. It is projected that 2,500 million cubic meters of water will be needed for irrigation alone by 1980. The present plan makes significant allocations to meet this demand. There will also be 3,000 projects undertaken in small villages to improve the water supply. These will include "drilling, repair, and replacement of wells, and construction of distribution systems."⁽¹⁾

Due to the difficulty in identifying particular projects and their power requirements, the Saudi photovoltaic market potential has been based on the amount of money budgeted to the Ministry of Agriculture and Water. Table II-5 gives the results of this estimate to be a cumulative market

for 4,946 kW by 1985. Conservative penetrations of less than 1% of the total water plan budget have been assumed in each year. A higher penetration was not assumed due to the large expenditure which can be expected for well drilling, pipes, administrative costs, labor, and assorted hardware required.

TABLE II--5
WATER PUMPING MARKET

<u>Year+</u>	<u>Budget (million \$U.S.)</u>	<u>Penetration (%)</u>	<u>PV System Cost (\$/W)</u>	<u>Sales (kW)</u>
1977-78	391.3	0.057	11.1	20
1978-79	429.7	0.079	8.3	41
1979-80	477.2	0.100	6.6	72
1980-81	560*	0.119	5.4	123
1981-82	660*	0.146	4.2	229
1982-83	760*	0.204	3.3	470
1983-84	880*	0.332	2.6	1124
1984-85	1060*	0.568	2.1	<u>2867</u>
			TOTAL	4946

+ Based on Saudi fiscal year.

* Estimate based on past growth rate.

b. Desalination

Desalination is important in providing water in Saudi Arabia and its importance is rising. As increasing quantities of water are required the more brackish aquifers must be tapped. Much of the ground water contains 2,000 to 5,000 parts per million of total dissolved solids (TDS). This level must be reduced to about 500 ppm of TDS for the water to be considered potable. Somewhat higher levels are allowable for irrigation water. In rural areas away from the seacoast, electrodialysis units are often used for desalination. These electrically powered units represent an excellent market for photovoltaics. Economic breakeven prices for units of various capacities are shown in Table II-6.

TABLE II-6
PHOTOVOLTAIC ELECTRODIALYSIS ECONOMICS

<u>Load (gal/day)</u>	<u>Breakeven Price (\$/W)</u>	<u>Generator</u>
1300	39	Gasoline
2600	38	Gasoline
3900	17	Gasoline
6500	10	Gasoline
9750	6.4	Gasoline
13000	3.9	Diesel

The breakeven prices shown in Table II-6 (see Appendix IA) indicate that photovoltaic systems are cost-competitive with gas generators for units of 6,500 gallons per day even at today's prices. If one assumes that each person in a village requires 20 gallons per day, such a unit could service a village of 325 people. Having established the cost-competitiveness of a photovoltaic-powered electrodialysis unit, the needs and desires of the Saudi government are again difficult to establish. As in the case of water pumping, we must once again look to the desalination budget to find the funds available. Based upon the budget for the Water Desalination Organization, estimates are given in Table II-7 of the potential photovoltaic sales through 1985. The impact of photovoltaics on the desalination budget is assumed to be less than 1% for each year. The cumulative market through 1985 is estimated to be 3,657 kW.

TABLE II-7
WATER DESALINATION MARKET

<u>Year+</u>	<u>Budget (millions \$U.S.)</u>	<u>Penetration (%)</u>	<u>PV System Cost (\$/W)</u>	<u>Sales (kW)</u>
1977-78	386	0	11.7	0
1978-79	1762	0.0031	9.0	6
1979-80	1687	0.0091	7.3	21
1980-81	1773*	0.021	6.0	62
1981-82	1912*	0.036	4.8	145
1982-83	2015*	0.057	3.9	294
1983-84	2131*	0.143	3.2	952
1984-85	2342	0.251	2.7	<u>2177</u>
			TOTAL	3657

+ Based on Saudi fiscal year.

* Estimate

c. Telecommunications

The Saudis are making a strong effort to improve telecommunications in the kingdom. The current plan calls for establishing "trunk dialing facilities between important cities in the kingdom through coaxial and/or microwave networks."⁽¹⁾ Phase I plans call for 1,560 km of coaxial cable and 160 km of microwave links. Phase 2 of the present plan calls for a total of 7,115 km of long-haul communications links. Since the mixture of microwave and coaxial cable is not specified it is assumed to be the same as the Phase I plans. In the next five year plan it is assumed that the telecommunications capabilities will increase to 110% of the previous five year plan. This assumption is based upon Saudi projections of system inadequacies during the early 1980's. Based upon discussions with equipment manufacturers, the power requirements are estimated to be 5 watts per kilometer for coaxial cable. Repeaters which require 8.8 continuous watts must be placed every 1.75 km along the cable. Such small power requirements are best met in the rural areas of Saudi Arabia by photovoltaics, primary batteries, or periodic recharge of secondary batteries. The microwave relay stations were

assumed to require 6.25 watts per kilometer continuously. Economic analysis by microwave repeater manufacturers indicates that photovoltaics are cost-competitive in Saudi Arabia at present prices for this size unit. In addition to public telecommunications, private companies such as Aramco and other oil companies will provide a substantial market for telecommunications equipment. Tables II-8 and II-9 summarize the potential telecommunications market potential.

d. Mass Communications Market

Radio and television are expected to play an increasing role in information dissemination in Saudi Arabia. In such a vast country as Saudi Arabia these are the most effective means of rapidly informing the populace of important matters.

It is expected that solar cells could play an important role in battery charging for transistor radios. A small transistor radio was assumed to be used with a 1.4 watt solar array for battery charging. The alternative for photovoltaics was assumed to be primary dry cell batteries.

TABLE II-8
COAXIAL CABLE MARKET

Year	Cable Laid (km)	Penetration (%)	Market (kW)
1977	1560	10	3
1978	1560	30	9
1979	1560	50	16
1980	1560	75	23
1981	1720	80	28
1982	1720	90	31
1983	1720	90	31
1984	1720	90	31
1985	1720	90	31
	TOTAL		203

TABLE II-9
MICROWAVE RELAY MARKET

<u>Year</u>	<u>Relay Distance (km)</u>	<u>Penetration (%)</u>	<u>Market (kW)</u>
1977	160	50	3
1978	960*	90*	31
1979	960*	90*	31
1980	160	80	6
1981	176	85	5
1982	976**	97	34
1983	976**	97	34
1984	176	90	6
1985	176	90	6
TOTAL			156

* Includes communication system for Aramco planned oil pipeline.

** Includes communication system for Aramco planned natural gas pipeline.

On strictly a cost-analysis basis the solar cells have a clear advantage at costs of \$100 per watt or more. However on low-cost consumer items such as this, the first cost will be the dominant factor. If the cost of a good 9-volt dry cell is assumed to be \$1.50, the solar panel probably would not find an appreciable market if the cost of the panel is over \$3.00. This assumes that the cost of the radio is less than \$10. Based upon radio sales in similar countries the Saudi radio sales are estimated in Table II-10. A 5% growth rate of sales is assumed. Cumulative sales of 58 kilowatts could be achieved by 1985. It should be noted that this is the type of market which Japanese solar cell manufacturers have indicated they will pursue.

Television is coming into more prevalent use in the kingdom for mass communications. The current plan calls for extending the television viewing area over 90% of the kingdom. Assuming a 36-watt television⁽³⁾

used daily for 5 hours (Saudi TV broadcasts 5 hours daily and 10 hours Friday), it was determined that recharging of secondary batteries from a central station would be economical only for photovoltaic array prices greater than \$32/watt. This assumes that the recharging station is 20 miles from the point of use. There are at least 4,600 villages not served by roads and hence assumed to be without electricity. If we assume 80% of these villages to be in a viewing area and 50% of the villages to receive one TV, the total market is 1,840 units. It is probably reasonable to assume this as a minimum market size. The market estimates shown in Table II-11 indicate a total photovoltaic market of 81 kilowatts through 1985.

e. Cathodic Protection

The major market foreseen for cathodic protection in Saudi Arabia is for pipeline and water well protection. Pipeline is being installed in Saudi Arabia at a rate of 340 miles per year. For a well-coated pipe in moderate resistivity soil, the current requirement is 0.010 amps per miles per inch of pipe diameter. The well-coated pipe criteria is probably valid for new pipe-

TABLE II-10
RADIO RECEIVERS MARKET

Year	Radio Sales (Thousands)	Penetration (%)	Market (kW)
1977	58	0	0
1978	61	0	0
1979	64	0.05	0
1980	67	0.1	0.1
1981	70	0.5	0.5
1982	74	2	2
1983	78	9	10
1984	82	15	18
1985	86	22	27
	TOTAL		58

TABLE II-11
TELEVISION RECEIVER MARKET

Year	PV Powered TV's	Market (kW)
1977	10	0.4
1978	25	1
1979	100	4
1980	250	11
1981	291	13
1982	291	13
1983	291	13
1984	291	13
1985	<u>291</u>	<u>13</u>
TOTAL	1840	81

lines. The impressed voltage is assumed to be 8 volts. Average pipe diameter is assumed to be 24 inches. A uniform 50% market penetration is assumed. Higher penetration is not likely since pumping stations located along the pipelines are able to provide large quantities of inexpensive power. Table II-12 indicates that the cumulative market for pipeline cathodic protection equipment will be only 9 kilowatts by 1985.

Water wells require a much greater amount of power for protection since there is no coating on the pipe. The current requirement is about 2 amps per mile per inch of pipe diameter. For an assumed well depth of 1,000 feet a voltage of 4 volts should be sufficient. Average pipe diameter will be assumed to be 12 inches. On the basis of the present plan it will be assumed that 400 wells per year will be drilled. Table II-13 shows a cumulative market of 79 kilowatts by 1985.

f. Aviation Aids

The importance of aviation in the kingdom cannot be overstressed. Due to the vast distances between cities and lack of roads, the use of aircraft is most important. The Central Planning Organization, in recognizing this need, has allocated \$3.9 billion for projects relating to air transportation. In addition to improving airports, the Civil Aviation Department wishes to extend the navigational aids and air-ground remote communications to cover the entire kingdom. Based upon discussions with FAA officials the following requirements are foreseen:

Air-ground remote communications

Total units required: 100

PV power: 570 W peak

Duty cycle: 100%

PV penetration: 60%

Break-even cost: > \$60/W

Total market: 34 kW

VOR

Total units required: 100 (50 inner; 50 outer)

PV power: 143 W peak

Duty cycle: 100%

PV penetration: 50% outer, 0% inner

Break-even cost: \$1.60 inner, \$64 inner

Total market: 4 kW

Instrument Landing System

Total units required: 5 (away from airport)

PV power: 28.6 kW peak

Duty cycle: 100%

PV penetration: 1 unit in 1981

Break-even cost: \$4.00/W

Total market: 28.6 kW

TABLE II-12
PIPELINE CATHODIC PROTECTION

<u>Year</u>	<u>Pipe Length (Miles)</u>	<u>Penetration (%)</u>	<u>Market (kW)</u>
1977	340	50	1
1978	340	50	1
1979	340	50	1
1980	340	50	1
1981	340	50	1
1982	340	50	1
1983	340	50	1
1984	340	50	1
1985	340	50	<u>1</u>
TOTAL			9

TABLE II-13
WATER WELL CATHODIC PROTECTION

<u>Year</u>	<u>Number of Wells</u>	<u>Penetration (%)</u>	<u>Market (kW)</u>
1977	400	0	0
1978	400	2	1
1979	400	4	2
1980	400	7	3
1981	400	15	6
1982	400	25	10
1983	400	35	15
1984	400	45	19
1985	400	55	<u>23</u>
TOTAL			79

g. Saudi Arabia Market Summary

The estimated market for photovoltaics in Saudi Arabia through 1985 is presented in Table II-14. The cumulative market through 1985 is expected to be 9,256 kilowatts of photovoltaics. This market is expected to be dominated by government purchases as indicated in the preceding descriptions. Each market has been realistically assessed in terms of the financing available for photovoltaic purchases as well as the economic aspects of the situation.

3. Iran

Iran is presently in the midst of its 5th Five Year Plan.⁽⁴⁾ Similar to the Saudi plan, the Iranian plan addresses the country's development on many fronts. Both the infrastructure of the country and social welfare of the people are to be improved. The infrastructure improvements most relevant to this photovoltaic marketing study involve improvements in the water supply for domestic use and agriculture, increased rural electrification, expanded intercity microwave links, increased education and information dissemination via radio and television, and improved air transportation. Market potential estimates will be made in all of these areas.

The funding available for each of these projects was carefully assessed and compared with the amount of money that would be required for the photovoltaic arrays. Penetration of the budget for a given project was kept to what appeared to be a reasonable level (usually less than 1%). In all cases photovoltaics were assumed to make no market penetration until a competitive cost could be achieved.

TABLE II-14
SAUDI ARABIA MARKET POTENTIAL (kw)

	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>CUMULATIVE</u>
Water Pumping	1	20	41	72	123	229	470	1124	2867	4947
Desalination	0	0	6	21	62	145	294	952	2177	3657
Communications	6	41	51	40	47	80	88	68	77	498
Cathodic Protection	1	2	3	4	7	11	16	20	24	88
Aviation Aids	<u>0</u>	<u>0</u>	<u>4</u>	<u>5</u>	<u>7</u>	<u>8</u>	<u>35*</u>	<u>7</u>	<u>0</u>	<u>66</u>
TOTAL	8	63	105	142	246	473	903	2171	5145	9256

* Saturated market

a. Water Pumping Applications - Potable

Iran is making strong efforts to provide piped water for residents in rural areas. The emphasis on rural development is necessary since the 1966 census indicated that "57 percent of the population lived in 66,000 rural villages and settlements."⁽⁴⁾ Nearly half of these people lived in 48,000 villages.⁽⁵⁾ Such rural areas indicate a good potential market for small photovoltaic panels to power water pumps. There are 15,000 piped drinking water projects to be accomplished during the Fifth Plan.⁽⁴⁾ If we assume that 5,000 of these projects will require a new pump and power source, 1,000 pumps would be required each year. If an array of 4.2 kW peak which pumps 25 gallons per day per person, is assumed to be an average size unit, the potential market can be seen in Table II-15. Economic comparison with a gasoline generator reveals a breakeven cost of \$24/W. Low market penetrations are assumed in the early years due to the lack of familiarity with the product. Table II-15 shows the cumulative market through 1985 to be 1,790 kW. The amount spent for photovoltaic panels represents .2% of the estimated rural infrastructure budget.

b. Water Pumping Applications - Irrigation

As in all agricultural societies, water for irrigation is an important commodity in Iran. The present plan calls for an increase of 100,000 hectares per year of irrigated land. This rate of expansion has been assumed to be constant throughout the subsequent plans. Based upon data for areas of the United States with similar climate and topography it is assumed that 1.5 feet of water will be required for each irrigated hectare.⁽⁶⁾ Since surface water for irrigation is fairly abundant, an

TABLE II-15
POTABLE WATER PUMPING MARKET

<u>Year</u>	<u>Pumps</u>	<u>Market Penetration (%)</u>	<u>Market (kW)</u>
1977	1000	0.01	0.4
1978	1000	0.05	2
1979	1000	0.2	8
1980	1000	0.4	17
1981	1000	2	84
1982	1000	5	210
1983	1000	8	336
1984	1000	12	504
1985	<u>1000</u>	15	<u>630</u>
TOTAL	10,000		1790

average 20-foot lift will be assumed for ditch irrigation.⁽⁶⁾ It is assumed that water will be pumped 1,000 hours per year.⁽⁷⁾ The size of the land to be irrigated is one of the most important factors in assessing the economics of photovoltaics in this case. As can be seen in Table II-16, the increase from 10 irrigated hectares to 50 hectares substantially reduces the breakeven price of photovoltaics. The size of these government-funded irrigation projects is not known but is assumed to be 50 hectares or greater for a maximum return on investment. The unfavorable economics are greatly influenced by the low load factor of 1,000 hours per year. Long power line extensions, such as those listed, may be practical in regions irrigated by surface water due to the availability of electricity from the hydroelectric dams which contain the water. The irrigation pumping market estimates are presented in Table II-16. The cumulative market through 1985 is estimated to be 1,501 kW. This investment represents .11% of the estimated budget for irrigation networks.

TABLE II-16
IRRIGATION ECONOMICS

Irrigated Land (Hectares)	Gasoline Generator Breakpoint (\$/W)	Powerline Extension Breakpoint	
		Miles	(\$/W)
10	11	1	2
		2	5
		3	8
		4	11
		5	14
50	4.50	2	<0.50
		3	0.80
		4	1.50
		5	2.00
		6	2.60
		7	3.20
		8	3.70
		9	4.20
		10	4.75

TABLE II-17
IRRIGATION MARKET POTENTIAL

Year	Irrigated Land (hectares)	Penetration (%)	Market (kW)
1977	100,000	0	0
1978	100,000	0	0
1979	100,000	0	0
1980	100,000	0.01	1.8
1981	100,000	0.05	9.2
1982	100,000	0.1	18
1983	100,000	1	184
1984	100,000	2	368
1985	100,000	5	920
	TOTAL		1501

c. General Rural Electrification

Under the 5th Plan there are to be 1,180 rural development centers to be created to serve 12,000 villages. Each of the development centers is to receive electric power along with other infrastructure improvements. It is assumed that this program will continue with subsequent plans. It is further assumed that 400 of these centers are to receive individual power plants fired by fossil fuels with the remainder of the centers to be connected to the national utility grid. Power requirements have been estimated as 40 installed watts of photovoltaics per person. This estimate may be high for the small villages and low by a factor of two or three for larger villages. Also included in the 5th Plan is the electrification of 200 individual villages of more than 250 people. All of these villages will require individual power plants.

The villages covered under this plan are assumed to be distributed in size as shown in Table II-18. As shown in the table, the development centers are assumed to have a distribution that favors the larger villages. It is assumed that the individual villages to be electrified tend to be smaller in population than the development centers. The calculated breakeven price for photovoltaics for the different village sizes is also shown in Table II-18. The distribution of village sizes and breakeven costs for photovoltaics were used to calculate the weighted average photovoltaic penetrations shown in Table II-19. The table shows that the cumulative market through 1985 for development center power is estimated to be 876 kW. The cumulative market through 1985 for individual village electrification is estimated to be 1,540 kW. This purchase represents 1.2% of the estimated rural electrification budget.

TABLE II-18
VILLAGE SIZE DISTRIBUTION AND BREAKEVEN COST

<u>Number of Persons</u>	<u>Number of Development Centers</u>	<u>Number of Individual Villages</u>	<u>Breakeven Cost (\$/W)</u>
250	0	39	12.00
350	20	34	9.50
450	30	31	6.00
550	40	28	4.50
650	60	24	3.00
750	70	20	2.50
850	80	14	2.00
950	<u>100</u>	<u>10</u>	1.00
TOTAL	400	200	

TABLE II-19
GENERAL RURAL ELECTRIFICATION MARKET PENETRATION

<u>Year</u>	<u>Development Centers</u>		<u>Individual Villages</u>	
	<u>Penetration (%)</u>	<u>Market (kW)</u>	<u>Penetration (%)</u>	<u>Market (kW)</u>
1977	0	0	0.1	0.4
1978	0.25	2.8	1	4
1979	0.72	9.3	5	25
1980	1.5	22	10	55
1981	2.2	32	22	126
1982	4.7	82	36	215
1983	7.8	143	46	305
1984	12	241	54	392
1985	18	<u>344</u>	61	<u>418</u>
TOTAL		876		1540

d. Telecommunications

To aid in the industrial development of the country, Iran plans to greatly expand its telecommunications capabilities. According to the present plan, "The general policy in the telecommunications field is to expand services to meet the growing needs of the economy and to cover the entire country."⁽⁴⁾ To increase the capacity and reach of long distance telephone and telegraph communications, the 5th Plan calls for expansion of the "microwave telecommunications system by 40,000 canals (channels) and the number of lines from 89 to 250."⁽⁴⁾ Based upon an average distance of 300 kilometers between major cities and an average repeater size of only 250 channels the estimated microwave relay market is shown in Table II-20. The power requirements for the relays are assumed to be 2.5×10^{-3} continuous watts per channel per kilometer. An array size of 800 peak watts is assumed. The estimated number of units required is based upon the planned expansion during the 6th Plan.⁽⁴⁾ The money to be spent on solar panels represents .07% of the estimated main telecommunications lines budget or 1.0% of the secondary lines and rural telecommunications budget. The cumulative market through 1985 is 146 kW.

TABLE II-20
MICROWAVE RELAY MARKETS

<u>Year</u>	<u>Units</u>	<u>Penetration (%)</u>	<u>Market (kW)</u>
1977	32	5	1.3
1978	35	8	2.2
1979	41	12	3.9
1980	47	20	7.5
1981	53	30	13
1982	60	40	19
1983	66	50	26
1984	72	60	35
1985	<u>79</u>	60	<u>38</u>
TOTAL	485		146

c. Mass Communications Market

The government of Iran uses both radio and television for news dissemination and for education. The number of radio sales in Iran was not available and was estimated from the radio market in Nigeria. On a life-cycle cost basis, photovoltaics have a clear advantage over primary batteries but similarly to the Saudi market, appreciable sales are not expected until a 2-watt array sells for about \$3. On this basis the market penetration and market size are shown in Table II-21. The estimated cumulative market for photovoltaics through 1985 is estimated to be 178 kW.

The government of Iran uses television for educational purposes. There are two channels with 65% of the population expected to be within a receiving area by 1978. It is expected that the 66,000 rural villages and settlements represent the major markets for educational television. The potential market penetration and market size are shown in Table II-22. The cumulative market is estimated to be only 20 kW. The small market size is estimated because of the small budget for rural education. The photovoltaic purchases represent 0.37% of this estimated budget. However, it is expected that there will be quite a few televisions powered by photovoltaics under the category of general power which has already been discussed.

TABLE II-21
RADIO MARKET

<u>Year</u>	<u>Radio Sales (Thousands)</u>	<u>Penetration (%)</u>	<u>Market (kW)</u>
1977	172	0	0
1978	181	0.5	0
1979	190	0.05	0.01
1980	199	0.1	0.3
1981	209	0.5	1.6
1982	220	2	7
1983	231	9	31
1984	242	15	54
1985	<u>254</u>	22	<u>84</u>
TOTAL	1898		178

TABLE II-22
EDUCATIONAL TELEVISION

<u>Year</u>	<u>Units Installed</u>	<u>Market (kW)</u>
1977	3	0.1
1978	10	0.4
1979	15	0.7
1980	25	1.1
1981	40	1.8
1982	60	2.7
1983	80	3.6
1984	100	4.5
1985	<u>120</u>	<u>5.4</u>
TOTAL	453	20.3

f. Aviation Aids

Iran is in the process of building new airports and improving the air navigation systems. Based upon the discernible requirements it is judged that photovoltaics will only impact upon the remote air-ground communications equipment. With a 60% penetration of the estimated 70 units necessary, the total market through 1985 is only 25 kW.

g. Iran Market Summary

The estimated photovoltaic market for photovoltaics through 1985 is shown in Table II-23. Due to government ownership of the national power and telecommunications systems, the major purchases are expected to be made by the government. Each of the markets dominated by the government has been appraised with due regard to the funding available. Table II-23 indicates a cumulative market in Iran through 1985 of 6,077 kW.

TABLE II-23
IRAN MARKET POTENTIAL (kW)

	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>TOTAL</u>
Water pumping	0.4	2	8	17	84	210	336	504	630	1790
Irrigation	0	0	0	1.8	9.2	18	184	368	920	1501
Rural Electrification	0.4	6.8	34	77	158	297	448	633	762	2416
Telecommunications	1.4	2.6	4.7	8.9	16	29	61	94	127	345
Aviation Aids	<u>0</u>	<u>0</u>	<u>3.6</u>	<u>3.6</u>	<u>3.6</u>	<u>3.6</u>	<u>3.6</u>	<u>3.6</u>	<u>3.6</u>	<u>25</u>
TOTAL	2	11	50	108	271	558	1033	1603	2443	6077

4. Nigeria

Nigeria is presently in the midst of its Third National Development Plan.⁽⁸⁾ In April 1977 the scope of this plan was revised upward by the Federal Military Government to \$68.4 billion.⁽⁹⁾ This plan, apparently the most ambitious in Black Africa, is to be financed primarily by foreign exchange revenues gained through the export of petroleum products.

Most photovoltaic purchases can be expected to be made for federal or state projects. Relatively little consumer spending is expected since only about one-fifth of the population has progressed from a barter economy to a money economy. The photovoltaic market estimates for Nigeria are heavily based on the government spending expected during the Third Plan.

a. Water Pumping - Potable

The improvement of the national water systems is receiving high priority from the Nigerian government. Old systems are being upgraded and new systems installed under the Third National Development Plan (1975-1980).⁽⁸⁾ Both the federal and state governments are participating in this development project. Cities and towns will probably receive the bulk of the funds for developing urban water systems. Funds have also been specifically allocated for rural development such as the \$16.5 million allocated for 9,000 wells in the Kano state. As in the case of Saudi Arabia, the number and magnitude of the projects are not available. For this reason the market penetration is based upon the expected water supply expenditures. The Nigerian water supply expenditures shown in Table II-24 are only 60% of the total budgeted expenditures. This budget reduction is because the Federal Military Government only expects to be able to procure enough capital and labor to spend 60% of the available resources.⁽⁹⁾ The expected cumulative market through 1985 is 3,597 kW.

The water sources to be tapped will be surface reservoirs and ground-water. Wells are expected to be shallow since many wells now in use are shallow pit wells dug by hand.⁽⁸⁾ Diesel generators are currently used to power water pumps away from the utility grid.

TABLE II-24
POTABLE WATER MARKET

<u>Year</u>	<u>Budget*</u> <u>(millions of \$U.S.)</u>	<u>Penetration</u> <u>(%)</u>	<u>PV System Cost</u> <u>(\$/W)</u>	<u>Market</u> <u>(kW)</u>
1977	228	0	12	0
1978	296	0.005	8	1.8
1979	362	0.05	6.6	28
1980	425	0.07	5.6	53
1981	486	0.09	4	109
1982	555	0.11	3.2	191
1983	624	0.14	2	437
1984	690	0.18	1.4	887
1985	756	0.25	1	<u>1890</u>
TOTAL				3597

*Figures given are 60% of budgeted expenditures (see text).

The penetration of this market by U.S. manufacturers will be difficult. The major suppliers of equipment for water supply and water treatment in Nigeria are the United Kingdom and Germany with market shares of 50% and 21% respectively.⁽⁸⁾ The Nigerian preference for turn-key operations will make it necessary for U.S. photovoltaic companies to join forces with pump manufacturers to offer a unified pump and power system. U.S. companies can expect strong competition for European cell manufacturers in this Nigerian market. There is also some reluctance on the part of the Nigerians to use advanced technologies in preference to the more familiar methods.

b. Irrigation Market

The irrigation projects slated under the Third Plan are intended to increase the productivity of semi-arid land in the six northern states. The Third Plan calls for the extension of irrigation to 440,000 hectares.⁽⁸⁾ It appears that most of this irrigation will be accomplished through large-scale projects involving the damming of rivers to provide upstream reservoirs and a constant flow downstream. The large-scale projects in which large amounts of land are irrigated by one pump will not provide good markets for photovoltaics until the prices fall below \$2/W for photovoltaics. Smaller projects, such as those in the Galma River Basin, present a market for photovoltaics at higher panel costs. The economics of photovoltaic irrigation in Nigeria is presented in Table II-25. The analysis assumes 1,000 hours of operation per year and a 20-foot lift of surface water.

There are several barriers to the introduction of photovoltaics for irrigation in Nigeria. As mentioned previously, the Nigerians are wary of new technology. An attempt must be made far in advance of expected sales to familiarize the Nigerians with photovoltaics if significant sales are to be made in the 1980's. Another potential problem here is the dominance of pumps and generators from the United Kingdom. It would be highly desirable to sell integrated systems for irrigation but such an approach requires a significant U.S. market share.

The estimated market is shown in Table II-26. The market penetrations are the same as those assumed for Iran with a one-year time lag. The number of hectares to be irrigated is based upon the Third Plan.⁽⁸⁾

TABLE II-25
IRRIGATION ECONOMICS

Irrigated Land (Hectares)	Gasoline Generator	Powerline Extension	
	Breakpoint (\$/W)	Breakpoint (Miles)	(\$/W)
10	10	1	2.20
		2	5.00
		3	7.80
		4	10.00
		5	13.00
50	4	1	<0.50
		2	<0.50
		3	<0.75
		4	1.25
		5	1.80
200	1.3	1	<0.50
		2	<0.50
		3	<0.50
		4	<0.50
		5	<0.50

TABLE II-26
IRRIGATION MARKET POTENTIAL

<u>Year</u>	<u>Irrigated Land (Hectares)</u>	<u>Penetration (%)</u>	<u>Market (kW)</u>
1977	89,000	0	0
1978	89,000	0	0
1979	89,000	0	0
1980	89,000	0	0
1981	89,000	0.01	1.8
1982	89,000	0.05	8.9
1983	89,000	0.1	17.8
1984	89,000	1	178
1985	89,000	2	<u>356</u>
		TOTAL	563

It is somewhat in doubt however that these goals will be met on time since only 16,200 hectares were under irrigation in all of Nigeria as of May 1976. The total market potential can be seen to be 563 kW through 1985. This represents .04% of the budget estimated by the Federal Military Government. Since only 60% of this budget can realistically be expected to be spent, the actual photovoltaic purchases could be 0.024% of the budget.

c. General Rural Electrification

The role of photovoltaics in rural electrification in Nigeria is uncertain. In towns unreachable by the national utility grid in the short term the government plans to install diesel generators with a minimum size of 75 kW. The government definition of a town as opposed to a village or other small unit is not clear. The utility grid currently reaches many areas of the country and significant expansions of the grid are planned. In the field of rural electrification: "NEPA (National Electric Power Authority) planners expect that by 1980 the national grid will reach so

far that the lower marginal cost of electrifying towns will almost always enable a qualifying rate of return."⁽⁸⁾ However another source states that "extensive areas of Nigeria have no source of electricity except for portable generators."⁽¹⁰⁾ Based upon gasoline generator sales to Nigeria of \$251,205,⁽¹¹⁾ or roughly 800 units in 1975, there appears to be a significant market. All of these generators are over 5 kW. If we assume that the U.S. has a 20% market share, the annual requirement is roughly 4,000 kW for gasoline generators. Significant penetration for this size generator is not expected to begin until the photovoltaic cost reaches \$5 to \$6 per watt. The possible market for photovoltaics is shown in Table II-27. The peak photovoltaic requirement is assumed to be 50% greater than the generator requirement. The exact requirements and economics are difficult to assess due to variable load factors and duty cycles.

TABLE II-27
RURAL ELECTRIFICATION MARKET

<u>Year</u>	<u>Generator Requirement (kW)</u>	<u>Penetration (%)</u>	<u>Market (kW)</u>
1977	4000	0	0
1978	4000	0	0
1979	4000	0.2	1.2
1980	4000	0.2	12
1981	4000	0.5	30
1982	4000	1	60
1983	4000	2	120
1984	4000	3	180
1985	<u>4000</u>	8	<u>480</u>
TOTAL	36000		883

d. Telecommunications

The Third Plan calls for the extension and improvement of the telephone

system. Contracts will be awarded to international telecommunications firms for the construction of microwave links. The Third Plan calls for the purchase of 250 power generation plants with capacities of 6.5 kW to 200 kW.⁽⁸⁾ The large generators will serve as a standby reserve for new telephone exchanges and transmission stations. The smaller generators will power radio terminals and repeater stations. The number of small generators to be purchased in each year is shown in Table II-28. The uneven distribution is based upon the expected construction dates for the microwave systems. Although the smallest generator to be purchased is 6.5 kW, it is expected that a 1.6 kW solar panel could power a 2,400 channel microwave repeater. The 6.5 kW generator appears to be greatly oversized in order to get a generator which is capable of operating continuously with high reliability. Table II-28 indicates that the cumulative market in telecommunications is 286 kW through 1985. The cumulative market represents 1.4% of the power supply budget. This small penetration of the budget is due to the substantial savings from buying photovoltaic systems of the proper size rather than engine generators which are grossly oversized. An approach to the microwave equipment manufacturers could yield excellent results in this market.

TABLE II-28
MICROWAVE RELAY MARKET

<u>Year</u>	<u>Units</u>	<u>Penetration (%)</u>	<u>Market (kW)</u>
1977	0	10	0
1978	40	20	13
1979	40	40	26
1980	20	60	19
1981	20	80	26
1982	20	90	29
1983	50	90	72
1984	50	90	72
1985	20	90	<u>29</u>
TOTAL			286

e. Mass Communications

Radio is very important to the average Nigerian. Radios are apparently a prized family possession. There were about 315,000 transistor radios sold in Nigeria in 1976. Sales of photovoltaic panels for battery recharging are not likely until the price for a recharger reaches about \$3 for use in conjunction with a \$10 radio. This requires a selling price of \$1.80/W or less. Based upon a compound growth rate of 5% per year for radios, the expected transistor radio sales are shown in Table II-29. Photovoltaic sales are also shown in the table. The estimated cumulative market is 371 kW through 1985. Market penetration will be difficult due to the dominance of European and Japanese radios produced by companies capable of supplying photovoltaic models.

TABLE II-29
RADIO MARKET

<u>Year</u>	<u>Radio Sales</u> <u>(thousands)</u>	<u>Penetration</u> <u>(%)</u>	<u>Market</u> <u>(kW)</u>
1977	331	0	0
1978	347	0	0
1979	365	0.05	0.3
1980	383	0.1	0.6
1981	407	0.5	3.3
1982	422	2	14
1983	443	9	65
1984	465	15	113
1985	<u>489</u>	22	<u>175</u>
TOTAL	3962		371

Educational television is still under debate in Nigeria. There is currently no educational television except on closed circuit. It appears to be an excellent option for meeting the proclaimed goal of giving all children a primary education. It is especially interesting in light of the severe teacher shortage. The estimated requirements are given in Table II-30. The estimated cumulative market through 1985 is 43 kW. This figure is, of course, highly dependent upon the adoption of educational television as a teaching method.

TABLE II-30
EDUCATIONAL TELEVISION MARKET

<u>Year</u>	<u>TV's</u>	<u>Market (kW)</u>
1977	5	0.25
1978	10	0.5
1979	25	1.25
1980	50	2.5
1981	75	3.75
1982	100	5
1983	150	7.5
1984	200	10
1985	<u>250</u>	<u>12.5</u>
TOTAL	865	43

f. Cathodic Protection

Nigeria's oil-dependent economy requires pipelines to be built to move crude oil, refined products, and natural gas. The expected crude oil and finished product pipeline is to be constructed at a rate of 300 miles per year. It is estimated that the natural gas pipeline will be constructed at a rate of 150 miles per year. The power requirements are .08 watts per miles per inch of pipe diameter. The average diameter is assumed to be 24 inches. A 50% penetration is assumed due to the availability of low-cost power at the pumping stations. This indicates a requirement for 2 kW per year for a cumulative need for 18 kW through 1985.

g. Aviation

The need for aviation aids will probably be satisfied before a photovoltaic market can develop. Most of the required equipment is to be installed during 1977 and 1978. It is doubtful that photovoltaics will impact during that time.

h. Nigerian Market Summary

The estimated markets for photovoltaics in Nigeria are summarized in Table II-31. The cumulative market through 1985 is estimated to be 5,790 kW. The market is expected to be dominated by purchases in support of federal and state projects.

TABLE II-31
NIGERIA MARKET SUMMARY

	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>TOTAL</u>
Potable Water Pumping	0	1.8	28	53	109	191	437	887	1890	3597
Irrigation Water Pumping	0	0	0	0	1.8	8.9	18	178	356	563
General Rural Electrification	0	0	1.2	12	30	60	120	180	480	883
Telecommunications	0	13	26	19	26	29	72	72	29	286
Mass Communications	.2	.5	1.6	3.1	7.0	19	72	123	188	414
Cathodic Protection	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>18</u>
TOTAL	2	17	59	89	176	310	721	1442	2945	5761

5. India

This analysis of the Indian photovoltaic market focuses heavily on the most pressing Indian needs and on the country's ability to pay to satisfy its requirements. With the vast quantity of developmental work to be done, India must focus her attention upon projects which give the greatest returns for the least investment. This country of 439 million people⁽¹²⁾ with an average per-capita income of only \$91⁽¹³⁾ (1972 estimate) must conserve its scarce foreign exchange reserves whenever possible. This report attempts to quantify these factors as they relate to photovoltaic purchases.

It should be noted that the Indians will, probably buy solar panels separately and assemble a system in India using as many Indian components as possible. Batteries, blocking diodes, and support structure will all be manufactured in India. It is also highly likely that the Indians will develop their own photovoltaic industry in the early 1980s.⁽¹⁵⁾

If this happens it is unlikely that U.S. manufacturers will be able to continue to export panels to India. It is customary to tax heavily or to restrict imports of an import item which is also made in India.

Actual U.S. sales to India may very possibly drop sharply after 1982 or 1983. It will still be an export market, though, in the sense that the Indians wish to buy advanced technology. Licensing may become the major market.

a. Potable Water

Many villages in India suffer from an inadequate or unsafe water supply. One of the aims of the National Minimum Needs Program is to supply water to rural villages with substandard water sources.⁽¹⁴⁾ The budget during the Fifth Plan allocates \$16.3 million for this purpose. The money is to be spent on 116,000 villages which qualify under the Minimum Needs Program. Plans have been made to electrify only one-third of these villages. Economic calculations show that water for a village of about 1,000 people can economically be pumped by photovoltaics at panel costs

of \$10 per watt or less. Indian government sponsorship of the system would greatly accelerate the acceptance of this power source.

Market penetration has been based upon penetration of the rural water supply budget. The penetration remains constant after 1983 on the assumption that most of the market is covered at this level. These calculations agree reasonably closely with a market estimate based on the penetration of some fraction of the 1,400 villages per year to be provided with water. Table II-32 shows the cumulative market through 1985 to be 853 kW.

TABLE II-32
INDIA - RURAL WATER SUPPLY

<u>Year</u>	<u>Budget</u> <u>(\$)</u>	<u>Penetration</u> <u>(%)</u>	<u>Market</u> <u>(kW)</u>
1977	16.4 x 10 ⁶	0	0
1978	16.4 x 10 ⁶	0.1	2
1979	16.4 x 10 ⁶	0.2	5
1980	16.4 x 10 ⁶	0.4	12
1981	16.4 x 10 ⁶	0.8	33
1982	16.4 x 10 ⁶	1.5	77
1983	16.4 x 10 ⁶	2	163
1984	16.4 x 10 ⁶	2	234
1985	16.4 x 10 ⁶	2	<u>327</u>
	TOTAL		853

b. Irrigation Water Pumping

Irrigation is vital to the Indian economy. A high level of agricultural output is required to sustain the large number of people who live in India. The current plan calls for the addition of 300,000 new irrigation pumpsets per year.⁽¹⁴⁾ The vast majority of these pumpsets are powered by electricity

obtained by expanding the existing grid system. The present plan allocates about \$10 per pumpset for expanding the national utility grid. With the extremely low cost of labor in India (\$.05 to \$.20 per hour) this is probably a reasonable cost for powerline extension. In India the average privately owned tubewell is capable of pumping 30 liters per second from a depth of 30 meters.⁽²¹⁾ This requires about a 22 kW photovoltaic array and a breakeven cost against a gasoline generator of \$1.30 per peak watt. Powerline extensions of more than 15 miles are possible in India to compete with photovoltaic panels which sell for \$1.30 per watt. Tubewells which are furnished by the government are capable of pumping 120 liters per second from 70 meters.⁽²¹⁾ Photovoltaic penetration of these units is highly unlikely. If the government does not use photovoltaics to power the tubewells that it supplies it is somewhat unlikely that private enterprise will accept this new technology.

Expansion of the existing electric grid seems most cost-effective for powering irrigation pumps in India. Foreign exchange reserves are not required for fuel for electricity since large reserves of coal are available as are nuclear fuels. Only 40% of the rural population is to be served by the national grid by the end of the Fifth Plan.⁽¹⁴⁾ The rest of the rural population is to be connected with the grid in accordance with the availability of funds. Thus, further rural electrification is limited by the availability of funds and not by diminishing returns on further powerline extensions. These factors severely limit the market for photovoltaics.

Table II-33 shows the expected market for photovoltaics to be used in conjunction with irrigation. Due to the factors mentioned previously, low penetrations have been assumed. The cumulative market through 1985 is estimated to be 930 kW. This figure represents a cumulative penetration of only .002% of the pumpsets to be installed through 1985. The expenditure for photovoltaics represents about .4% of the money available for rural electrification. Alternatively, photovoltaics could be regarded as replacing about 5% of the diesel generators used for water pumping in India.

TABLE II-33
IRRIGATION WATER PUMPING

<u>Year</u>	<u>Pumps (units)</u>	<u>Penetration (%)</u>	<u>Market (kW)</u>
1977	300,000	0	0
1978	300,000	0	0
1979	300,000	0	0
1980	300,000	0	0
1981	300,000	0	0
1982	300,000	0	0
1983	300,000	.001	66
1984	300,000	.003	198
1985	300,000	.01	<u>666</u>
TOTAL			930

c. Rural Home Lighting

As mentioned previously, only 40% of the rural population receives electricity. The basic premise of the rural electrification program is to energize pumpsets for irrigation. The United Nation in their comments on the Indian electrification plan has stated: "The basic purpose (of the rural electrification) is to supply electricity to pumpsets, with the electrification of villages generally taken as an incidental benefit."⁽⁵⁾ It seems unlikely that rural electrification in excess of that budgeted for grid extension will be undertaken unless some positive economic benefit will be accrued by the country. Rural lighting seems to offer these economic benefits.

The present method of lighting for villages which are not electrified is the use of kerosene lamps. The quantities of kerosene used are very significant, with an estimated 28% of the petroleum imported into India used for kerosene lighting.⁽¹⁶⁾ This use represents a significant drain on foreign exchange reserves with an estimated \$380 million spent annually for kerosene. An abatement of this expenditure would be well received by the Indian Government.

Photovoltaically powered fluorescent lights are a viable alternative to kerosene lighting. A system consisting of two 8-watt fluorescent lights, a 16-watt solar panel, and a small storage battery could replace and significantly upgrade the quality of kerosene lighting. Fluorescent lights and storage batteries are produced locally. It would only be necessary to import the solar panels.

A market estimate of 42.7 peak megawatts by 1985 has been made on the basis of kerosene purchases. Table II-34 shows the annual market potential. This form of lighting becomes cost-effective at about \$10 per watt. At photovoltaic costs of \$1 per unit the system only costs about twice as much as the average annual family kerosene bill. In this market an expenditure of about 4% of the money normally used for kerosene could supply photovoltaics for 5% of the rural families.

Due to the large size of this market and the means of estimating its size, there are large potential errors in the estimate. The estimate could easily be in error by a factor of two. The market could be half as large if government support is not forthcoming or twice as large if the Indian government gives the program strong backing. In any case it represents a very large market.

d. Electric Cooking

Large quantities of firewood are used annually for cooking.⁽¹⁶⁾ Severe problems are arising due to the deforestation resulting from the inefficiency of wood for cooking. For this reason photovoltaics for cooking has been assessed. It appears that photovoltaics will not be accepted for this use. A panel size of about 225 peak watts would be required. Even at \$1 per watt this is a very large investment for an Indian family. It also appears that even in rural areas where electricity is available it is

TABLE II-34
HOME LIGHTING - KEROSENE REPLACEMENT

Year	Annual	Penetration	System	PV Cost		Market
	Fuel Cost		Expenditures	System	First Cost	
	(\$)	(%)	(\$ x 10 ⁻³)	(%)	(%)	(kW)
1977	3.8 x 10 ⁸	0	0	0		0
1978	3.8 x 10 ⁸	.05	190	83		20
1979	3.8 x 10 ⁸	.08	304	80		37
1980	3.8 x 10 ⁸	.2	759	77		104
1981	3.8 x 10 ⁸	1	3790	71		673
1982	3.7 x 10 ⁸	2	7500	66		1550
1983	3.7 x 10 ⁸	5	18400	55		5060
1984	3.5 x 10 ⁸	10	34900	46		11400
1985	3.1 x 10 ⁸	20	62800	38		<u>23900</u>
	TOTAL					42744

not used for cooking. This is based upon an average energy use per family of only 450 watt hours per day including the irrigation pump. Also, according to the Fifth Plan, "Each of these resources (cowdung, vegetable waste, and firewood) has important alternate uses which are profitable from the social point of view, but for the domestic user located in rural areas, they are available at zero cost."⁽¹⁴⁾ The Plan calls for corrective action but provides no money to remedy the situation. There appears to be insufficient incentive to switch to photovoltaics.

e. Telecommunications

The Posts and Telegraphs Department Telecommunications Branch has planned the Indian trunk network through fiscal year 1979.⁽¹⁷⁾ Both coaxial cables and microwave relays are to be expanded as shown in Tables II-35 and II-36. After 1979 the future requirements are based on average past

requirements. The cumulative market through 1985 for powering microwave relays is about 510 kW. The coaxial cable market is about 89 kW.

TABLE II-35
MICROWAVE RELAYS

<u>Year</u>	<u>Kilometers</u>	<u>Channels</u>	<u>Penetration</u> <u>(%)</u>	<u>Market</u> <u>(kW)</u>
1977	3284	5167	2	3.5
1978	4068	3000	8	10
1979	3204	3914	20	26
1980	3310	3840	35	47
1981	3310	3840	50	66
1982	3310	3840	60	79
1983	3310	3840	70	93
1984	3310	3840	70	93
1985	3310	3840	70	<u>93</u>
TOTAL				510

TABLE II-36
COAXIAL CABLES

<u>Year</u>	<u>Kilometers</u>	<u>Penetration</u> <u>(%)</u>	<u>Market</u> <u>(kW)</u>
1977	1913	5	2
1978	682	10	1
1979	790	20	3
1980	1225	30	7
1981	1225	40	10
1982	1225	50	12
1983	1225	75	18
1984	1225	75	18
1985	1225	75	<u>18</u>
TOTAL			89

f. Mass Communications

Photovoltaics are currently in use to power educational television receivers in India.⁽¹⁸⁾ The Ministry of Information and Broadcasting provides community television sets for this purpose.⁽¹⁴⁾ At the present time only 17% of the population is in an area capable of receiving TV signals. It is expected that the entire country will receive television via satellite by 1980.⁽¹⁹⁾ This increased potential is reflected in Table II-37. The expected cumulative market through 1985 is 454 kW. This market represents the expenditure of about 2% of the funds for rural education to reach about 2% of the Indian villages which are not electrified.

Radio is another important means of mass communications in India. There are now about 3 million transistor radios produced annually in India for domestic use.⁽²⁰⁾ About half of these are of the low-cost (\$8) single band or two-band type. Table II-38 shows an estimate of 2.9 MW of photovoltaics by 1985. There is a strong possibility that this market will not actually reach this size. The importation of radio receivers in India is banned so it will be necessary for solar cell manufacturers to work with Indian radio manufacturers. Even this may be difficult since 60% of the radio components must be of Indian manufacture.⁽²⁰⁾ The magnitude of the market, however, may make it profitable to pursue these opportunities.

g. Miscellaneous

Other markets such as cathodic protection and aviation aids have been surveyed for India. They appear to represent a market of only about 5 kW annually. They have a relatively low price elasticity.

TABLE II-37
EDUCATIONAL TV

<u>Year</u>	<u>Potential Villages</u>	<u>Penetration (%)</u>	<u>TVs</u>	<u>Market (kW)</u>
1977	17,280	0.1	17	1
1978	17,280	1	170	11
1979	17,280	2	340	22
1980	320,000	0.2	640	40
1981	320,000	0.3	960	60
1982	320,000	0.4	1280	80
1983	320,000	0.4	1280	80
1984	320,000	0.4	1280	80
1985	320,000	0.4	1280	<u>80</u>
TOTAL				454

TABLE II-38
RADIO MARKET

<u>Year</u>	<u>Radio Sales</u>	<u>Penetration (%)</u>	<u>Market (kW)</u>
1977	3×10^6	0	0
1978	3×10^6	0	0
1979	3×10^6	0.05	3
1980	3×10^6	0.1	6
1981	3×10^6	0.5	30
1982	3×10^6	2	120
1983	3×10^6	9	540
1984	3×10^6	15	900
1985	3×10^6	22	<u>1320</u>
TOTAL			2919

h. India Market Summary

The cumulative market through 1985 for photovoltaics in India is estimated in Table II-39 as 48,536 kW. It is doubtful that U.S. suppliers will supply a major portion of the solar panels after the early 1980's. The market will probably be for solar panels only, as opposed to complete systems. It is expected that government will be the major procurer of panels through 1982 or 1983. After this time private purchases for lighting are assumed to dominate the market. It should be noted that the Indians plan to produce 2,400 MW of photovoltaics by 1985.⁽¹⁵⁾ No assessment has been made during this study as to the feasibility of attaining this goal. Overall, India appears to offer a very lucrative market for photovoltaics.

TABLE II-39
INDIA MARKET POTENTIAL (kW)

	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>TOTAL</u>
Rural Water Supply	0	2	5	12	33	77	163	234	327	853
Irrigation	0	0	0	0	0	0	66	198	666	930
Home Lighting	0	20	37	104	673	1550	5060	11400	23900	42744
Telecommunications	5	11	29	54	76	91	111	111	111	599
Mass Communications	1	11	25	46	90	200	620	980	1400	3373
Miscellaneous	<u>1</u>	<u>2</u>	<u>4</u>	<u>5</u>	<u>5</u>	<u>5</u>	<u>5</u>	<u>5</u>	<u>5</u>	<u>37</u>
TOTAL	7	46	100	221	877	1923	6025	12928	26409	48536

6. Pakistan

Pakistan, like India, is a developing nation facing many development problems. This country of 67 million people derives one-third of its gross domestic product from agriculture.⁽²²⁾ Foreign exchange is regarded as a scarce resource. The following market analysis attempts to quantify the needs and availability of resources as they relate to photovoltaics.

Statistics for Pakistan have proven to be difficult to find. Some of the data were obtained from the Fourth Five Year Plan (1970-75).⁽²³⁾ A more recent plan was not readily available. Other information was obtained from United Nations documents but they also were not up-to-date. Recent political actions such as development aid from Saudi Arabia were not taken into account in this analysis since sufficient data were not available. This aid could have a moderate effect on the market estimates. In total this market analysis probably represents a reasonable estimate for Pakistan.

a. Potable Water Pumping

During the Fourth Plan the government planned to install rural water supplies and sanitation for 100 villages per year.⁽²³⁾ The money allotted for each project is about \$10,000 per village. Assuming a well depth of 30 meters as in India, a 1.6 kW array could pump about 80 liters per day for 550 people. If we assume that no more than about 15% of the funds for a project are to be available for pumping power, Table II-40 shows the cumulative market through 1985 to be 13 kW. Substantial penetration should not occur until the prices approach \$1 per watt. This figure is in reasonable agreement with a penetration of the Pakistan water budget such as that used for Saudi Arabia. The market could be greater if foreign assistance is made available for this purpose.

TABLE II-40
POTABLE WATER PUMPING MARKET

<u>Year</u>	<u>Villages</u>	<u>Penetration (%)</u>	<u>Market (kW)</u>
1977	100	0	0
1978	100	0	0
1979	100	0	0
1980	100	0	0
1981	100	0	0
1982	100	0	0
1983	100	1	2
1984	100	2	3
1985	100	5	<u>8</u>
TOTAL			13

b. Irrigation

No market for irrigation water pumping in Pakistan is expected. As in the other countries surveyed, the breakeven costs of photovoltaics are on the order of \$1 per watt or less. In the populous sectors of Pakistan the national utility grid is well developed with almost all areas within 25 kilometers of the high-voltage feeder lines.⁽²⁴⁾ Another strong damper on the use of photovoltaics for irrigation is Pakistani industry which produces one- and two-cylinder diesel engines for irrigation. It will undoubtedly be important to the government to protect this industry from encroachment by foreign-made photovoltaics.

c. Rural Home Lighting

Although specific references could not be found, it is assumed that rural homes in Pakistan are lighted by kerosene lamps. Due to the higher electric grid density and greater urbanization of Pakistan as compared with India,

it is assumed that 20% of the imported crude petroleum is used for kerosene lighting as opposed to 28% in India. The lighting system would be identical to that proposed for India. Based upon a penetration of the resources used for purchasing kerosene, the cumulative market through 1985 is estimated to be 5.5 megawatts. Table II-41 shows an annual breakdown of the markets.

TABLE II-41
HOME LIGHTING - KEROSENE REPLACEMENT

Year	Annual Fuel	Penetration	System		
	Cost (\$)		Expenditures (\$ x 10 ⁻³)	PV Cost (% of system)	Market (kW)
1977	49 x 10 ⁶	0	0	86	0
1978	49 x 10 ⁶	.05	24	83	2
1979	49 x 10 ⁶	.08	39	80	5
1980	48 x 10 ⁶	.2	97	77	13
1981	48 x 10 ⁶	1	484	71	86
1982	48 x 10 ⁶	2	959	66	198
1983	47 x 10 ⁶	5	2350	55	646
1984	45 x 10 ⁶	10	4465	46	1470
1985	40 x 10 ⁶	20	8040	38	<u>3055</u>
	TOTAL				5475

d. Telecommunications

The plans for expansion of the microwave and coaxial cable links in Pakistan could not be procured during this study. As a result, the market estimate is based upon the markets in the other countries surveyed. Based upon the average number of kilowatts required in the other countries per telephone in use, the estimated cumulative requirement through 1985 is 367 kW.

The market potential in each year is based upon the annual market potential in the other countries. The market is shown in Table II-44, the Pakistan market summary table.

e. Mass Communications

Educational TV was introduced in Pakistan during the Fourth Plan. The funding commitment was about \$1.5 million.⁽²³⁾ The market estimates for photovoltaic-powered television have been made on the basis of a five-year funding commitment of \$2 million. About 25% of the money is to go toward the purchase of TVs and photovoltaics in later years. The remainder is assumed to be used for programming and administration. The television power requirement is assumed to be 65 peak watts of photovoltaics. As shown in Table II-42 the cumulative market through 1985 is expected to approach 149 kW.

The radio market in Pakistan is also fairly large. The demand for radios is about 2.5 million units per year.⁽²⁰⁾ About half of these are expected to be inexpensive transistor models. For a two-peak-watt panel the expected market for photovoltaically powered radios is shown in Table II-43. The cumulative market through 1985 has been estimated as 615 kW.

f. Cathodic Protection and Miscellaneous

The cathodic protection market has been assessed based upon the pipeline requirements.⁽²³⁾ A requirement of only 500 peak watts per year has been ascertained. This requirement has been grouped with other miscellaneous requirements for a total market of about 2 kW per year.

TABLE II-42
EDUCATIONAL TELEVISION MARKET

<u>Year</u>	<u>Budget</u> <u>(\$ x 10⁻³)</u>	<u>Penetration</u> <u>(%)</u>	<u>PV Cost</u> <u>(% of system)</u>	<u>Market</u> <u>(kW)</u>
1977	400	5	86	1
1978	400	10	81	4
1979	400	15	77	7
1980	400	20	74	11
1981	400	25	68	17
1982	400	25	62	19
1983	400	25	51	26
1984	400	25	42	30
1985	400	25	34	<u>34</u>
TOTAL				149

TABLE II-43
RADIO MARKET

<u>Year</u>	<u>Radios</u>	<u>Penetration</u> <u>(%)</u>	<u>Market</u> <u>(kW)</u>
1977	1.2 x 10 ⁶	0	0
1978	1.2 x 10 ⁶	0	0
1979	1.2 x 10 ⁶	0.05	1
1980	1.2 x 10 ⁶	0.1	2
1981	1.2 x 10 ⁶	0.5	12
1982	1.2 x 10 ⁶	2	48
1983	1.2 x 10 ⁶	9	108
1984	1.2 x 10 ⁶	15	180
1985	1.2 x 10 ⁶	22	<u>264</u>
TOTAL			615

g. Pakistan Market Summary

The cumulative market for Pakistan through 1985 is estimated to be 6,634 kW as shown in Table II-44. The most dominant market by far is the home lighting market. The availability of foreign aid, particularly from the OPEC nations, could cause some expansion of the estimated market.

TABLE II-44
PAKISTAN MARKET POTENTIAL (kW)

	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>TOTAL</u>
Potable Water Pumping	0	0	0	0	0	0	2	3	8	13
Home Lighting	0	2	5	13	86	198	646	1470	3055	5475
Telecommunications	3	18	28	29	40	55	73	66	55	367
Mass Communications	1	4	8	13	29	67	134	210	298	764
Miscellaneous	<u>0</u>	<u>1</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>	<u>15</u>
TOTAL	4	25	43	57	157	322	857	1751	3418	6634

D. World Photovoltaic Market

The limited scope of this study does not permit the individual evaluation of each of the world's countries. The countries which have been surveyed in detail were chosen as countries representative of three types of economics. Saudi Arabia, Iran, and Nigeria were chosen to represent the oil-rich developing OPEC nations. They also typify the developmental differences found among the OPEC countries. India and Pakistan were surveyed as developing nations which must conserve foreign exchange and attempt to raise their standard of living from the \$100 per capita now experienced. An attempt to survey the market for Mexico met with little success due to a lack of information and the language barrier. The only data point obtained for the countries with developed economies is the United States. It would have been desirable to survey at least one other developed country but the scope of this study did not permit the extra effort. The countries surveyed which represent the various world economies should permit us to make a gross extrapolation to find the total world market through 1985.

Extrapolation of this type is not without its pitfalls. Gross errors are certainly possible when one extrapolates to such a great degree from such a small sample. The nature of the estimate makes an error by a factor of two quite conceivable if not likely. Special cases certainly abound as it will be pointed out. A thorough analysis would require that each country be studied in detail and visited in person in order to get a reasonable market estimate. The results of the present analysis should be viewed from this perspective.

As has been stressed throughout this report, the availability of funds is a key issue in the purchasing of photovoltaics. Large investments will be required for this formation of capital. As such the two most valuable

statistics relating to the purchase of photovoltaics are the gross national product (GNP) of a country and the percentage of the GNP which goes into fixed capital formation. Both of these statistics are available from the United Nations for most of the countries of the world. (22)

For the countries studied it was determined that the ratio of estimated market to GNP times the percentage of the GNP which goes into fixed capital formation is relatively constant for each type of economy. (See Equation 1.)

$$k = \frac{\text{Market (kW)}}{\text{GNP (millions of \$ U.S.)} \cdot \text{Fixed Capital Formation (\%)}} \quad (1)$$

Table II-45 shows the market size, GNP, capital formation, and k value for the countries surveyed. The GNP given is for 1973 except in the case of Saudi Arabia. Since the Saudi GNP increased more than fourfold between 1973 and 1975 it seemed more appropriate to use the 1975 gross national product minus the money invested or deposited in banks outside Saudi Arabia during that year. Hence the number used for Saudi GNP was \$31,000 million rather than the 1973 figure of \$7,520 million.

Table II-45 shows the value of k used for the three types of economies under consideration. The value of k for OPEC nations was taken as .015. This represents an average of the three countries surveyed. Inaccuracies of the method can be seen to exist from the 25% variation of the value for Nigeria from the average value. For developing countries the value of k was taken to be .057. This represents the average of India and Pakistan. Again, large sources of error exist which should be recognized. For the United States markets surveyed the value of k is .0006.

According to Equation 1, a knowledge of the k value, the GNP, and the gross fixed capital formation of a particular country permit a gross estimation of the market for photovoltaics in that country. Such an

estimate has been made for all of the world's countries for which the relevant data could be obtained. The results of this country-by-country estimate is shown in Table II-46. The data indicate a cumulative world market of 521 megawatts by 1985.

Several qualifying remarks must be made on this rather large world market estimate. The estimate is based on a representative sample of six countries; it is not a survey of each individual country listed in Table II-46. As has been pointed out previously, there is a degree of uncertainty associated with the k values used. Since it is not an individual country market survey, no factor to incorporate the attitude of the national leadership has been included. The alternate sources of energy in any of the countries for which an extrapolation is made have not been examined.

Brazil is an excellent example of a country whose market has probably been overestimated. The cumulative market of 101 megawatts by 1985 fails to account for the tremendously large hydroelectric potential in Brazil. The government has a policy which embraces the development of nuclear power rather than solar energy. The only advantage of photovoltaics seems to be as a hedge against the perennial rampant inflation which is prevalent in Brazil.

Another factor which is not considered in this method is the effects of weather on the economies, hence, the sales of photovoltaics. Europe is probably a good example of an area where the GNP indicates high potential sales but poor weather and latitude adversely affect the economics. The failure to establish an efficient worldwide marketing network before 1985 will also greatly hinder the industry. It is easy to visualize a suitable marketing organization in the six countries studied but the establishment of such an organization to cover all of the countries listed in Table II-46 would be very difficult. It is also possible that there will be trade

barriers to overcome in order to sell photovoltaics in some of the countries.

Tables II-47, -48, -49, and -50 show annual estimates of the market in OPEC nations, developing non-OPEC nations, and developed-economy nations respectively. The representative countries were used to determine the percent of the cumulative amount sold in any given year. The next step in computing the table was to sum the cumulative markets for all other countries in the given economic category. The percentages calculated were then used to calculate the annual distribution of the cumulative total. Figure II-14 shows the cumulative world annual sales of photovoltaics through 1985. Table II-51 shows the estimated annual sales of each of the photovoltaically powered products surveyed. This table was also developed on the basis of the countries surveyed.

TABLE II-45

Country	Market (kW)	GNP (5×10^{-6})	Gross Capital Formation		k_{Ave}
			(%)	k_c	
Saudi Arabia	9,256	31,000	20	.015	.015
Iran	6,077	25,598	19	.012	
Nigeria	5,790	14,802	20	.019	
India	48,536	71,000	16	.043	.057
Pakistan	6,634	8,340	11	.072	
United States	12,890	1,294,900	17	.0006	

TABLE II-46
WORLD PHOTOVOLTAIC MARKET

<u>Countries</u>	Gross National Product 1973 (Millions of \$U.S.)	Gross Fixed Capital Formation (%)	Market (kW)
Developed Market- Economy <u>Countries:</u>			
Canada	118,000	23	1,600
United States	1,294,900	17	12,890
Belgium	45,740	22	600
France	255,060	24	3,700
Germany, Fed. Rep. of	348,170	22	4,600
Italy	138,270	23	1,900
Luxembourg	1,829	27	0
Netherlands	59,670	22	800
Denmark	27,350	22	400
Ireland	6,560	25	0
United Kingdom	174,800	20	2,100
Austria	27,900	28	500
Finland	17,060	29	300
Iceland	1,025	31	0
Norway	18,750	32	400
Portugal	11,200	20	100
Sweden	50,100	22	700
Switzerland	40,870	26	600
Greece	16,290	21	200
Spain	60,230	22	800
Turkey	22,036	18	200
Yugoslavia	22,250	28	400
South Africa	26,125	26	400
Japan	413,070	37	9,200

TABLE II-46 (CONTINUED)
WORLD PHOTOVOLTAIC MARKET

<u>Countries</u>	Gross National Product 1973 (Millions of \$U.S.)	Gross Fixed Capital Formation (%)	Market (kW)
Australia	52,160	24	800
New Zealand	11,710	21	100
Developing Countries and <u>Territories:</u>			
Argentina	31,385	20	35,780
Brazil	77,220	23	101,000
Mexico	48,650	23	63,800
Paraguay	979	18	1,000
Uruguay	2,585	10	1,500
Bolivia	1,014	12	700
Chile	7,640	13	5,600
Columbia	9,968	18	10,200
Ecuador	2,496	20	2,800
Peru	9,080	13	6,700
Venezuela (OPEC)	16,120	16	5,200
Costa Rica	1,461	25	2,100
El Salvador	1,335	18	1,400
Guatemala	2,545	15	2,200
Honduras	869	21	1,000
Nicaragua	1,065	13	800
Cuba	4,850	21	5,800
Dominican Republic	2,378	21	2,800
Haiti	694	9	400
Panama	1,418	23	1,900
Puerto Rico	6,774	21	8,100
Guyana	294	24	400
Windward Islands	150	17	100
Jamaica	1,714	23	2,200
Algeria (OPEC)	7,730	40	6,200
Morocco	5,012	16	4,600

TABLE II-46 (CONTINUED)
WORLD PHOTOVOLTAIC MARKET

Countries	Gross National Product 1973 (Millions of \$U.S.)	Gross Fixed Capital Formation (%)	Market (kW)
Tunisia	2,515	22	3,200
Egypt	9,100	13	6,700
Libyan Arab Republic (OPEC)	6,230	29	3,600
Sudan	2,300	10	1,000
Benin	348	17	300
Madagascar	1,258	13	900
Zaire	3,129	27	4,800
Ivory Coast	2,393	20	2,700
Niger	525	6	200
Senegal	1,014	10	600
Kenya	2,249	20	2,600
Uganda	1,715	14	1,400
United Rep. of Tanzania	1,834	23	1,834
Angola	2,980	16	2,700
Ethiopia	2,240	10	1,300
Ghana	2,857	9	1,500
Guinea	575	8	300
Malawi	535	20	600
Mozambique	2,905	15	2,905
Nigeria (OPEC)	14,802	20	5,800
Reunion	570	27	900
Southern Rhodesia	2,493	21	3,000
Zambia	2,425	31	4,300
Cyprus	963	24	1,300
Iran (OPEC)	25,598	19	9,700
Iraq (OPEC)	6,680	13	1,700
Israel	8,950	31	15,800
Jordan	870	19	900

TABLE II-46 (CONTINUED)
WORLD PHOTOVOLTAIC MARKET

Countries	Gross National Product 1973 (Millions of \$U.S.)	Gross Fixed Capital Formation (%)	Market (kW)
Kuwait (OPEC)	7,165	5	500
Lebanon	2,841	20	3,200
Qatar (OPEC)	511	(~10)	80
Saudi Arabia (OPEC)	7,520	8	9,300
Syrian Arab Republic	2,379	22	3,000
United Arab Emirates (OPEC)	1,425	(~10)	200
Yemen	500	10	300
Indonesia	15,370	18	15,800
Malaysia	6,565	20	7,500
Philippines	10,330	21	12,400
Singapore	4,283	36	8,800
Thailand	9,180	22	11,500
Burma	2,416	8	1,100
Hong Kong	5,998	22	7,500
India	71,000	16	48,892
Pakistan	8,340	11	6,549
Sri Lanka	2,612	13	1,900
Fiji	367	22	500
Papua New Guinea	945	11	600
Malta	353	23	500

TABLE II-47
ANNUAL OPEC MARKET ESTIMATES

	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>TOTAL</u>
Saudi Arabia	8	63	105	142	246	473	903	2171	5145	9256
Iran	2	11	50	108	271	558	1033	1603	2443	6079
Nigeria	2	17	59	89	176	310	721	1442	2945	5761
Total Annual	12	91	214	339	693	1341	2657	5216	10533	21096
% of Cumulative	.057	.43	1.0	1.6	3.3	6.4	13	25	50	
Other OPEC	7.6	57	130	210	440	850	1700	3300	6600	13280
All OPEC	20	150	340	550	1130	2200	4400	8500	17000	34000

TABLE II-48
ANNUAL DEVELOPING COUNTRY MARKET ESTIMATES, kwp

	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>TOTAL</u>
India	7	46	100	221	877	1923	6025	12928	26409	48536
Pakistan	4	25	43	57	157	322	857	1751	3418	6634
Total Annual	11	71	143	278	1034	2245	6882	14679	29827	55170
% of Cumulative	.020	.13	.26	.50	1.9	4.1	12	27	54	
Other Developing	80	520	1000	2000	7600	16400	48000	95900	215800	399680
All Developing	91	591	1100	2300	8600	18600	55000	111000	246000	455000

TABLE II-49
ANNUAL DEVELOPED COUNTRY MARKET ESTIMATES, kwp

	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>TOTAL</u>
United States*	250	420	660	960	1330	1690	2080	2500	3000	12,890
% of Cumulative	1.9	3.3	5.1	7.4	10	13	16	19	23	
Other Developed	580	1000	1600	2200	3000	4000	4900	5800	7000	30,400
Climate & Market										
Development Factor**	3.5	3	2.5	2	1.5	1.4	1.4	1.4	1.4	
Expected Other Developed	165	330	640	1100	2000	2900	3500	4100	5000	19,735
Total Developed	415	750	1300	2060	3330	4590	5580	6600	8000	32,625

* The United States figure is based on TMA's results for four applications. See Table II-5.

** This factor is included to account for less amenable climates or less developed PV markets in other developed countries.

TABLE II-50
WORLD ANNUAL MARKET ESTIMATES, kWp

	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>TOTAL</u>
OPEC	20	150	340	550	1,130	2,200	4,400	8,500	17,000	34,000
Developing	91	591	1,100	2,300	8,600	18,600	55,000	111,000	246,000	455,000
Developed	<u>415</u>	<u>750</u>	<u>1,300</u>	<u>2,060</u>	<u>3,330</u>	<u>4,590</u>	<u>5,580</u>	<u>6,600</u>	<u>8,000</u>	<u>32,625</u>
TOTAL	526	1,490	1,440	4,910	13,060	25,390	64,980	126,100	271,000	521,625

TABLE II-51
ESTIMATED ANNUAL PRODUCT MARKETS, kwp

	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>TOTAL</u>
Rural Electric	.6	1	6	14	31	59	94	132	200	532
Navigation Aids	83	97	10	79	47	24	11	2	6	604
Cathodic Protection	37	34	59	100	120	130	174	200	187	1032
Miscellaneous	58	117	184	264	358	493	619	876	1925	4891
Desalination	0	0	10	34	101	237	486	1551	3514	5080
Telecommunications	194	801	1349	2282	3810	5294	6410	7221	7670	34757
Water Pumping	2	56	160	332	1110	2979	4785	7799	19009	34793
Mass Communications	16	126	262	511	1023	2268	6182	10189	14371	35010
Lighting	<u>0</u>	<u>183</u>	<u>323</u>	<u>950</u>	<u>6312</u>	<u>14482</u>	<u>45601</u>	<u>97320</u>	<u>222313</u>	<u>352519</u>
TOTAL	390	1415	2363	4566	12912	25966	64362	125290	269195	469218

FIGURE II-12
ESTIMATED ANNUAL WORLD PHOTOVOLTAIC SALES

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III. GENERATION OF NEW APPLICATIONS FOR PHOTOVOLTAICS

A. Introduction

1. Objective

The purpose of the second phase of InterTechnology/Solar's investigation of the market potential for photovoltaic power systems was to develop a list of 100 applications most likely to generate substantial markets for photovoltaics as the price drops from \$20 to 50¢ per peak watt over the next ten years.

2. Background

In the two years prior to this study seven different groups (1,7) investigated the market potential for photovoltaic power converters. These studies dealt primarily with the domestic U.S. market; one of the main thrusts of the work reported herein was to expand the previous work to include more information on the international market. In addition, the present work, by building on the previous, attempts to be thorough in the identification of potential markets.

Discussions of the results of other studies are included elsewhere in this report, therefore, a complete discussion will not be included here. However, comparisons will be made between the ideas and evaluations made under this contract and those made under the other seven contracts.

3. Description of Approach

The primary method that was planned to generate the 100 uses of solar cells was based on the method of brainstorming. Originally, a preliminary brainstorming session was planned, to be followed by an information session in which the brainstorming participants were to be told of many of the characteristics of solar cells which, in turn, was to be followed

by a second brainstorming session. Many of the participants were completely uninitiated in the photovoltaics technology, so some information had to be transferred at the beginning of the first brainstorming session. Logistics also dictated that the brainstorming-information-brainstorming sequence be conducted at one sitting.

The brainstorming sessions were to be supplemented by directed interviews, in which selected experts were asked for their opinions both with and without prompting by the interviewer. Both the brainstorming and directed interviews were supplemented by individual private brainstorming sessions.

In keeping with the emphasis on foreign markets, most of the participants in the creativity sessions were representatives of foreign countries. However, some of the most productive creativity sessions were staffed entirely by members of the contract team (InterTechnology/ Solar Corporation, the Mobil Tyco Company, and the University of Delaware). Originally, plans had been made to enlist the assistance of several advisors to InterTechnology from various regions in the United States. The timing of the study was so short, however, that few could respond in the allowable period. At least one of those who could provide the time insisted on receiving a substantial consulting contract and having a major role in the entire program. Hence, no assistance was obtained from the advisors. Since there was considerable emphasis on foreign applications and since most of the U.S. applications would be uncovered in the brainstorming sessions associated with the team members, there was little incentive to seek substitute advisors. The creativity sessions were followed by a judgmental period, in which the most promising early-market applications were identified by polls conducted among the

staffs of the three team members. Each team member was asked to generate a list of the 100 best. Comparison of the three lists so generated permitted the distillation of a single list of the 100 best ideas.

The list of 100 was then grouped into categories of applications. The groupings themselves suggested new applications, which were then added to the list of 100. Examination of the groupings and some informal brainstorming among InterTechnology staff members as they examined these groupings assured that the lists of applications would be complete. The analysis of the groupings was the major method used in assuring completeness.

The final steps in this phase of the study were to estimate the markets for the leading concepts on the basis of the total potential market and a projected share of that market by photovoltaics. The market estimates permitted a relative ranking of the ideas so that the top twenty or so could be identified.

A secondary method of assuring completeness was to compare the lists generated with those lists generated by prior contractors.

B. Generating Ideas

1. Creativity Sessions

The lists of ideas generated in the various sessions are reported in Appendixes II-A through II-G of this report. The appendixes also contain descriptions of the creativity sessions themselves and the prompts used to stimulate new ideas. The main difficulties encountered stemmed from two causes: (1) at the projected price of 50¢ per peak watt, photocells

competed favorably in so many cases that listing the ideas became tedious; and (2) the participants were strangers to each other and therefore did not feel at ease in proposing seemingly outrageous ideas. Even the use of InterTechnology people in the groups to propose far-fetched concepts could not remove this second barrier. The most effective stimulant was the morphological diagram presented as Figure III-1. This morphological diagram forced the focus on sometimes ridiculous combinations (or so they seemed) but did assist in keeping the creativity session light. In addition, the morphological diagram provided the tension needed for generating truly new concepts.

Table III-1 shows the number of ideas generated in each of the sessions. The data show that the most creative groups were those that knew each other well enough to be at ease. Even informal sessions over meals were relatively unproductive if the participants were strangers to each other. Even in the warm-up sessions, in which such classical problems as "other uses of a brick" were used, strangeness still constrained creativity.

A more relaxed atmosphere might have been produced if the groups had first met at lunch and the early conversations had been restricted to pleasantries. The sessions, as conducted, were obviously working sessions and significant outputs were expected. As a consequence, the sessions had an air of seriousness which, in itself, was inhibiting. The use of smaller groups, competing with each other might have been more effective, especially if the competition had been based on the number of ideas rather than the quality.

2. Completeness

Most assuredly, applications can be found that are not included in the ideas generated under this contract. Two distinct steps were taken to

TABLE III-1
Talley of Ideas Generated in Brainstorming Sessions

<u>Session</u>	<u>Number of Ideas</u>
InterTechnology/Solar Staff	219
Mobil-Tyco Staff	57
University of Delaware Staff	157
World Bank Representative	25
Representatives of Hungary, Japan, Poland	160
Representatives of Kuwait, Italy, France, and Germany	113
Representatives of Indonesia, Morocco, Spain, and Australia	103
Ruritan Club	49
Interviews (Brazil, Mexico, Cyprus)	<u>11</u>
*Total	894

*Repeated ideas not subtracted

minimize the number of applications that would be overlooked. First, the concepts generated by others and reported in the literature of various kinds were tabulated. The tabulations were compared to the list of ideas generated under the present contract. Any ideas identified by others but omitted from the list generated under this contract were identified and added to those to be evaluated in the judgmental phase. The list of ideas generated by others but missing during the creativity sessions are tabulated in Table III-2. Generation of this list was not a trivial task, since many of the ideas in this list rightfully belong to subdivisions of categories generated during the brainstorming sessions. This list adds approximately 30 concepts to the list generated under this contract.

Applications generated in the brainstorming sessions (and later augmented as shown in Table III-3) were compared with listings reported by Aerospace. These include studies by Aerospace (1), Heliotek (2), C. N. E. S. (3), Jet Propulsion Laboratories (4) and reports to conferences in Paris (5) and Melbourne (6). Additional ideas which have been presented by other groups are shown in Table III-2. These applications are specific variations of more general applications growing out of the brainstorming sessions.

The second attempt at completeness was based on grouping the various ideas into somewhat homogeneous classes. The generic nature of the groupings led immediately to ideas for new products. In most cases, the new products were simply refined definitions of the broad category previously identified. Table III-3 shows the categories as well as the new ideas (asterisked) generated after the categories were assembled.

TABLE III-2
SPECIFIC APPLICATIONS NOT IDENTIFIED ON THIS
CONTRACT BUT IDENTIFIED ON PREVIOUS CONTRACTS

Related to Application		Application	Source
Table III-5	Table III-3		
13	D4	Gas accumulation	(2)
13, 84	D4	Failure detection	(2)
31	D4	Snow pack measurement	(2)
19	C8, C9	Closed circuit TV surveillance	(2)
31	D4	Rain gauges	(6)
31	D4	Vulcanology	(3)
31	D4	Seismology	(3)
24	C12	Gas pipeline communication system	(5)
24	B3, D1	Lifeguard Tower Radio	(2)
24		Train Dispatch Station	(3)
36	A1	Irrigation Control Gate Power	(3)
	A1	Insecticide dispenser	(2)
31, 84	D4, C12	Ocean Data Stations	(2,3)
12, 30		Offshore Traffic Control	(2)
20	C9	Intrusion sensors	(1)
		Test sites	
		Nuclear facilities	
		Prisons	
86	C11	Caboose power	(1)

TABLE III-3
GROUPING OF PHOTOVOLTAIC DEVICES
FOR
COMPLETENESS OF COVERAGE

A. DEVELOPING NATIONS

1. Field Distributed Agricultural Appliances: Insect killer*, Bird chaser*, Crop monitor*, Electrifying fences, locating livestock.
2. High Power Multi-Use Agricultural Unit: Irrigation, Crop drying Frost prevention*, Crop handling, Desalination.
3. Refrigerator: Medical or Small Units.
4. Refrigerator: Commercial Operations and Shipment.
5. Water pump, five horsepower: Irrigation and potable water, Livestock, Aquaculture, Power for Snail*#, Conveying and Air blowing.
6. Water pump, half horsepower: Potable water, Livestock water.
7. Remote Communication: Center-Border stations, Military and police stations, Work camps, Natural disaster coordination.
8. Battery Charger: General purpose, Auto battery.
9. Village Community Center Power: Small industry. Remote Education center.
10. Hospital equipment for Remote Use or Emergency Portable: Ozone sterilizer, Mobile clinic.

*Application not identified in previous contracts.

#Slow moving plow used primarily in developing countries for breaking up hard soil.

TABLE III-3 (CONTINUED)

B. CONSUMER PRODUCTS

1. Distributed Appliance, Low Power: Clock, Bugkiller*, Art, Toys, Radios, Fans, Novelties, Calculators, Games.
2. Refrigeration, remote or mobile: Campers, Hunters.
3. Emergency Radio: Beacon, Airplane, Boat, Hikers, Hunters.
4. Small Electric Vehicles: Elderly, Fork-lifts, Security patrol, Recreational.
5. Tool Recharger: Power tools, Garden tools*, Household appliances.
6. Whole House Power: Houses in remote sites, Self-sufficient living units
7. Outside Lighting: Farmyard lights, Security lighting for industry.
8. Water pump, half horsepower: Potable water, Swimming pools.

C. INDUSTRIAL PRODUCTS

1. Support Equipment for Solar Heating Systems: Pump power, Fans, Window vents*, Corrosion protection*, Tracking units.
2. Refrigeration: Commercial/Shipping.
3. Industrial Process, Remote location: Ore concentration, Pollution control, Pumping, Aviation.
4. Large-Scale Power Fields: Terrestrial or Orbital.

*Application not identified in previous contracts.

TABLE III-3 (CONTINUED)

5. Battery Charger: Construction tools and lights.
6. Battery Charger: Auto batteries, General Purpose, Marine auxiliary power.
7. Battery Charger: Electric Vehicles, Plants, Parking lots.
8. Light Metering Equipment: Cameras, HVAC controls, Electronic controls (TV, lights, etc.).
9. Security Equipment: Railroad, Trailers, Remote cameras, Boats.
10. Corrosion Protection: Pipelines, Wells, Bridges, Offshore platforms, Boats.
11. Construction Trailer*: Temporary office at site.
12. Remote repeaters: Cable, Microwave.

D. INSTITUTIONAL - GOVERNMENT

1. Emergency Radio: Remote stations, Call boxes.
2. Space power: Unmanned satellite & probes.
3. Power for Remote Camps: Ranger stations, Off-shore platforms.
4. Remote Detectors: Forest-fire detectors, Pollution monitors.
5. Highway Applications: Flashers, Signs, Railroad crossing, Rest stops.
6. Navigational Aids: Buoys, Airport radio beacons.

*Application not identified in previous contracts.

TABLE III-3 (CONTINUED)

E. AGRIBUSINESS

1. High-Power Multi-Agricultural Unit.
2. Field Distributed Agricultural Appliances.
3. Refrigerator: Commercial/Shipping.
4. Small pumps, five horsepower: Livestock.
5. Remote Radio: Work camp.
6. Corrosion Prevention: Well casings.
7. Greenhouse: Ventilation, Pumps, Controls.

TABLE III-4

IDEAS NOT PREVIOUSLY IDENTIFIED

A. Agricultural Appliances

Insect killer	Crop monitor
Bird chaser	Frost prevention
Power for snail	

B. Consumer Products

Bugkiller	Garden tools
Antenna-mounted television power supply	

C. Industrial Products

Window vents	Construction trailer
Corrosion protection for solar thermal systems	

3. New Applications Identified

Ideas not previously reported but generated under this contract are listed in Table III-4. Of these, only two--the electric bug killer and the antennae-mounted television power supply--are of commercial interest. Although not reported, the bug killer has also been identified by the group at NASA-Lewis. Mounting the array with the antennae is actually an old idea with a new twist that permits the sale of a single package.

Possibly the best assurance of completeness is that the reported concepts consist of the ideas generated by at least seven major organizations and augmented by the creativity sessions conducted under the present contract.

C. Evaluating Ideas

1. Preliminary Evaluations

A poll was taken among the three participating team members who, in turn, conducted polls within their respective organizations. These polls were to identify the approximately 100 leading applications. The individual groups of 100 were then combined into a master list of slightly more than 100. Preliminary market estimates were made for this expanded list and a final list of the 100 most attractive concepts were generated. Appendix II-G lists the rankings made by the University of Delaware (Table G-1), Mobil Tyco (Table G-2) and InterTechnology/Solar (Table G-3). The consolidated ranking is indicated in Table III-5.

Ideas for applications of solar cells, generated in the brainstorming session and recorded in Appendixes A through F, were ranked with respect to overall market potential by teams at the University of Delaware, Mobil Tyco and InterTechnology/Solar Corporation.

Each person ranked applications according to a scale ranging from 1 to 5 (or equivalently, A to E) where 1 represents the highest and 5 the lowest

estimate of market potential. Factors accounted for in this ranking include price of first application, market size, and price elasticity. Then, for each team, the applications receiving a rating of 1 or 2 (or A or B) were selected and grouped according to the total number of ratings of 2 or better. From among these, the applications receiving the highest overall rating were ranked the highest.

The lists from each team were then merged into a single list of applications with the most promising potential by considering the top 70 from each of the three teams (Table III-5). Point scores were given to the groups in each team listing according to the following scheme:

Team Group	Point Score		
	UD	M-T	ITC/Solar
1	10	10	10
2	8	8	8
3	6	6	6
4	4	4	4
5		2	

Groupings in the final listing then give an approximate ranking of estimates from all teams.

TABLE III-5
MOST PROMISING APPLICATIONS OF PHOTOVOLTAICS
CONSOLIDATED RATING OF ALL TEAMS
 (Top score is 30 points.)

Group 1 (Point score of 24 or more)

1. Irrigation pumps	See Table III-3: A2
2. Pumping potable water	A5
3. Communications	A6
4. DC battery charger	A7, C5, C6, C7
5. Corrosion control	C10, E6
6. Educational TV	A8

Group 2 (Point score of 16 or more)

7. Remote repeaters	A6
8. Portable powerpack	A7
9. Lighting, rural	B7
10. Military	A6
11. Lighting, general	B6, B7
12. Buoys	D6

Group 3 (Point score of 12 or more)

13. Testing equipment	D4
14. Remote switching	dropped
15. Remote activation of explosives	dropped
16. Reliable remote power	A8

Group 4 (Point score of 10 or more)

17. Space power	D2
18. Safety equipment	C9, B3
19. Rural television	A8

TABLE III-5 (CONTINUED)

20. Intrusion detectors	C9
21. National park power	B6, B7, D1
22. Closed water system	A6
23. Intrusion defense	A1
<u>Group 5 (Point score of 8 or more)</u>	
24. Remote communications	A6
25. Remote alarms	D4, D1
26. Calculators	B1
27. Police stations	A6
28. Railroad stations	A6
29. Lighting, community center	A8
30. Navigational equipment	B7, A8, D6
31. Instrumentation (sensors)	D4
32. Thermistors	dropped
33. Insolation meter	C8
34. Electronic filtering	dropped
35. DC for bells	dropped
36. Power controls	C8
37. Measuring distances	D4
38. Road profile calculator	D4
39. Hat communication equipment	B1
40. Sterilization	A9
41. DC for better lights	dropped
42. H ₂ production	C3
43. Powering citizen's band radios	B3
44. Cathodic protection	repeat
45. Educational devices	A8
46. Refrigerate medicine	A3
47. Portable medical machines	A9
48. Environmental monitors	D4
49. Warning flashing lights	D5
50. Railroad signals and controls	B7, D4

TABLE III-5 (CONTINUED)

51. Electric toys	B1
52. Radio	B1
53. Telephone systems	C12, A7

Group 6 (Point score of 4 or more)

54. Weather station	D4, C12
55. Combining with solar heating	B6
56. Pumped storage	C4
57. Driving solar thermal systems	B6
58. Refrigerate food	A3, A4, B2
59. Water treatment	C3
60. Power for simple industries	A8
61. Remote telephones	C12, A7
62. Watches	B1
63. Pool pump	B8
64. Back up to utility	C4
65. Food preservation	A2
66. Television	B1
67. DC to electronics	dropped
68. Air conditioning	B6
69. Power system	C4
70. Boats, sailboats (auxiliary power)	A8
71. H ₂ O desalination	A2
73. Clocks	B1
74. Garden appliances	B5
75. Remote medical centers	A9
76. Greenhouse controls	E7
77. Outside lighting	See item 9: B7
78. DC for motors	dropped
79. Peak load for utilities	C4
80. National alert network	D1
81. Traffic signals	D5

TABLE III-5- (CONTINUED)

82. Electric car (for general use, for retirement community)	B4
83. Emergency power	C4
84. Data transmission	C12
85. Controlled tractor	D4, E5
86. Power for construction trailer	C11
87. Phonograph	B1
88. Vent fan	B1
89. Electrostatic precipitator	dropped

Group 7 (Point score of 2 or more)

90. Detecting crop harvesting time	A1
91. Surveying	D4
92. Leveling	D4
93. Medical telemetry	D4
94. Human and animal telemetry	D4
95. Conversation pieces	B1
96. Power skier's radio	B1
97. Anti-static device	B1
98. Power LED	B1
99. Electric games	B1
100. Purify camp water	A9
101. Food sterilization	dropped
102. Electric tractor with batteries	B4

2. Market Estimates

The 100 leading applications found in the preliminary evaluations were analyzed in further detail to obtain quantitative market estimates. In the process of performing the quantitative evaluations, some of the redundancies in the list of 100 caused difficulty. As a consequence, some consolidation was helpful.

The consolidated list is shown as Table III-6, which lists the application, estimated United States market and estimated world market. The group numbers indicated some from the consolidated rankings. A group number of 1, for example, indicates that the polls taken at the team member companies indicated a high probability that a significant market would develop. The items in Table III-6 are listed in the order of decreasing estimated market size for the U.S. market. Some disagreement between the group rankings and the estimated markets is evident; however, the groups rankings were made on the basis of significant markets and not necessarily the size of the significant market.

To determine the total potential market for photovoltaics in terms of panel area by application, the following steps were taken. For each item on the consolidated list some typical target markets were identified for the United States market. By developing scenarios for these target markets, it was possible to obtain gross estimates of the size of market that might be captured by the various photovoltaic applications. While this method is inaccurate it provides a means of ordering the proposed applications according to their capture potential. References 7 through 17 provide the general statistical data used in developing these scenarios. The panel area requirements for the application were calculated in most cases by first determining energy requirements in kilowatt-hours per day from the power requirement and the duty cycle of the device. Multiplication

of the energy requirement per unit by an estimate of the potential number of units yields the total electrical energy requirement. A panel output of 48 watt-hours/day-ft² was used to translate the energy figure to panel size for photovoltaic cells. A 1985 figure of 12 peak watts per gross square foot of finished panels was used to estimate the photovoltaic power potential.* The world market was determined by assuming that all countries consumed energy at the U.S. rate per consuming entity and that the product mix of the United States holds worldwide.

To obtain a more reasonable extrapolation from United States to world figures, a second calculation based upon the ratio of U.S. GNP to world gross national product was used. In this way the market is bounded by available funds.

Referring to equation (1) of Section II-D, we have the ratio of the estimated photovoltaic market for the world to that for the United States:

$$\frac{\text{Market}_{\text{World}}}{\text{Market}_{\text{U.S.}}} = \frac{\text{Fixed Capital Formation}_{\text{World}}}{\text{Fixed Capital Formation}_{\text{U.S.}}} = \frac{\text{GNP}_{\text{World}}}{\text{GNP}_{\text{U.S.}}} = \frac{K_{\text{World}}}{K_{\text{U.S.}}}$$

Thus, we are assuming a fixed ratio of fixed capital formation and a fixed ratio of market share.

The rationale above was used for Table III-6 in developing the gross panel areas required to supply 100 percent of the market. The percentage of market share was estimated by InterTechnology/Solar staff members. These estimates were made without the benefit of a market survey such as was conducted in the subsequent tasks, but were thought to be accurate enough to establish which of the markets would lead to large demands for photovoltaics. Table III-6 was used directly in subsequent tasks of the subject contract. This table represents the culmination of this phase of the study.

*Jet Propulsion Laboratory

Scenarios upon which estimates in Table III-6 are based follow. Numbers correspond with numbers in Table III-5.

(1) Irrigation Pumps

Two kinds of irrigation systems were considered: sprinkler and small gravity systems. For sprinkler systems it was assumed that a 100-HP pump was used for every 160 acres. Sixteen million acres are now under sprinkler irrigation in the U.S. Total energy requirements, assuming 3,000 hours per year of irrigation, are 78 million kWh per day. For small gravity irrigation systems, 30 million acres of the remaining 56 million acres of irrigated acreage in the United States were assumed to need a 1-HP pump for 1,000 hours per year. To obtain world irrigation requirements, it was assumed that the same portion of irrigable land in the world is irrigated as is U.S. land. Thus the world figure is six times that for the U.S.

(2) Pumping Potable Water

System energy requirements were obtained by assuming 1/2 HP to 3/4 HP pumps with a 5% daily duty cycle. The number of units required in the United States as based on the number of households in "places with less than 1,000 population" as defined in the Statistical Abstract of the United States. The number of world units was obtained by using the ratio of U.S. population to world population. Assumptions inherent in this calculation are that the water supply distribution is the same in the world on the whole as it is in the United States and the number of persons served per well is uniform throughout the world.

(3) Communications

Applications under this general heading are treated under the specific applications subordinate to it.

(4) Battery Charger

This estimate was based on 50 million storage batteries, equal to the total sales over a period of three years at an average price of \$40 per battery. A 12 V lead-acid battery was assumed to require an average of one charge per year. The world figure was obtained on the basis of population ratio.

(5,44) Corrosion Control

Two specific applications were considered: pipelines and steel highway bridges. Energy requirements were calculated on the basis of 8 milliwatts per square foot of surface to be supplied 100% of the time. For 174,000 miles of an average pipe diameter of approximately two feet, the energy requirement is about 700,000 kWh/day for corrosion protection. Figures for the United States were extended to the world by using the ratio of U.S. area to world area.

(6) Educational Television

To determine the total energy requirements, it was assumed that one small black and white television using 50 watts power will be provided for each of the schools in the United States. The U.S.-to-world population ratio was used to obtain the world figure.

(7) Remote Repeaters

It was assumed that each of 7,000 telephone repeaters stations used 9.2 kWh/day and that at least one repeater unit using 1.2 kWh/day was incorporated into the 5,000 radio stations for which there are frequency assignments in the United States. To account for the greater number of remote sites over the world, global requirements were about sixteen times greater than U.S.

(8) Portable Power Pack

Two sizes of power pack were considered: a larger one of 1-kilowatt size for power tools and a smaller one of 3-watt size for such small devices as calculators, watches and toys. To estimate the total daily energy requirements for the power-tool power pack the figures are based on one power pack for each of four million construction workers in the United States. (Though this apportionment is high, we thus include other trades and activities.) To obtain the daily energy requirements for the smaller power pack it is assumed that there would be one per household in the United States. In both cases the U.S.-to-world population ratio was used to obtain the world figure.

(9) Lighting, Rural

Energy requirements were obtained for a 300-watt unit being used 12 hours a day in all U.S. rural households. Again, the U.S.-to-world population ratio was used to obtain the world figure.

(10) Military

Using the BDM tabulation of the gasoline-powered generator in the 1.5 to 10 kilowatt range now used to provide power for airport runway lighting, remote communications equipment and other power for instrumentation at remote test sites an energy requirement of 5.3×10^6 kWh/day was calculated. Since the U.S. armed forces are one-sixth of the world forces, this ratio of one to six was used to obtain the world figure.

(11,29) Lighting, General

For this application a village system of 25 kilowatts was assumed to be used 4 hours per day. The number of units was obtained by considering all the places in the United States with less than 1,000 population and extending this figure on the basis of U.S.-to-world population ratio.

(12) Buoys

A 100% duty cycle was assumed for about 14,000 buoys of various types such as off-shore buoys, navigational markers and monitor buoys to obtain the total daily energy usage. It was assumed that buoys are associated primarily with approaches to ports and the ratio of U.S. ports to world estimate.

(13) Testing Equipment

Typical electronic devices of 5 to 10 watts were assumed to be used one hour a day for the 260 working days of the year by 200,000 of the 700,000 aeronautical, astronautical, civil, electrical, electronic, and mechanical engineers and 735 engineering and science technicians in the United States. It was assumed that world usage followed the same pattern.

(18) Safety Equipment

Two kinds of devices were considered: miners' lamps and beacon lights for remote airfields. A one-half-watt miner's lamp with associated daylight charging unit was assumed to be provided for each of the workers in underground mines in the United States. Assuming that productivity is the same worldwide the world estimate was obtained from the ratio of U.S. production to world production. The figure for beacon lights used in remote airfields was obtained for 200-watt units used in the private airfields in the United States. The extension to world figures was obtained by taking the ratio of United States area to world land area.

(19) Rural Television

The United States figure, based on supplying one television set using 200 kilowatt-hours per day to each of the 17 million rural households, was extended to a global figure by using the world-to-U.S. ratio of rural households.

(20) Intrusion Detectors

This estimate was based on the supposition of burglar alarms being provided for the non-rural dwellings in the United States, commercial buildings, and institutional buildings, assuming one unit per building. Population ratio was used to obtain the world estimate. Secondly, remote security units with radio signals were proposed for boxcars, trucks and boats in the United States and the world estimate was obtained from the land area ratio.

(21) National Park Power

It was assumed that a whole-house power unit would be provided for each 5,000 acres of park land in the United States. A world figure was not generated for this application.

(22) Closed Water System

The estimate of energy requirements for closed water systems in the United States was based on the 32,000 private campgrounds and 13,000 work camps. World energy requirements were based on providing a closed water system for every 1,000 persons in the developing regions of the world. This estimate was obtained on the basis of 75% of the world's population which lives in developing regions.

(23) Intrusion Defense

The figure for the United States was based on the assumption that the perimeter of total acreage devoted to pasture land is provided with electric fencing. Assuming each square mile of pasture land is fenced, this amounts to 3.6×10^6 mile of fence. An energy demand of a tenth of a watt per mile was used to obtain the domestic estimate. The world estimate was based on the ratio of arable land.

(24) Remote Communications

Small receiver-transmitters using 3 watt-hours per day were assumed to be used by about 3 million remote stations for on-the-job communications in the United States. The world estimate was based on population ratio.

(25) Remote Alarms

This category is restricted to smoke detectors. Other remote alarms are covered in category number 20. The number of smoke detectors required for all households in the United States was extended to the world estimate by population ratio.

(26) Calculators

It was assumed that a calculator would be provided for each family with an income of over \$15,000, each pupil in high school or college, each engineer, each accountant, the remainder of the white collar, sales and managerial positions and 10% of the craftsmen. The U.S. figure was extended to a world estimate by population ratio. This category of application overlaps portable power packs, number 8 on this list.

(27) Police Stations

The estimate for the United States was based on one for each of the broadcast stations licensed for police in 1974. The world population ratio was used for the world estimate.

(28) Railroad Stations

Again, it was assumed that each of the licensed broadcast stations for railroads in the United States used one unit. U.S.-to-world area ratio was used for the world estimate.

(31) Instrumentation

Portable assembly line test equipment was proposed for this application. One assembly line per manufacturer of equipment was assumed and ten devices per line to obtain the U.S. estimate. The population ratio was used to obtain the world estimate.

(33) Insolation Meter

It was assumed that 7 watt-recording pyroheliometers were to be used at 5 100,000 sites in the United States. The world population ratio was used for the global estimate.

(34) Electronic Filtering

It was assumed that one electronic filtering device is provided for each warm air furnace in a housing unit in the United States. The world population ratio was used for the world estimate.

(36) Power Controls

These are designed to operate controls automatically and drive small motors either timed or sensor-triggered. It was assumed that there were 5 per dwelling and 50 per building in the United States. Control units in buildings would be used to operate vents, panels, shades and awnings automatically to reduce heating and cooling loads. The population ratio was used for the world estimate.

(37,38,91,92) Surveying Instruments

It was assumed that a typical surveying instrument for short and medium distance measuring was provided to each surveyor in the United States. The population ratio provided the world estimate.

(39) Two-Way Communication Equipment

A walkie-talkie unit for outdoor or disbursed workers was assumed. Worker categories were construction workers, farm workers, and loggers. The population ratio was used to obtain the world estimate.

(40) Sterilization

This estimate was based on the use of electric cauterizers in 100,000 centers distributed throughout the world. The number of centers is based on the assumption that one-third of the world's population would be served by one such center for every 7,500 persons. The power requirement for each device was assumed to be 100 watts.

(42) Hydrogen Production

The estimated energy required for the production of hydrogen by electrolysis of water was taken to be 120 kilowatt-hours per 1,000 cubic feet of hydrogen. It was assumed that units sized to produce 1,000 cubic feet per day are used and the total figure is based on 1,000 units in use. World figures are based on the population ratio.

(46) Medical Refrigeration

If one treatment unit (clinic, hospital, mobile clinic) is to be provided for every 3,750 persons, one million units will be required worldwide. Each unit would consume 1 kilowatt-hour per day. World figures are based on the population ratio.

(47) Portable Medical Machines

As in item 47, the world figure was taken to be one million treatment units. In addition, 100,000 emergency units for disaster coverage in the United States and 100,000 portable units for extension of medical coverage to the American population was assumed. World figures are based on population ratio.

(48) Environmental Monitors

Three kinds of devices were considered: seismic sensors using 50 milliwatts of power 100% of the time, hydrological monitors using 62 watts for hourly reports (1 hour per day), and air pollution using 50 milliwatts 100% of the time. Seismic devices were assumed to be placed every 720 square miles. Hydrological monitors were assumed to be placed every ten miles along principal rivers. One air pollution monitor each was assumed for factories in pollution-prone industries and four for each standard metropolitan statistical area. World figures are based on the population ratio.

(49) Warning Flashing Lights

Based on the 950,000 miles of new highway construction in 1973, it was estimated that one million warning flashing lights are operated each day on U.S. highways for six hours a day. It was assumed that world road building runs apace with United States road building in using the ratio of U.S.-to-world area to obtain the world estimate.

(50) Railroad Signals and Controls

The estimate was based on the number of grade crossings in the United States and provides for 1.2 kilowatt-hours per day to the signal and a motor to operate an arm. The world figure was based on the ratio of land area in the United States to that in the world.

(51) Electric Toys

This estimate was based on three categories of usage: (a) children under five, for whom two 1-watt toys per child were used for one-half hour a day once a week; (b) children between five and thirteen-years old, for whom two 10-watt toys were used once a week for one hour a day; (c) persons between fourteen and seventeen-years old, for whom one 500-watt toy, such as a model plane, was used by every second child for two hours a day once a week. The world figure was obtained by taking the population ratio.

(54) Weather Stations

This estimate was based on 2,000 units using 62 watts for hourly reports in the United States. The world figure was obtained by using the ratio of land areas. NOTE: The figure of 2,000 units was based on distribution of one station every 14,000 square miles.

(59) Water Treatment

Two types of devices are proposed for this application. The first is a secondary water purification unit for campers and hunters using two-tenths of a kilowatt of power. The second device is an ozonizer using six-tenths of a kilowatt hour per day per unit and designed to be used in remote homes. The population ratio was used to obtain the world figure.

(60) Power for Simple Industries

In this case, it was assumed that 1,000 watts of power would be used for 2.4 hours a day 260 days per year for such activities as cabinetmaking, weaving, spinning, and pottery making. The number of users in the United States was assumed to be twice the number of cabinetmakers. It was assumed that the world ratio parallels the population ratio.

(62) Watches

A one-half milliwatt watch was estimated to be used by all the persons over 14 in the United States, which usage represents 1,600 kilowatt-hours per day. The world figure was obtained by the population ratio.

(63) Pool Pump

The estimate for energy requirements for swimming pool pumps was based on a one-half horsepower pump and provided for the estimated one million existing home swimming pools being in use ten hours a day for one-half the days of a four-month season and for a unit twice this size to be used in the community pools in the United States. The world figure was obtained by the population ratio.

(64, 69) Back-up to Utility

This estimate was based on providing one-sixth of the power capability

of the electric utility system for emergencies and peak load in the United States. World needs were estimated by using the ratio of population.

(68) Air Conditioning

A 700-watt air-conditioning unit was proposed for use eight hours a day for six months a year, in households in the South Atlantic and South Central states, Arizona, New Mexico, Colorado and California. It was assumed that the portion of population in these latitudes is the same worldwide.

(70) Auxiliary Power for Boats or Sailboats

One-tenth of a kilowatt-hour a day was assumed for use in providing energy for running lights in eight million boats in the United States. It was assumed that the world usage parallels the ratio of ports.

(73) Clocks

One-half-watt power was assumed to be used for one clock in each of the households in the United States and the population ratio was used to extend this estimate to the world.

(74) Garden Appliances

Such garden appliances as lawn trimmers and hedge trimmers were assumed to be supplied to all suburban households in the United States. The world figure was obtained on the population ratio.

(75) Remote Medical Centers

Energy requirements for this application were assumed to be the same for the whole house and was estimated for one million clinics throughout the world.

(76) Greenhouse Controls

The electrical energy requirements for controls and operations of vents in greenhouses in California were calculated. It was then assumed that the density of greenhouses for all over the United States and the world is the same as for California.

(77) Outside Lighting

Two general types of applications were considered: house lanterns and walk lights for suburban households and mercury vapor lights for rural security. An estimate of the electrical requirements for these applications was then based on the number of suburban households and the number of rural households in the United States and the population ratio was used to obtain the world estimate.

(80) National Alert Network

A network of transceivers having a range of 100 miles was proposed. To determine the number of stations required to cover the United States, the total area of the country was divided by the area covered by such a station. The world figure was obtained by the area ratio.

(81) Traffic Signals

A typical traffic signal was taken to consist of 8 signal heads for each controlled intersection. One 100-watt bulb was to be on for 20 hours a day. A 25-watt timer motor with cam switches was included for the 250,000 controlled intersections in this country. Energy requirements were determined on the basis of the above figures. The world ratio was based on population ratio.

(82) Electric Vehicles

Two kinds of electric vehicles were considered: The off-road cart used primarily for golf or retirement communities and the commuter car used primarily for driving in cities or metropolitan areas. It was assumed that 5400 watt-hours per day of electrical energy were required for charging the off-road cart and that there would be one cart for each ten

retirees drawing social security payments, or 1.9 million cars. For commuter cars the number was based on the projected 1.5 million to be in use by 1990, and it was assumed that the energy usage would be ten kilowatt-hours per day on the working days of the year.

(83) Emergency Power

The specific device chosen for this application was the highway callbox. An average of five callboxes per mile was assumed for the 3.8 million miles of roadways. Energy requirements were based on .06 square feet of panel per box.

(86) Power for Construction Trailers

The number of units was determined by assuming that there would be a crew size of ten using the equipment and the total number of construction workers is four million. These devices have a power requirement of one kilowatt and were assumed to be used four hours a day for all the 260 working days of the year.

(87) Phonograph

The number of units was estimated on the basis of providing one in each household for which the annual income level is greater than \$15,000. The power requirements per unit including the radio were 110 watts and it was assumed the device would be used three hours a day, daily.

(88) Ventilating Fan

A one-third horsepower unit was assumed to be used 6 hours per day 90 days a year in all the households of the United States.

(89) Electro-Static Precipitators

A power requirement of 250 watts per unit and a duty cycle of 100% was taken for 676 steam generators used by utilities.

(90) Crop Harvesting Time Detector

Energy requirements for such a sensing device are .04 kilowatt hours

per day. One such device was allotted for each 2.8 million farms in the United States. The extrapolation to a world estimate was based on the ratio of arable land.

(93) Medical Telemetry

For this usage a 60-kilowatt station consisting of a data center, relay station, and remote units was postulated. One hundred such stations operating 24 hours a day yield a total energy usage of 48,000 kilowatt hours per day.

(94) Human and Animal Telemetry

One 60-kilowatt station operating 24 hours a day was assumed for 123 national park natural and recreational areas. The world figure was based on the population ratio.

(95) Conversation Pieces

Small gadgets such as shavers, tape recorders, pencil sharpeners, pagers, games, "window hanging clocks," and other novelties are included in this category. It was assumed that each of the 39.8 million middle or upper income households in the United States would be equipped with a single charger for a selection of devices. Assuming the world proportion of middle and upper income families is the same as the U.S. The population ratio was used to extrapolate the world figure.

(96) Skier's Radio

A radio beacon for emergencies, which uses 100 watts, was assumed to be used by each of 7.2 million skiers in the U.S. The U.S. energy requirement was calculated. Taking the number of persons living in the temperate zones, the world figure was estimated.

TABLE III-6

ESTIMATED 1985 CAPTURE POTENTIAL FOR APPLICATIONS OF PHOTOVOLTAICS

		Estimated U.S. Market			Estimated World Market		
Position in Table III-5 Item, Group	Application	Gross Panel Area (10 ⁶ ft ²)	Market Share (%)	PV Peak Power* (MWp)	PV Peak Power* (MWp)	PV Peak Power** (MWp)	
1	1	Irrigation pumps	1680	40	8060	48300	23500
58	6	Refrigeration of food ²	700}	5}	420}	7200}	1230
			118}	20}	280}	4800}	820
65	6	Food preservation (drying)	300	30	360	6000	1050
88	6	Ventilating fans ¹	530	5	320	5400	930
2	1	Pumping potable water	214	10	260	4300	760
19	4	Rural television	70	20	170	2900	500
9	2	Rural lighting	1360	1	160	2800	470
8	2	Portable power pack	257	5	150	2600	440
59	6	Water treatment	197	5	120	2000	350
68	6	Air conditioning ¹	437	2	100	1800	290
5	1	Corrosion control	14.5	40	70	960	200
77	6	Outside lighting	134}	3}	64	410	180
			440}	1.3}			
82	6	Electric vehicles	524	1	63	1100	180
57	6	With solar thermal	42	10	50	840	150
86	6	Construction Trailers	23.7	15	43	720	125
49	5	Warning flashing lights	12.5	20	30	510	90
59	5	Railroad signals/controls	5	40	24	310	70
56	6	Pumped storage	180	1	22	--	60
66	6	Television ²	290	0.5	17	290	50

TABLE III-6 (Continued)

ESTIMATED 1985 CAPTURE POTENTIAL FOR APPLICATIONS OF PHOTOVOLTAICS

Position in Table III-5 Item, Group		Application	Estimated U.S. Market			Estimated World Market	
			Gross Panel Area (10 ⁶ ft ²)	Market Share (%)	Peak PV Power* (MWp)	Peak PV Power* (MWp)	Peak PV Power** (MWp)
64	6	Back-up to utility ¹	11400	0.01	16	230	45
70	6	Boats, sailboats	24	0.05	14	8.6	40
7	2	Remote repeaters	1.42	70	12	200	35
63	6	Pool pump	42	2	10.1	170	30
47	5	Portable medical machines	4	20	9.6	48	30
21	4	National park power	.8	90	8.6	--	25
83	6	Emergency power	1.2	40	5.8	96	20
10	2	Military*	110	1	13.6	79	40
75	6	Remote medical centers	2	20	4.9	630	15
52	5	Radio	4	10	4.9	82	15
22	4	Closed water system	8.1	3	2.9	144	8.5
11	2	Lighting, general	20	1	2.4	400	7.0
90	7	Detecting crop harvesting time	3	5	1.8	4.2	5.3
24	5	Remote communications	.15	90	1.6	32	4.7
27	5	Police station	4	3	1.4	24	4.1
28	5	Railroad station	1.1	10	1.3	17	3.8
39	5	Hat communication equipment	.6	15	1.1	16.2	3.2
12	2	Buoys	.07	80	.67	3.2	2.0
34	5	Electronic air cleaning	424	0.01	.48	8.6	1.4
102	7	Electric tractor	33	0.7	.40	47	1.2

TABLE III-6 (Continued)
ESTIMATED 1985 CAPTURE POTENTIAL FOR APPLICATIONS OF PHOTOVOLTAICS

Position in Table III-5 Item, Group		Application	Estimated U.S. Market			Estimated World Market	
			Gross Panel Area (10 ⁶ ft ²)	Market Share (%)	Peak PV Power* (MWp)	Peak PV Power* (MWp)	Peak PV Power** (MWp)
45	5	Educational devices	.30	10	.36	6	1.1
26	5	Calculators	.5	5	.36	5.1	1.1
42	5	H ₂ production	2.5	1	.36	5.1	1.1
6	1	Educational TV	.27	10	.32	5.5	0.93
87	6	Phonograph ²	247	0.01	.30	5.0	0.88
33	5	Insolation meter	.17	10	.24	3.5	0.70
96	7	Power skier's radio	20	0.1	.24	3.7	0.70
4	1	DC battery charger	1.4	1	.17	2.9	0.50
53	5	Telephone systems	140	.01	.17	2.9	0.50
37,91,92	5,7	Surveying instruments	.14	10	.12	2.9	0.35
51	5	Electric toys	124	.01	.15	2.4	0.44
18	4	Safety equipment	.03	40	.14	.96	0.41
43	5	Powering CB radios	.6	2	.14	2.4	0.41
74	6	Garden appliances	11	.1	.13	2.4	0.38
25	5	Remote alarms	1.2	1	.12	2.2	0.35
61	6	Remote telephones	20	.01	.08	.41	0.23
23	4	Intrusion defense	.032	20	.08	.24	0.23
10	7	Food sterilization	62	.01	.07	.97	0.20
60	6	Power for simple industries	4.8	1	.06	9.7	0.18
20	4	Intrusion detectors	.02	20	.05	.82	0.15

TABLE III-6 (Continued)

ESTIMATED 1985 CAPTURE POTENTIAL FOR APPLICATIONS OF PHOTOVOLTAICS

			Estimated U.S. Market		Estimated World Market		
Position in Table III-5 Item, Group	Application	Gross Panel Area (10 ⁶ ft ²)	Market Share (%)	Peak PV Power* (MWp)	Peak PV Power** (MWp)	Peak PV Power** (MWp)	
31	5	Instrumentation	.4	1	.05	.82	0.15
81	6	Traffic signals	120	.03	.04	7.3	0.12
62	6	Watches	.03	10	.04	.61	0.12
80	6	National alert network	.01	30	.04	.47	0.12

*Based 1985 figure of 12.0 pW per gross square foot of finished PV panels

**Figure based on ratio of GNP's

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IV. SPECIFICATION OF PHOTOVOLTAIC PRODUCTS LIKELY TO GENERATE SIGNIFICANT MARKETS

A. Introduction

This phase of the study has a two-fold objective: creating useful conceptual designs to develop specific products selected from those identified by controlled brainstorming and assessing market acceptance for these products.

1. Scope

Analysis of Table III-3 indicates that the more than 100 ideas culled from creativity sessions can be covered by 32 products. These are listed in Table IV-1, grouped according to related products. Budget limitations focus was then placed on the most pertinent products for various aspects of the analysis. The first selection of products from the initial thirty-two was a group of twelve products either accepted or deemed likely to be accepted by the market in the near future. The capture potential estimates of the preceding task (Table III-6), present state of the art of photovoltaic devices, and an initial judgment as to marketability were factors in choosing these twelve products.

The twelve applications were:

- (1) 6- and 12-volt battery chargers;
- (2) outdoor lighting;
- (3) 50-horsepower motors to power irrigation pumps and other agricultural equipment;
- (4) refrigerators;
- (5) repeater stations;
- (6) corrosion protection;
- (7) construction trailers;
- (8) small motors to pump water;
- (9) security devices;
- (10) field agricultural devices;
- (11) battery chargers for battery packs and for small electric vehicles;
and
- (12) radio transceivers.

TABLE IV-1
LIST OF 32 PHOTOVOLTAIC PRODUCTS

1. Heavy Agricultural Units: agricultural irrigation, crop drying, crop handling; aquaculture; remote industries such as ore concentration.
2. Water Pump: irrigation of small plots; aquaculture; small industries such as sea-salt recovery.
3. Water Pumps: watering livestock; irrigating small plots; providing drinking water; pumping liquids in small industries (wineries, tanneries).
4. Crop Drying Units: crop drying; agricultural irrigation; crop handling.
5. Agricultural Field Devices: chasing birds away; monitoring soil moisture; monitoring frost conditions; electrifying fences; locating livestock; determining harvest time.
6. Insect Killer: specific agricultural insects; general garden insects; disease control in livestock and humans.
7. 12-volt Battery Charger: small battery-assisted vehicles; lawn mowers and garden tractors; garage and service stations.
8. Small Electrical Appliances: radios, record players, tape recorders; calculators, dictaphones, pagers; flashlights; grass trimmers and shears.

TABLE IV-1 (CONTINUED)

9. Battery Charger for Power Tools: power tools--drills, screwdrivers, saws, staplers; lights--flashlights, lamps, cap lights, camera-strobes, and high flashers; garden and yard tools--trimmers, edgers.
10. Small Electric Vehicles: industrial vehicles such as forklifts; vehicles for elderly persons; security patrol vehicles; recreation and sports vehicles.
11. Battery Charger for Small Boats: corrosion protection; radio transceiver; navigational instruments; lights; preservation of engine starter battery during storage.
12. Commercial Refrigerator: preservation of fish, meat and crops; ice for shipment of perishable goods; general refrigeration.
13. Refrigerator: preparing food in campers, trailers, and tents; refrigeration for remote cabins and work camps; preserving food in developing nations; preserving medicines in remote areas; preserving medicines in emergency mobile clinics.
14. Outside Lighting: lighting farmyards; security lighting around remote buildings; lighting for signs; lighting for parking areas.
15. Highway Lighting: power for highway rest stops; lighting for highway signs; power for warning flashers; lighting for commercial signs.
16. Corrosion Protection for Industrial Applications: pipelines, well-casings and tanks; bridges, piers, docks and locks; ship hulls, off-shore platforms and buoys.

TABLE IV-1 (CONTINUED)

17. Repeater Stations: microwave repeater stations; telephone cable repeater stations; satellite ground stations; radio-telephone interlink units.
18. Radio Transceiver: work camps and ranches; military and police stations; natural disaster coordination.
19. Emergency Radio Beacon: private airplanes; private boats; hunters, hikers, skiers.
20. Remote Call-Box: along highways; on bridges and crossways; on city streets; as fire alarm boxes.
21. Power Fields: daytime peak-load power; power for remote villages and industries.
22. Village Power Supply: villages in developing nations; remote industries, logging camps, ranches, etc.; schools, community centers, remote clinics.
23. House: houses in remote sites; self-sufficient living units; locations where grid power is overloaded during summer days.
24. Industrial Photovoltaic Power: pipeline pumping stations; mine ventilation; well pumping.
25. Construction Trailer: temporary office space at construction sites; temporary office of living space for remote industries.

TABLE IV-1 (CONTINUED)

26. Emergency Clinic: disaster relief; epidemic control; population control programs; routine clinical uses.

27. Solar Collector Systems: power for the fluid circulation pump; power for the control system; corrosion protection for collectors, pipes and storage tanks.

28. Greenhouse Control: greenhouses, livestock buildings; solar heated houses.

29. Electronic Controls: solar heat-controlling louvers; light meters; gas-light control units; light-level sensors.

30. Navigational Aids: navigational buoys; obstruction lights for aircraft; on-shore marker lights.

31. Security Equipment: security for box cars; security for truck trailers; security for remote industrial sites; security for boats and small craft.

32. Remote Detectors: flood monitors; forest fire monitors; earthquake monitors; pollution monitors.

	ELECTRICAL											MECHANICAL											OPTICAL				
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y		
	Current	Voltage	Direct Current	Power Source	Intermittent	Backed Up	Storage System	Low Price	Low Maintenance	Low-Technology	Maintenance	Temperature	Dependence	Thin	Rugged	Encapsulated	Quiet	Lightweight	Modular	Flexible	Locally Available	Undetectable	Non-Polluting	Safe	Utility-Free	Light Sensitive	IR Transmitting
Basic Individual Needs																											
1 Shelter																											
2 Light																											
3 Warmth																											
4 Oxygen																											
5 Nutrition																											
6 Water																											
7 Sleep																											
8 Health																											
9 Cleanliness																											
10 Sanitation																											
11 Safety																											
Derived Individual Needs																											
12 Love																											
13 No Drudgery																											
14 Privacy																											
15 Self Respect																											
16 Power																											
17 Clothing																											
18 Wealth																											
19 Material Goods																											
20 Peace of Mind																											
21 Intellectual Satisfaction																											
22 Aesthetic Satisfaction																											
23 Salvation																											
24 Variety of Experiences																											
25 Creative Opportunities																											
26 Leisure																											
27 Excess Capital																											
Functions of Society																											
28 Communication																											
29 Production																											
30 Education																											
31 Distribution																											
32 Defense																											
33 Member Replacement																											
34 Social Control																											
35 Demographic Balance																											
36 Transportation																											

FIGURE III-1
MORPHOLOGICAL DIAGRAM

Six applications having the highest market capture potential and/or likelihood of early entry into the market were selected. For more detailed study these six were: outside lighting, irrigation pumps, corrosion protection devices, remote repeaters, small refrigerators and 12-volt battery chargers.

The most detailed analysis was further limited to four products. Corrosion protection and repeater stations having been included in other photovoltaic market studies were then eliminated, leaving four prime products: outside lighting, irrigation pumps, small refrigerators and 12-volt battery chargers.

Interviews of up to twenty-five persons working for companies located in one of the five major cities (Los Angeles, Chicago, Washington, Philadelphia, and New York) for each of the four products.

2. Approach

From the listings of applications and their related photovoltaically powered products generated in the preceding task, generic descriptions and conceptual designs of thirty-two products were developed. Selected products thus described were used as the basis for obtaining detailed market acceptance information by national survey; their designs were then selected with respect to size, cost and consumer sales appeal.

For twelve of these products questionnaires were developed to assess market acceptance potential in terms of market penetration, obstacles and incentives to adoption of photovoltaic products. These were mailed to a selected number of decision-makers among manufacturers and operating

companies across the nation. Interviews, which provided a more controlled instrument for determining market acceptance, were administered to experts and key decision-makers in four product areas. Interview responses regarding the promise of various segments of the product markets, barriers to adoption and incentives for adoption were summarized for four prime products and mailed questionnaire responses for corrosion protection and repeater stations were summarized.

Interview responses formed the basis for demand curve and market penetration analyses. A mathematical model of the decision-making process was developed from which demand functions were derived.

For the six products covered by interview and mailed questionnaires, a computer based optimization with respect to size and cost was carried out. Input for optimization calculations is location, insolation and load requirements.

In addition, expertise in industrial design and product development formed the basis for refinements of design for increasing consumer acceptance of the four prime products. Such factors as portability, modularity and styling were included.

The output of this phase of the study consists of conceptual designs and descriptions for thirty-two products, market acceptance information and optimization data for six products, and demand curves, market penetration projections and design improvement suggestions for four products.

B. Product Selection and Product Descriptions

1. Initial Product Selection

The brainstorming sessions produced a large number of ideas for the use of photovoltaic cells, phrased in one- to four-word descriptions. The

ideas in these lists were consolidated by identifying concrete products which exemplified several applications. These products were grouped under specific concepts such as "ideas for agricultural use" or "ideas for use in developing countries." (See Table III-3). Thirty-two products have been singled out as covering the original wide range of applications developed by the brainstorming sessions and for which specific market information could be sought. (Table IV-1).

2. Product Descriptions

a. Estimation Values

To ensure that the technical descriptions for all the products were uniform and that the assumptions made in describing the units were clearly stated, an outline was drawn up stating the numerical values for all the parameters needed to describe these devices. These parameters included the typical level of insolation, the price per peak watt of the solar panel, the storage capacity, and standard reference values and costs for alternative power supplies. Ensuring uniform parameter values also saved considerable time in the preparation of the substantial number of product description sheets required.

For calculation of panel output, an insolation value of 550,000 Btu/ft²/yr was chosen. This is an average U.S. value for insolation on a plane tilted at the latitude angle and facing the equator.⁽¹⁾

A projected panel efficiency of 13%^(4,5,6) was used to calculate panel output. Making an allowance of 75% for the worst month the engineering level was determined. These values are:

Annual (kWh/yr-ft ²)	<u>Panel Output</u>		Average Engineering Level (Watts/ft ²)
	24 hour average (Watts/ft ²)		
20.9	2.39		1.79

For all estimations the life expectancy of solar cells is 20 years with 1% of initial cost per year maintenance. The reference standard used for incident insolation is 100 mW/cm^2 (92.9 W/ft^2). Peak wattage per gross square foot of panel is 12 Wp/ft^2 in 1985⁽³⁾. DOE cost goals for photovoltaic array cost in 1975 dollars are shown in Table IV-2.

TABLE IV-2
DOE PRICE GOALS^(2,13)
(\$/Wp)

1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
20.00	10.00	7.25	5.56	4.30	3.10	2.20	1.50	1.00	0.65	0.50

Market prices for batteries, summarized below, were obtained from the appropriate catalogues and brochures.

<u>Battery</u>	<u>Price</u>	<u>Life Expectancy</u>
Rechargeable batteries	(\$ per 1000 volt-amp-hr stored)	
4 amp-hr NiCd ⁽⁷⁾	\$625	10 years
240 amp-hr NiCd ⁽⁹⁾	\$290	10 years
Lead-Acid ⁽⁸⁾	\$50	5 years
Primary batteries ⁽¹⁰⁾	(\$ per 1000 volt-amp-hr)	<u>Efficiency</u>
Small	\$390	80%
Large bank	\$370	80%

Gasoline generator figures are related to electrical output wherever appropriate. Overseas data⁽¹⁰⁾ and domestic data⁽¹²⁾ formed a basis for estimation values. Maintenance cost used for all units is 10% of capital cost per year. Domestic gasoline cost used is \$1.00/gal; developing nation gasoline cost used is \$3.00/gal.

Values for gasoline generators are summarized below.

<u>Generator Size</u>	<u>Cost/kW Capacity</u>	<u>Fuel Consumption</u>	<u>Life Expectancy</u>
Small plant (500W)	\$500	0.18 gal/hr	5 years
(1kW)	\$300	0.25 gal/hr	5 years
Large plant (>1kW)	\$300 + \$150/kW	0.25 gal/hr for first kW + 0.20 gal/hr for each additional kW	10-15 years

The estimation values used for capital cost per mile of subtransmission lines is \$10,000. Life expectancy used is 20 years with 5% per year allotted for maintenance and repairs. Cost per kilowatt-hour used is \$.05 in 1975 and \$.08 in 1985.

Estimated capital cost above inflation rate is 5% for developing nations and 3% for developed nations.

b. Calculations and Text Preparation

For each of the 32 specific devices chosen for product development, initial sizing of the solar panels, and electrical storage was calculated. The physical size of the device, the initial cost of the device, the operating costs and the cost of alternative energy sources were estimated. As the products covered a very wide range of sizes and uses, some of the design considerations, such as the amount of storage to be provided, varied to suit the application.

The load of the individual device is the key parameter for all size and price considerations. These loads were determined primarily by comparison with existing devices which have non-solar power supplies. In cases where there was not an existing alternative device, a simple electric diagram was devised and the load requirements estimated for the total of the components.

The size of the panel was then determined from the average load over 24 hours using the previously stated insolation and the estimated values. As a check, the ratio of average load to peak watt for the chosen panel size was calculated and used to indicate how conservative the design was. The cost of the panel could then be calculated from the peak-watts-per-square-foot and dollars-per-peak-watt parameters.

Next, the electrical storage was determined by considering the distribution of the load over light and dark periods of the day, the number of consecutive overcast days through which continuous operation might be required, and the penalty paid when the system failed to operate because of lack of sunlight. For devices requiring small amounts of power, a figure of three consecutive days was used; for devices requiring more power, the particular needs of the user were considered. Batteries available off the shelf today were used for sizing and pricing considerations for most applications.

For those applications requiring a very large amount of storage, consideration was given to advance batteries or fly-wheel storage units expected to be available by 1985.

The one or two most likely alternatives for each device were chosen. The initial cost, operating cost, and maintenance requirements of these alternative power sources were determined by comparing existing off-the-shelf units under present and future conditions in the field. The cost of petroleum fuels was arbitrarily set at a rather nominal figure. Exact figures were not used because of wide variations in the cost of delivering fuel to the often remote locations in which the solar-powered devices would be used and uncertainties as to the future price of petroleum fuel.

The product description sheet includes a brief physical description and the principal purpose or mode of operation of the device. The first of applications listed on the product description sheet is the primary example. An artist's rendering shows the size and relationship of the major components.

The size of the photovoltaic panel, electrical information about its operation and the size of the job it is intended to perform, follow. Also, information about the amount of storage, the estimated lifetime of the unit and the economic value of the energy it provides are given. Basic economic information about one or two major energy alternatives is given for comparison with the photovoltaic system. Finally, a general statement about the cost of the solar equipment is given, but specific financial statements are withheld for later inclusion in the questionnaires.

A sample product description sheet is shown in Figure IV-1.

The 32 product description sheets are given in Appendix III-A.

PHOTOVOLTAICALLY POWERED 12-VOLT BATTERY CHARGER

DESCRIPTION: A solar-powered, general-purpose battery-charger for 12-volt batteries will recharge a standard battery in one day. The device is simple, requires little maintenance, and has a long lifetime.

APPLICATIONS:

1. Small battery-assisted vehicles.
2. Lawn mowers and garden tractors.
3. Garage and service stations.

FIGURE IV-1
SAMPLE PRODUCT DESCRIPTION SHEET

PERFORMANCE AND SIZE: This battery charger consists of a photovoltaic panel, totaling 24 square feet, which may be mounted on a roof or in an open yard. The device is simple, has no moving parts and should last about 20 years. The panel provides approximately 600 kilowatt hours of electricity per year.

ALTERNATIVE ENERGY SOURCES: A battery charger can, of course, be powered either from the electrical grid, or by a small gasoline generator. In the case of the electrical grid it is not the cost of the electricity that is the important consideration but the cost of installing the electrical outlet. For a simple function such as charging a battery, only a modest expense for the initial installation would be appropriate. The cost of installing even a few hundred yards of electrical line, for example, out to a farm shed in which battery-powered tools were stored might equal the cost of the photovoltaically powered system. Once the electrical connection is installed, however, it could be used for other purposes such as lighting, in addition to the battery-charging function.

If a gasoline generator is used, it would cost initially about \$300 and would require about \$100 worth of fuel per year plus about \$30 in maintenance and oil. The device would last two or three years but would require considerable maintenance. The gasoline generator would be portable, however, and could be used for other tasks, such as operating power tools. The total cost for operating such a generator would be about \$250 per year.

The cost of the solar panels is currently quite high, but as usage and mass-production increase the cost will come down dramatically.

C. Market Acceptance of Products

1. Measurement of Market Acceptance

Under the guidance of consultants, eighteen variations of a questionnaire were designed to measure the market penetration of twelve different applications (see Section IV.A.2) of photovoltaic cells under different economic conditions. Information about barriers to market adoption of photovoltaically powered products, potential incentives for market adoption, and estimates of the size of both current and future markets for solar and conventionally powered products was requested. In addition, questions about the experience of the respondent and his or her organization with solar and conventionally powered products were included in the questionnaire.

Two versions of the questionnaire, a long form for personal interviews and a short form for the mail survey, were designed for each of the first six products. Only a short-version questionnaire was designed for each of the last six applications (agricultural devices, construction trailers, water pumps, security devices, small electric vehicles, and radio transceivers).

a. Questionnaire Content

Both the interview and the mailed questionnaires started with detailed product descriptions to give the respondents a basis for making market judgments about the manufacture and operation of solar-powered products.

Five types of information were requested in both versions of the questionnaires: market penetration of solar products, barriers to adoption, incentives to encourage adoption, market size, and characteristics of the respondent and his/her organization. Market penetration questions included:

- (1) judgment about the promise of solar-powered products in each of several applications;
- (2) estimates of the likelihood of purchase of several different types of buyers under two different scenarios of added first cost and expected period of time necessary for solar power to pay back the added first cost; (One scenario was pessimistic in assuming high added first cost of purchasing and installing solar rather than conventional power and low annual operating savings from solar. The second, optimistic scenario was based on lower costs of photovoltaic cells which can result from mass production of these cells, a high cost of installing conventional power, and high annual operating savings because of rising fuel costs and locations where maintenance is expensive.)
- (3) judgment about the share of the total market solar-powered products will achieve under each of the six sets of added initial costs and annual operating savings. Three different levels of added initial costs were combined with two different annual operating savings to produce the six sets; and
- (4) estimates of market penetration of solar-powered products described by three different sets of conditions: one of several amounts of added first costs, one of several amounts of annual operating savings, and in the case of irrigation pumps, one of several tax incentives. (These description and penetration questions which extended approximately twenty-five pages, depending on the number of first costs, operating savings, and the presence of or absence of financial incentives, were excluded from the short mail version to reduce the possibility of non-response.)

Questions about barriers to adoption included an open-ended question about the major barriers to acceptance of solar-powered products by manufacturers, distributors, or users. A structured question which required the respondent to allocate 100 points among five barriers to

market acceptance of solar-powered products was also asked. Usually, cited as these barriers were "unreliability," "higher initial cost," "vandalism," "installation difficulties" and "maintenance problems" of solar systems.

Three open-ended questions were asked about factors that would encourage adoption of solar systems. Respondents were asked to suggest what information they would need prior to adopting solar systems; why manufacturers, distributors, and buyers would adopt solar-powered products; and what the government should do to stimulate use of solar-powered products. In addition, respondents were asked specifically if they favored giving tax incentives to manufacturers and/or buyers in order to stimulate use of solar power. The mail questionnaire also included a question about the relative importance of several reasons why users would adopt solar products.

Respondents were asked to estimate the sales, in number of units, for the product applications under study. These estimates were requested for market segments, such as different sizes of refrigerators or motors, because the market acceptance of solar power and the respondent's ability to estimate market size was expected to vary by segment. A question about the relative accuracy of demand estimates for each segment permitted judgment of the reliability of the market estimates. The respondent was also asked to predict the average growth or decline in each market segment for the next ten years.

Level of expertise was judged through responses to questions about amount of relevant experience of the respondents and their companies, the annual sales volume of the companies, and respondents' position with their companies.

In accordance with standard procedures these instruments were pretested before use in the field. For each of the six applications two

organizations or firms in the Washington, DC area representing potential manufacturers, distributors or users were asked to participate in the pretesting.

A sample questionnaire, as formatted by the interview company and including instructions to interviewers, is given in Appendix III-B.

A sample mailed questionnaire is given in Appendix III-C.

b. Respondents

Respondents were chosen based on their experience with conventional equipment and their ability to make experience-based judgments about the likelihood of market acceptance of the photovoltaic equipment. All of those who were chosen to receive either the long-version or the short-version questionnaire were carefully selected to represent the major manufacturers, marketers and/or users of products that could be solar-powered. Their cooperation was obtained prior to the administration of the questionnaire. Interview respondents were selected from five major market areas: Chicago, Washington, DC, Philadelphia, New York City, and Los Angeles.

These cities provide a national spread of the highest concentration of industries that might either manufacture, distribute or use solar-powered products.

In selecting participants, ITC/Solar relied primarily upon the Thomas Register of American Manufacturers, supplementing the names obtained from that publication with suggestions from government and private sources. Contact within these firms was directed to top decision-makers or those whose personal and/or professional experience would most likely produce informed, reliable responses. In all, 83 interviews were conducted, representing 76 firms. Table IV-3 categorizes these businesses according to total tangible assets. Potential respondents to mailed questionnaires were selected in the same manner. Participating organizations are cited in Appendix III-G.

TABLE IV-3
COMPANIES INTERVIEWED, BY TOTAL TANGIBLE ASSETS

<u>Application</u>	<u>Thomas Register Classification</u>				
	<u>A</u>	<u>AA</u>	<u>AAA</u>	<u>AAAA</u>	<u>Other</u>
1. Battery Charger	2		1	14	
2. Outside Lighting	3		2	10	
3. Irrigation	2	1	1	15	4
4. Refrigerators	4	2	1	8	6
TOTAL (76) *	11	3	5	47	10
				(62%)	

AAAA = assets of \$1,000,000 and up

AAA = assets of \$500,000 and up

AA = assets of \$300,000 and up

A = assets of \$100,000 and up

Other = assets not listed or
trade associations

* In some cases, more than one person within a company was interviewed.

2. Analysis of Photovoltaic Market Acceptance Data

a. Objectives

The primary objectives of this analysis are: (1) to establish individual and market demand functions for four applications of solar photovoltaic devices; (2) to make market penetration projections through the year 1986 based on specified solar-cell cost reductions; and (3) to document the methodologies used in making demand curve and market penetration estimates. The study findings presented in the report should not be construed as an interpretive analysis although the results are straightforward and unambiguous.

b. Overview of the Research Approach

The approach taken was to model the decision making process of known experts in the four application areas. In-depth, personal interviews were conducted with 83 experts at their office locations. From these interviews, parametric values of decision-making functions were derived and used to construct demand curves for each expert. Individual demand functions were then aggregated by application to produce a "market consensus" estimate of demand for each application. These consensus demand functions were then used as input to derive a market penetration model. The procedure for estimating individual and "market consensus" demand functions and the method for making quantitative projections are detailed below.

The sample is best described as an area and expertise, stratified quota control sample of expert judges. The geographic spread and the nature of respondents' expertise, as well as the selected sample size, are reported previously in this section.

The sample disposition of total and usable responses by application is as follows:

	<u>Total Responses</u>	<u>Usable Responses</u>
Battery Chargers	20	18
Outside Lighting	17	15
Irrigation Equipment	24	20
Refrigeration	<u>22</u>	<u>20</u>
	83	73

Responses from a few subjects were considered invalid due to difficulties in handling the data collection task for the demand curve estimation procedure. The shrinkage encountered here is less than typical due to the professional qualifications of the respondents.

c. Demand Curves

i. Methodology for Demand Curve Estimation

Demand functions, expressing market penetration as a function of attributes of photovoltaic devices, are derived by modeling the decision-making process of the professionals interviewed in the study. The procedure works by having the respondents make judgments about how specific photovoltaic devices would be accepted by the market. The devices are described by factorial arrays of attribute combinations and judgments of market penetration are requested for each alternative. Using these judgments a demand function expressing the relationship between market penetration and attributes of the devices is recovered using least-squares techniques. The function expresses the quantitative relations between attributes of the devices and market penetration. It specifies the relative importance of the attributes, trade-off relations among the attributes, and apparent information processing rules such as attribute interactions and non-linear judgments.

The procedure requires that the products be described in terms of their attributes. In evaluating an expensive purchase such as a photovoltaically powered device, decision makers weigh the perceived benefits with alternative ways of obtaining the same satisfaction.

Operationally, this entails comparisons of the salient attributes of a particular product with those of competitive alternatives. If one alternative has more desired attributes than another, or more of an attribute, it is preferred. Therefore, before realistic judgments can be made, the solar systems must be described in terms of the primary attributes that could be determinant in the choice situation. The attributes chosen and their relation to the research objective are:

1. Initial Cost Difference - difference in initial installation cost of the solar alternative compared to a conventionally powered unit. Previous research has demonstrated that high initial cost may be the most important attribute considered in evaluating a solar purchase.
2. Operational Cost Savings - the high initial cost will be considered against anticipated operational cost savings in judging the desirability of a solar purchase. The interaction between initial cost difference and savings in operation will make possible a determination of the willingness to accept life cycle arguments. Operational savings is expressed on an annual basis.
3. Tax Incentive - In two of the applications, lighting and irrigation, a federal tax credit was investigated with the demand curve procedure. This will permit an investigation of the potential impact of government stimulation of the market. Incentives were not investigated for refrigeration or battery chargers because it is likely that incentives would be appropriate for these applications.

In this part of the investigation respondents were instructed to treat the photovoltaic equipment as having excellent reliability and performance, thereby controlling these factors. Obviously, reliability and performance, as well as other attributes, may also play an important role in consumer acceptance, and they are investigated in other parts of the research not concerned with demand curve estimation.

The specific values the above attributes can take in formulating alternative photovoltaic product descriptions are listed in Table IV-4. These values were chosen to span most of the reasonable range of initial cost differences and operating cost savings which are projected to occur over the ten-year period. DOE projections of future photovoltaic costs are reflected in these estimates.

TABLE IV-4
VALUES FOR PRIMARY ATTRIBUTES USED IN DEMAND CURVE ESTIMATION
 (Numbers are all expressed in dollars)

Battery Chargers: 16 possible descriptions (4 X 4)

Initial Cost Difference	100	200	300	500
Operating Cost Savings	15	30	50	90

Outside Lighting: 24 possible descriptions (4 X 3 X 2)

Initial Cost Difference	0	200	400	800
Operating Cost Savings	40	80	120	
Tax Credit	0	60		

Irrigation: 27 possible descriptions (3 X 3 X 3)

Initial Cost Difference	10,000	20,000	40,000	
Operating Cost Savings	500	1,000	1,500	
Tax Credit	0	2,000	4,000	

Refrigeration: 16 possible descriptions (4 X 4)

Initial Cost Difference	100	250	500	1,000
Operating Cost Savings	10	25	75	150

Based on an expert's judgment of the market penetration to be expected for each of the alternative photovoltaic descriptions a demand function is estimated for each expert. The function expresses market penetration as dependent on first cost difference, conditional on operating cost savings and the availability of incentives. The result is a mathematical equation which can be used to predict each expert's estimate of market penetration for any values taken by the attributes. In addition to estimating the impact of first costs, these equations can be used to gain insights into the influence of one attribute while controlling the influence of others. This is extremely important in judging market response. Further, the market demand function derived provides the basis for making market projections in future years. Because the functions express market penetration as dependent on initial cost differences and operating cost savings, new penetrations can be calculated for future years as costs and savings change. This procedure will be discussed in detail later.

The demand curve procedure is implemented by asking each expert to indicate his estimate of market penetration for each of the photovoltaic descriptions. One of the descriptions for the irrigation application is shown in Figure IV-2. These estimates serve as the dependent variables in a least squares regression analysis where the independent variables are the attributes of the solar systems. In this manner a demand curve function is obtained. Instructions provided the subjects for performing these tasks are shown in Appendix III-B.

Because non-linearities and interactions with initial cost were anticipated, two functional forms were investigated for each respondent. They are:

Linear: $M = B_0 + B_1(FC) + B_2(FS) + B_3(TC)$

Linear with Interaction:

$$M = B_0 + B_1(FC) + B_2(FS) + B_3(FC)(FS) + B_4(TC) + B_5(FC)(TC)$$

1. Price increase if solar cell energy system is added. \$20,000
2. Average annual operating cost savings due to solar system. \$500
3. Federal tax credit available to operator is \$0.0

Your estimate of market penetration (check one)

☐ 0%
 ☐ 5%
 ☐ 10%
 ☐ 20%
 ☐ 30%
 ☐ 40%
 ☐ 50%
 ☐ 60%
 ☐ 70%
 ☐ 80%
 ☐ 90%
 ☐ 100%

FIGURE IV-2
MARKET PENETRATION SAMPLE QUESTION

Mixed Inverse:

$$M = B_0 + \frac{B_1}{FC + L} + B_2(FS) + B_3(TC)$$

Mixed Inverse with Interaction:

$$M = B_0 + \frac{B_1}{FC + L} + B_2(FS) + B_3\left(\frac{1}{FC + L}\right)(FS) + B_4(TC) + B_5\left(\frac{1}{FC + L}\right)(TC)$$

where, M = market penetration (%)

FC = initial cost difference

FS = operating cost savings

TC = tax credit

L = location parameter for curve fitting

B_i = estimated regression coefficients which define the demand curves.

The model chosen for each respondent is the one which gives the closest fit to the data using the coefficient of determination (R^2) as the criterion. Interaction terms, however, are included only if they are statistically significant. A discussion of the theoretical rationale for this technique is found in an article by Scott and Wright.⁽¹⁴⁾

After demand functions are obtained for each expert, they are combined to form the "market consensus" demand equations for each application. This is accomplished by obtaining predicted market penetrations for each expert for all possible attribute combinations for each application. These predicted market penetrations then serve as estimates of a dependent variable in a least squares analysis using the same functions as shown above. In this manner a demand equation is derived which aggregates the judgments of the individual experts. These functions become the basis for predicting market penetration in future years for specified values of the predictor variables.

ii. Market Demand Curve Equations and Demand Functions

The best fitting curve for the consensus equations for each application turned out to be the mixed inverse function.

$$M = B_0 + \frac{B_1}{FC + L} + B_2(FS) + B_3 \left(\frac{1}{FC + L} \right) (FS) + B_4(TC) + B_5 \left(\frac{1}{FC + L} \right) (TC)$$

Values for the Functions

<u>Application</u>	B_0	B_1	B_2	B_3	B_4	B_5	L
Battery Chargers	-8.234	3798.167	0.1327	36.861	-----	-----	40
Lighting	-9.0476	10638.398	0.1145	15.442	1.811	1103.854	200
Irrigation	6.00	24.44	0.003	0.176	-.236	43.34	0
Refrigeration	-2.711	5764.396	-0.0055	68.892	-----	-----	100

Plots of demand functions are presented in Figures IV-3 through Figure IV-7. Market demand curve data are summarized by product in Tables IV-5 through IV-8. Individual demand curves are collected in Appendix III-D.

FIGURE IV-3
DEMAND CURVE - BATTERY CHARGERS

TABLE IV-5
MARKET DEMAND CURVE DATA

Battery Chargers

Market Penetration Estimate (%)	Initial Cost Difference (\$)	Annual Operational Savings (\$)
37.3	100	15
44.8	100	30
54.8	100	50
74.8	100	90
15.5	200	15
20.3	200	30
26.6	200	50
39.3	200	90
8.3	300	15
12.1	300	30
17.2	300	50
27.4	300	90
2.5	500	15
5.6	500	30
9.7	500	50
18.0	500	90

FIGURE IV-4
DEMAND CURVE - OUTSIDE LIGHTING

TABLE IV-6
MARKET DEMAND CURVE DATA

<u>Lighting</u>			
Market Penetration Estimate (%)	Initial Cost Difference (\$)	Annual Operational Savings (\$)	Tax Credit
51.8	0	40	no
59.2	0	40	yes
59.5	0	80	no
66.9	0	80	yes
67.2	0	120	no
74.5	0	120	yes
23.7	200	40	no
28.3	200	40	yes
29.8	200	80	no
34.4	200	80	yes
36.0	200	120	no
40.6	200	120	yes
14.3	400	40	no
18.0	400	40	yes
19.9	400	80	no
23.6	400	80	yes
25.6	400	120	no
29.2	400	120	yes
6.8	800	40	no
9.7	800	40	yes
12.0	800	80	no
14.9	800	80	yes
17.2	800	120	no
20.2	800	120	yes

FIGURE IV-5
DEMAND CURVE
IRRIGATION: TAX CREDIT

FIGURE IV-6

DEMAND CURVE

IRRIGATION: FUEL SAVINGS

TABLE IV-7
MARKET DEMAND CURVE DATA

Irrigation

Market Penetration Estimate (%)	Initial Cost Difference (\$000)	Annual Operational Savings (\$)	Tax Credit (\$000)
18.7	10	500	0
26.9	10	500	2
35.1	10	500	4
29.0	10	1000	0
37.2	10	1000	2
45.4	10	1000	4
39.3	10	1500	0
47.5	10	1500	2
55.7	10	1500	4
13.1	20	500	0
17.0	20	500	2
20.8	20	500	4
19.0	20	1000	0
22.9	20	1000	2
26.7	20	1000	4
24.9	20	1500	0
28.8	20	1500	2
32.6	20	1500	4
10.3	40	500	0
12.0	40	500	2
13.7	40	500	4
14.0	40	1000	0
15.7	40	1000	2
17.4	40	1000	4
17.7	40	1500	0
19.4	40	1500	2
21.1	40	1500	4

FIGURE IV-7
DEMAND CURVE - REFRIGERATION

TABLE IV-8
MARKET DEMAND CURVE DATA

Refrigeration

Market Penetration Estimate (%)	Initial Cost Difference (\$)	Annual Operational Savings (\$)
31.0	100	10
38.3	100	25
62.8	100	75
99.4	100	150
16.5	250	10
20.7	250	25
34.5	250	75
55.3	250	150
8.5	500	10
10.9	500	25
18.9	500	75
30.8	500	150
3.4	1000	10
4.6	1000	25
8.9	1000	75
15.2	1000	150

d. Methodology for Market Penetration

Acceptance of solar photovoltaic devices depends fundamentally on decision makers' willingness to allocate a significant part of their scarce resources to such a purchase. In making such choices, these buyers subjectively assess performance, reliability, and financial factors. Seldom are such decisions made on strictly monetary (economic) grounds. Therefore, any model of market penetration must rely heavily on buyer research and a framework which expresses decision maker preferences.

This is the approach taken in the market penetration model used here. The principal construct of the model is a demand function which expresses the consensus judgments of the experts.

The approach permits market penetration to be quantitatively estimated for succeeding time periods. Because the demand functions are expressed as dependent on factors such as differences in installation costs and operating cost savings, new estimates of purchase intentions can be produced as these costs change in future years. The functions can be used to project penetration of the effective capture potential based on DOE assumptions concerning future photovoltaic costs, fuel prices and incentives.

To estimate penetration in future years, values for fuel savings and solar installation costs must be projected. Because these projections are clouded by unpredictable swings in the overall rate of inflation, the penetration estimates are made on a deflated basis. That is, future solar costs and fuel costs are expressed in constant 1976 dollars. This simplifies the forecasting task yet preserves the integrity of the forecast procedure. It is evident that if both solar costs and fuel costs are subject to the same overall rate of inflation, the overall inflation rate will not affect the estimates of penetration derived from the demand functions.

What must be incorporated, however, are anticipated changes in these costs on a deflated basis. For the purposes of this analysis, the ERDA price goals presented in Figure II-7 and Table IV-2 of this report were used.

In order to use the demand functions for future predictions they must be related to the product life-cycle curve. New product introductions which ultimately become commercial successes exhibit a characteristic life cycle. Several stages have been identified for a typical product life cycle. As shown in Figure IV-8, they are introduction, growth, maturity or saturation, and decline. During introduction sales are minimal, profits non-existent, buyer awareness low, distribution limited, and promotional efforts at modest levels as compared to those of later stages. Often several versions of the same product are available from a variety of manufacturers, including many small firms, and product differences may be present.

If the product achieves a reasonable degree of acceptance, sales and profits begin to grow rapidly, manufacturing costs decrease, prices fall, distribution widens, promotional efforts increase and focus on obtaining market share and new variations of the original product begin to emerge. Usually, during the later part of this stage, the marginal producers are forced out of the business or are absorbed by those with larger market shares. The size of the market, of course, limits the period of rapid growth and the maturity of saturation phase is reached. At this point a mature industry is established where sales are determined by basic economic growth factors such as population increase, by replacement demand, or by new uses for the product.

The length of time a product remains in the introductory stage and how rapidly sales grow depend on the extent to which decision makers perceive relative advantages (e.g., economic function, style) in using

FIGURE IV-8
PRODUCT LIFE CYCLE CURVE

the product as compared to alternatives. The rate of acceptance also depends on the compatibility of the product with existing social and cultural expectancies, how effectively it can be promoted, and how quickly distribution can be established.

If photovoltaic devices are to achieve market success, it can be expected that they will exhibit the typical life cycle of introduction, growth, maturity, and possibly decline. This raises two related questions about the demand functions described. First, how are they to be interpreted in light of life-cycle theory? Second, how are the introductory and growth periods to be specified? The answer to the first question is that the demand functions express what could happen given appropriate marketing effort. They are, therefore, most representative of the late growth or early maturity stages of the life cycle. This leads to the second question because the level of market penetration indicated by the demand functions obviously cannot be attained in the first year. This produces a difficult forecasting problem because it is hard to predict when a product will reach a certain stage in its life cycle. A procedure for handling this problem is explained in the model development which is presented in Appendix III-E.

The results of the market penetration analyses are presented in Section V following a discussion of selected scenarios and the assumptions upon which they are based.

3. Summary of Responses to Interviews

a. Introduction

Data obtained from the structured sections of the four interview questionnaires were subjected to tabulation and statistical analysis by computer. Mailed questionnaire responses were tabulated by hand and are summarized in the following section, IV.C.4.

In the sections below, summaries are given for each group of questions for the various uses of photovoltaic power included in the survey. Numbers in the supporting tables represent the mean value of responses. Standard deviation of responses is indicated in some cases by a horizontal line associated with each value, in others by a numerical value.

b. Descriptive Statistics from Interviews

i. Most Promising Applications

For each application, interviewees were asked to rank, on a scale from 1 to 5, the promise of specific uses or different market segments (see sample questionnaire in Appendix III-B). The respondents were given assumptions as to cost and were asked to base their opinions on the devices as specified in the product description sheets.

Tables IV-9 through IV-12 show the mean respondents' values of choices of the most promising applications of photovoltaic devices. The horizontal lines approximate standard deviations associated with the mean values.

(1) Battery Chargers

For the 6- or 12-volt battery chargers (Table IV-9), "temporary lighting for construction sites and other industrial purposes" received the highest ranking of 3.70. Boats (3.1) and two-way communications equipment (3.05) followed second and third, respectively. The remainder of uses (autos, trucks, small household appliances and battery-powered portable tools) fell below the mean of 3.0 points.

TABLE IV-9
MOST PROMISING APPLICATIONS

BATTERY CHARGERS

Product: 6 or 12-volt battery charger

Installed cost: \$300-\$450

APPLICATION	PROMISE				
	Poor Application			Very Promising Application	
	1	2	3	4	5
Today's automobiles and trucks	1.55				
Boats	3.1				
Battery-powered portable tools: drills, saws, impact wrenches	2.95				
Two-way communications equip- ment: ham radios, CB's	3.05				
Temporary lighting for con- struction sites and other in- dustrial purposes	3.70				
Small household appliances: radios, stereos, cassette tape players, grass clippers, etc.	2.4				

(2) Outside Lighting

Of the fifteen uses listed for a 175-watt capacity mercury vapor lamp, (Table IV-10), the highest rank of 4.06 was given to navigational aids such as buoys. Outdoor advertising (4.00) and security lights at remote industrial sites (3.81) received the second and third highest rankings. The remaining uses were clustered in the middle with rankings of 2.25 to 3.69.

(3) Irrigation

For a 50-horsepower pump (Table IV-11), respondents were asked to rate the promise of application for four different types of farms. The factory farm with managerial staff and corporate ownership was chosen as the most likely application with a rating of 4.00. The remaining three categories received successively lower rankings according to the scale of operation (3.44 for management-operated, privately owned by partnership or group; 2.87 for manager/operator, privately owned by individual; and 2.17 for family farm, owner-operated).

(4) Refrigerators

Of the five uses listed for a photovoltaic, 4- to 8-cubic-foot refrigerator, the highest ranking of 4.09 was given to remote cabins and facilities. Medical uses (3.32) followed second (Table IV-12). The remaining three uses received lower ratings (trailers and campers, 2.91; general household usage, 2.73; and commercial refrigeration, 2.23).

ii. Barriers to Acceptance

For each photovoltaic application, respondents were asked to rank the given reasons why the device might not be accepted in the marketplace by allotting points to each with a total of 100. (As Table IV-13 shows, in one case, points allotted totaled more than 100.)

TABLE IV-10
MOST PROMISING APPLICATIONS (CONT'D)

LIGHTING

Product: 175-watt capacity mercury vapor lamp

Installed cost: \$650

APPLICATION	PROMISE				
	Poor Application		Very Promising Application		
	1	2	3	4	5
Vacation houses and camps			3.56		
Outdoor advertising--highway billboards				4.00	
Aviation avoidance lights on tall structures			3.12		
Security lights at remote industrial sites				3.81	
Highway phone call boxes			3.31		
Offshore drilling and production platforms			3.31		
Navigational aids--e.g., buoys				4.06	
Highway rest stops			3.12		
Field construction offices (trailers)			3.00		
Parking lots			2.75		
Exterior security lights on remote factories and offices				3.44	
Farmyard lights				3.50	
Lighting for recreational vehicles			2.50		
Factory identification signs (located several hundred feet from factory)				3.69	
Airport runways			2.25		

TABLE IV-11
MOST PROMISING APPLICATIONS

IRRIGATION

Product: 50 horsepower pump

Installed cost: \$35,000-\$45,000

APPLICATION	PROMISE				
	Poor Application			Very Promising Application	
	1	2	3	4	5
Family farm, owner-operated	----- 2.17 -----				
Manager/operator, privately owned by individual	----- 2.87 -----				
Management operated, privately owned by partnership or group	----- 3.44 -----				
Factory farm, managerial staff, corporate ownership	----- 4.00 -----				

TABLE IV-12
MOST PROMISING APPLICATIONS

REFRIGERATORS

Product: 4 to 8-cubic foot refrigerator

Installed cost: \$500-\$600

APPLICATION	PROMISE				
	Poor Application			Very Promising Application	
	1	2	3	4	5
Remote cabins and facilities				4.09	
Trailers and campers			2.91		
Medical uses			3.32		
General household usage (8-20 cubic foot capacity)			2.73		
Commercial refrigeration (21 or more cubic foot capacity)			2.23		

TABLE IV-13
BARRIERS TO MARKET ACCEPTANCE

Suppose you have 100 points to spread among the five reasons listed below why solar cell (battery chargers, outside lighting, irrigation and refrigeration) may not be accepted by the marketplace. Allocate the most points to the factor you think the market will be most concerned about and smaller amounts to those you think the market will be less concerned about. Please read the entire list before assigning any points. Remember the total must be 100 points.

	<u>Battery Chargers</u>		<u>Lighting</u>		<u>Irrigation</u>		<u>Refrigeration</u>	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Risk that the system might not be available or work well	14.00	11.0	21.29	14.6	29.50	15.5	23.64	15.1
Higher initial cost than conventional-powered units	51.10	19.2	40.76	19.6	35.58	19.7	42.96	19.6
Lack of reputable solar suppliers who will guarantee or maintain their products	12.80	9.2	13.47	10.3	19.08	9.2	16.82	8.2
Risk of vandalism or theft	5.55	5.3	9.71	7.3	6.92	4.3	7.04	6.8
Space consumed by the solar units, especially the cells	15.55	10.3	16.18	9.0	8.92	7.1	9.54*	5.2
TOTAL	100.00		101.00		100.00		100.00	

*Difficulties of installing a solar unit, rather than space consumed by solar units

Generally, respondents believed that the major barrier to acceptance for all four applications would be the products' higher initial cost compared with conventional units; of least concern was vandalism or theft. Table IV-8 shows the rankings of each barrier. As noted, for the refrigerator questionnaire, the last barrier listed was changed to "difficulties of installing a solar unit."

iii. Tax Incentives

Respondents were asked to speculate whether tax incentives should be granted to manufacturers and/or purchasers for selling or buying solar-powered products. As shown on Table IV-14, the answers for each application are rated according to the key of 1.00 point for a "yes" answer, and 2.00 points for a "no" answer.

Of all of the suggested possibilities, only capital investment tax incentives for manufacturers of battery chargers received a "no" vote (> 1.5). All other possibilities, with an incentive to reduce add-on cost for purchases leading, received a "yes" vote (< 1.5).

c. Non-Structured Questions from Interviews

The open-ended questions for interviews, which preceded structured questions, solicited opinions from participants about (1) barriers to acceptance of photovoltaics; (2) the information they would need before buying or using photovoltaics; (3) reasons manufacturers and users would accept photovoltaics; and (4) the role of government in stimulating a photovoltaics market.

These questions served as a "warm-up" for the quantitative questions and provide certain kinds of information which support the data provided by the structured questions that followed. Also, the answers to the open-ended questions provide some additional information not sought elsewhere in the questionnaires.

TABLE IV-14
TAX INCENTIVES

Please indicate whether or not manufacturers and/or purchasers should be granted tax incentives for selling or buying solar powered (battery chargers, outside lighting, irrigation or refrigeration).

	<u>Battery Chargers</u>		<u>Lighting</u>		<u>Irrigation</u>		<u>Refrigeration</u>	
	Mean	σ	Mean	σ	Mean	σ	Mean	σ
a. Tax incentives should be used	1.35	.5	1.24	.4	1.13	.3	1.28	.5
b. Manufacturers should receive capital investment tax incentives	1.55	.5	1.29	.5	1.30	.5	1.29	.5
c. Purchasers should receive tax incentives to reduce the add-on cost of solar equipment	1.35	.5	1.24	.4	1.04	.4	1.33	.5

Key: Yes   No
1.00   2.00

i. Barriers to Market Acceptance

For example, as shown by Table IV-14 on barriers to market acceptance, most respondents felt that the initial cost of photovoltaics was the major negative factor. But, in addition, some said that size of system, "unfamiliarity of the buyer" with the product, and zoning restrictions in several states (the question of "sunrights"), might hinder market acceptance.

Interestingly, many voiced the idea that there is still a large segment of the public that does not yet believe that the rising cost of energy is a problem. Also, open-ended responses indicated a concern for vandalism and theft for remote applications which is not reflected in the structured question responses. This apparent inconsistency of opinion might be interpreted as concern with high replacement (or initial) cost.

ii. Information Needed

Information on photovoltaics deemed important included: costs, cost-savings, performance characteristics, size of market, technical specifications, life expectancy of product, maintenance, environmental characteristics, availability, and possibility of guarantees. Again, questions as to the public's awareness of the need for a photovoltaic alternative arose.

iii. Reasons to Consider Buying/Using Photovoltaics

Respondents cited the following reasons why they would buy or use photovoltaic products: profit, longevity, cost savings, novelty (sales appeal), improvement of the product over its conventional counterpart, and availability of power where needed. They specifically stated that independence from the electrical grid would not be a reason to buy/use photovoltaics.

iv. Role of the Government

Many respondents strongly opposed the intervention of government in the private sector; as many favored government involvement in some fashion: government financing of demonstration projects, R&D efforts, and tax incentives for manufacturers and buyers.

4. Summary of Responses to Mailed Questionnaires

Two important photovoltaically powered products, corrosion protection equipment and remote repeaters, were originally intended to be covered by personal interviews but, due to scope of study limitations, they were included in the mailed questionnaire survey instead. Nine valid responses were received for each of these two applications and are summarized in detail in sections 4a through 4g below.

In addition, ten other photovoltaic products were included in the mailed survey; however, six of these subjects (small pumps, transceivers, field devices, electric vehicles, construction trailers and security devices) did not receive adequate treatment by the respondents (a total of only 17 responses were received for the six) to enable detailed analysis. Further, the remaining four subjects (battery chargers, outside lighting, refrigeration and irrigation) were also covered by personal interviews. A brief summary of responses to the first six questionnaires is given in section 4 h below.

a. Promise of Applications

The mailed questionnaire sought participants' opinions as to the relative promise of certain applications for photovoltaic corrosion protection and remote repeater stations. The questionnaire asked respondents to rank the given applications on a scale of 1 (poor application) to 5 (very promising application).

As shown in Table IV-15, protection of pipelines was judged to be the best application of photovoltaic corrosion protection with a mean rank of 3.8. For remote repeater stations (Table IV-16), respondents favored radio telephone relay stations for mobile telephones along highways as the best application in the continental U.S., with a mean rank of 3.8. For applications of remote repeaters in foreign countries they judged

TABLE IV-15
MOST PROMISING APPLICATIONS

Product: 5-amp, 6-volt Solar-powered Corrosion Protection System
 Cost: \$500

Application	Promise				
	Poor 1	2	3	Very Promising 4	5
Pipeline				3.8	
Well Casings			2.7		
Storage Tanks			2.8		
Off-shore Platforms		2.0			
Piers and Docks		1.6			
Bridges		1.7			
Ships		1.3			

TABLE IV-16
MOST PROMISING APPLICATIONS

Product: 200 W Solar-powered Remote Repeater Station - Continental U.S.
 Cost: \$3,000 - \$5,000

Application	Promise				
	Poor 1	2	3	Very Promising 4	5
a) Inter-city microwave stations in urban areas	-----1.7-----				
b) Inter-city microwave stations in rural areas	-----3.6-----				
c) Single-channel microwave terminals (on schools, public buildings, etc.)	-----2.5-----				
d) Pole-mounted telephone repeaters	-----2.7-----				
e) Inter-city telephone cable repeater stations in urban areas	-----2.0-----				
f) Inter-city telephone cable repeater stations in rural areas	-----3.4-----				
g) Radio telephone relay stations for mobile telephones (along highways)	-----3.8-----				
h) Satellite ground stations	-----3.0-----				

TABLE IV-16 (CONTINUED)

Product: 200 W Solar-powered Remote Repeater Station - Foreign Countries

Cost: \$3,000 - \$5,000

Application	Promise				
	Poor			Very Promising	
	1	2	3	4	5
a) Inter-city microwave stations in urban areas		2.9			
b) Inter-city microwave stations in rural areas			4.0		
c) Single-channel microwave terminals (on schools, public buildings, etc.)		2.9			
d) Pole-mounted telephone repeaters		3.4			
e) Inter-city telephone cable repeater stations in urban areas		2.7			
f) Inter-city telephone cable repeater stations in rural areas		3.6			
g) Radio telephone relay stations for mobile telephones (along highways)		3.9			
h) Satellite ground stations		3.9			

inter-city microwave stations in rural areas as the best (4.0), with radio telephone relay stations for mobile telephones (3.9) and satellite ground stations (3.9) as second choices.

b. Probable Buyers of Photovoltaic Products

Participants were given two sets of circumstances regarding initial costs and payback periods for a corrosion protection product and a solar-cell-powered telecommunications unit, then asked to indicate the likelihood that either an industrial/operating firm or governmental agency would buy or use the product. A definite decision to use solar cells was rated 1, indecision was rated 3 and a definite decision to stick with conventional power was rated 5.

For a corrosion protection unit installed at a cost of \$4,000, where the conventional product costs \$2,000 and the life-expectancy is 20 years, respondents said that an operating industrial firm probably would not buy the photovoltaic product (3.6), but that a government agency probably would (2.4). In the case where the photovoltaic product cost equalled that of its conventional counterpart at \$2,200 and had only a four-year payback period, respondents said both an operating firm (1.7) and the government (1.4) would probably buy the photovoltaic product.

For solar-cell-powered telecommunication equipment costing \$4,000 more than its conventional counterpart and commanding a 25-year payback period, respondents said that neither the government (3.11) nor industrial firms (3.89) would choose solar. However, for the second case, where the difference between photovoltaic telecommunications equipment and standard equipment was only \$200 and the payback period was reduced to four years, they said that both government (2.11) and industry (2.22) would probably buy the photovoltaic equipment.

TABLE IV-17
BARRIERS TO MARKET ACCEPTANCE

Suppose you have 100 points to spread among the five reasons listed below why solar-cell (corrosion protection, telecommunications) equipment may not be accepted by the marketplace. Allocate the most points to the factor you are most concerned about and smaller amounts to those you are less concerned about. Please read the entire list before assigning any points. Remember, the total must be 100 points.

	<u>Corrosion Protection</u>		<u>Telecommunications</u>	
	Mean	Std. Dev.	Mean	Std. Dev.
Risk that the system might not be reliable or work well	20	17	24.4	14.7
Higher initial cost than conventional power	33.3	13.0	29.4	16.7
Lack of reputable firms who will guarantee or maintain their products	9.4	6.8	18.9	12.7
Space consumed by the solar unit, especially the cells	12.2	10.6	17.8	15.0
Risk of vandalism or theft	25.0	9.4	9.4	9.8

c. Barriers to Acceptance

The fourth set of questions in the mailed survey asked participants to spread 100 points among several reasons why the given photovoltaic product might not be accepted by the marketplace. As Table IV-17 shows, "higher initial cost than conventional power" was cited as the primary barrier to acceptance for both corrosion protection and remote repeaters, with relative mean scores of 33.3 and 29.4. For corrosion protection, the barrier of least concern was the lack of a product warranty (9.4); for remote repeaters, vandalism was of least concern (9.4). For corrosion protection, risk of vandalism was the second most important concern of respondents (25.0).

A subsequent question asked participants to cite reasons, other than those listed, which might hinder market acceptance. Respondents to the corrosion protection survey noted the following: risk of lightning and wind damage; need for continuous operation; difficulty of getting low anode-to-structure resistance but having adequate driving potential; economics of providing complete cathodic protection, and lack of proven reliability.

For remote repeaters, respondents cited: resistance to a "new" technology; and scepticism that the product would perform trouble-free for 20 years.

d. Tax Incentives

The mailed survey asked participants to indicate whether or not tax incentives should be used to stimulate the photovoltaic market. A "yes" answer was ranked 1 and a "no" answer was ranked 2.

For photovoltaic cathodic protection, respondents indicated a grudging willingness to grant tax incentives to manufacturers and/or non-government purchasers, with mean votes of 1.4 and 1.3 respectively. For remote repeaters, respondents indicated that a general tax incentive could be used, along with capital investment tax incentives to manufacturers, with mean rates of 1.25 each.

For photovoltaic telecommunications equipment, respondents reacted slightly more favorably to the idea of granting tax incentives to manufacturers, giving mean votes of 1.25 to general tax incentives and capital investment tax incentives for manufacturers alike. They were additionally asked what other kinds of actions, other than tax incentives, the federal and/or state and local governments should take to stimulate the use of solar technologies in the telecommunications industries. Respondents mentioned such measures as government-sponsored research (and dissemination of approved results), demonstration systems, solar R&D investment, and incentives for buyers. One respondent said the government should not take action but allow economics of the marketplace to prevail.

e. Reasons for Acceptance of Photovoltaics

The survey included two questions to find out why participants believe photovoltaic products may be accepted by the marketplace. The first of these asked them again to allot 100 points to several listed reasons, giving the most points to the most important factor.

Respondents to both the corrosion protection questionnaire and remote repeater questionnaire (Table IV-18) indicated that the availability of power in remote locations would be the most important factor in market acceptance (mean scores, 36.7 and 31.1, respectively). Also, both sets of participants said that use of photovoltaic equipment to enhance their public image was the least important factor (11.1, 7.2).

The second question asked respondents to list additional reasons why potential users would choose photovoltaically powered equipment over conventional. For corrosion protection, the increasing cost of electric power and the elimination of unsightly power lines were cited. For remote repeaters, minimizing maintenance and outage costs, especially in foreign countries, was noted.

TABLE IV-18
REASONS FOR MARKET ACCEPTANCE

	<u>Corrosion Protection</u>		<u>Telecommunications</u>	
	Mean	Std. Dev.	Mean	Std. Dev.
Reduce bills for conventional power	23.9	16.5	30.0	14.4
Availability in remote locations	36.7	18.7	31.1	16.2
More dependable than conventional energy	11.7	9.0	11.7	7.5
Conservation of scarce energy resources	16.7	9.7	20.0	15.8
Enhance public image	11.1	5.5	7.2	5.2

Added Cost Due to Solar:	\$2,000	\$1,000	\$0.0	\$2,000	\$1,000	\$0.0
Average Annual Operational Savings:	\$40	\$40	\$40	\$100	\$100	\$100

Market Penetration

Estimates (%):	0	5	40	0	10	50
	20	30	70	30	50	90
	0	0	10	20	20	30
	30	40	50	30	50	70
	10	20	30	40	50	50
	0	10	40	10	40	80
	0	0	20	0	0	40
	0	20	90	20	40	100
	0	5	5	10	10	20

Mean Estimate (%):	6.7	14.4	39.4	17.8	30.0	58.9
Std. Dev.:	11.2	14.0	27.7	13.9	20.0	27.6

FIGURE IV-9
MARKET PENETRATION - CORROSION PROTECTION

f. Market Penetration

The surveys for both corrosion protection and remote repeaters asked participants to estimate the market penetration potential of solar-powered products under varying sets of circumstances (added cost due to use of solar and average annual operating savings). As shown in Figure IV-9, a mean of 58.9% penetration was judged possible for corrosion protection equipment when the added first cost is \$0.00 and average annual savings of \$100. If added first cost is \$0.00 but annual savings only \$50, the product achieves only 39.4% penetration.

For remote repeaters (Figure IV-10) respondents said an added first cost for solar of \$0.00 and average annual savings of \$100 would produce a market penetration of 71.7%. With added first cost still at \$0.00 but annual savings at only \$50, respondents estimated a penetration of 66.7%. While this information is sketchy - there being only three data points - the curves of penetration versus added first cost for two annual operational savings are plotted to provide a quick summary of the data.

g. Information Needed Before Buying Solar

The survey asked participants to name the type of information they would need before selling/using photovoltaically powered equipment.

As potential manufacturers of solar cathodic protection equipment, respondents cited the following items: break-even cost of conventional equipment (since all terminals have access to electrical systems); information on reliability, maintenance (and replacement costs); proof of successful test operations and consistent operation; economic justification and vandalism protection. One person said that the arrays would have to be smaller.

As potential users of solar-cell-powered telecommunications equipment, respondents said they would need the following information: assurance

Added Cost Due to Solar:	\$2,000	\$1,000	\$0.0	\$2,000	\$1,000	\$0.0
Average Annual Operational Savings:	\$50	\$50	\$50	\$100	\$100	\$100

Market Penetration

Estimates (%):	10	30	90	40	60	90
	0	0	20	0	10	30
	30	50	70	30	50	70
	20	30	60	20	30	60
	5	10	70	10	30	80
	0	0	90	0	20	100

Mean Estimate (%):	10.8	20.0	66.7	16.7	33.3	71.7
Std. Dev.:	12.0	20.0	25.8	16.3	18.6	24.8

FIGURE IV-10
MARKET PENETRATION - TELECOMMUNICATIONS

about the availability of solar cells and a back-up system; proof of reliability and reasonable cost; demonstrated performance, outage statistics; maintenance requirements; economic feasibility studies; more engineering/cost data; and identification of problems and solutions by other users.

h. Other Mailed Questionnaires

i. Small Water Pumps

Respondents to mailed questionnaires indicated that photovoltaically powered water pumps would best be used for watering livestock and for pumping drinking water but would not be useful to small industries. Barriers to acceptance were said to be lack of a guarantee and maintenance problems. One said that a new product with unproven performance requires a great deal of capital and seven years of hard work to promote. Availability in remote locations and portability were prime reasons for using photovoltaic water pumps. Additional information respondents wanted includes reliable market information and performance characteristics.

ii. Electric Vehicles

Small delivery and amusement park vehicles were rated as the best applications of photovoltaically powered electric vehicles. The largest barriers to acceptance were high initial cost and reliability. Respondents also cited the need for night-time charging (necessitating an additional set of batteries) and long-term return on investment. Reasons to accept electric vehicles were cited as reduced power bills and use in remote areas. Additional information needed includes proof of feasibility and information on cost savings, reliability, maintenance and serviceability.

iii. Agricultural Field Devices

Moisture monitors and frost warning devices were rated as the best applications

for photovoltaic agricultural field devices. Barriers to acceptance cited were reliability and vandalism. Also noted was the need for proven reliability, maintenance and scepticism of farmers toward new, not universally sanctioned alternatives. Reasons for acceptance include reduced power bills and usability in remote locations plus interest in energy conservation. Respondents wanted information on costs, life expectancy, packaging, availability of original and replacement parts, and assurance that batteries will not freeze under normal conditions (including discharge at -30°F).

iv. Construction Trailers

Small, independent units intended for exterior locations such as construction sites if they are extremely remote were noted as fair applications for a photovoltaically powered construction trailer. Also noted were such uses as needed in emergencies and natural disasters. Cost and lack of a guarantee were cited as largest barriers to acceptance. Reasons for acceptance noted include use in remote areas, petroleum shortages and dependability. Additional information needed cited includes customer specifications including solar power, proof of reliability of service, cost-savings and customer interest, and legislation - more stringent air pollution regulations - limiting use of fossil-fuel-powered generating equipment.

v. Security Equipment

Security equipment for industrial sites in remote locations was judged to have fair promise. High initial cost was cited as the primary barrier to acceptance. A system large enough to provide power for other equipment was stated as a reason to buy photovoltaically powered security equipment.

No responses to the photovoltaically powered transceiver questionnaire were received.

D. Refinement of Product Design

1. Analysis for Sizing and Optimization

Six applications for photovoltaic markets were chosen for analysis: outside lighting, 50-horsepower irrigation pump, corrosion control, remote radio repeaters, rechargeable portable battery powerpack, and 5-cubic-foot refrigerator.

The analysis for sizing and optimization was performed using a computer program developed by the Institute of Energy Conversion (IEC) at the University of Delaware and certain ITC/Solar subroutines to generate the insolation data. The output data generated describes randomized weather, insolation data, electrical output, battery size, photovoltaic array area, and daily losses (energy collected but not used). The cases were limited to three: worst case, mean area of worst-case data, and half-mean area of worst-case data. Reliability vs. area of array and battery size were calculated, as well as system cost tradeoffs, using the photovoltaic irrigation system as an example. The dependence of system sizing on location of system installation indicates the need to localize applications. Sites chosen were deemed to be representative of the locations where related applications might be needed.

By trading off area of array for battery size, one can optimize the cost of a system for each individual application without sacrificing reliability. This is accomplished by feeding forward the previous day's losses (energy collected but not used) into excess battery capacity. Value engineering logic led to final configurations different from the original models.

a. Computer Program

As a further outgrowth of this project, ITC/Solar and the University of Delaware have developed computer programs to aid in the development and

application of solar thermal and solar electric systems. Operation of these programs is either in an automatic mode or in a conventional manual interaction mode. Input/Output and Flow are shown in the accompanying computer program description and program flow chart presented in Appendix III-E. Both beam and diffuse components are considered in this program. Daily, monthly and yearly data are generated for array area, battery capacity, loss, even where only monthly data are available for insolation values. The number of sun-days for a given month are also generated. Given an input load requirements and profile, one can generate all the necessary data for sizing, orientation and energy management of both array and storage. Careful observation of the outputs permits optimization of array and storage sizes with respect to the reliability of the system.

The model for the photovoltaic/storage/load system is predicated on the basis of a schematic shown in Figure IV-11. By comparing the program flow chart of Appendix III-F, one can identify the input and output data configuration of the program.

b. Worst-Case Analysis

Worst-case analysis is defined as the matching of array area sufficient to charge a battery (the capacity of which is equal to one day's operation of the load under prescribed profile conditions) on the day before the worst day of the year and replenish the storage on the day following this worst day. This output sizing ensures 100-percent reliable operation for day/weather insolation variations with base data derived from the 1972 ASHRAE Handbook of Fundamentals (used for the data base for all analyses contained in this project report).

Data obtained from this analysis are contained in Tables IV-19 through IV-24. Assumptions for load profiling are given at the head of each table.

FIGURE IV-11: SOLAR ELECTRICAL SYSTEM

c. Preliminary Optimization

The data obtained for worst case are, by nature, not optimized data with respect to tradeoff between array area and battery capacity. In order to look at optimization via tradeoff, mean area of array was calculated

$$\sum_{i=1}^{12} \frac{\text{worst case day area for month}}{12}$$

Half-mean area was this number divided by two.

By increasing battery capacity and forward feeding the daily losses into the excess battery capacity, operation with 100-percent reliability can be obtained with mean and half-mean worst-case area. For reasons of economy and time of contract, fully optimized battery size was not calculated. Double battery size was deemed useful for both mean area and half-mean areas in most cases.

A single optimization involving the irrigation system was performed. For worst-case data, array area vs. reliability was determined. These data are plotted in Figure IV-12. Figure IV-13 depicts the tradeoff between array area and battery size for 100-percent reliable operation of the irrigation system. Figure IV-14 shows the array area/battery capacity tradeoff for various costs of array (13-percent efficiency) area and battery capacity. Conclusions to those are given in the following section.

d. Conclusions

An observation of the general properties of the solar-powered systems leads to one very obvious conclusion: randomization of weather patterns is the greatest factor in sizing of a solar photovoltaic system. In "real" weather as well as in "simulated" weather, the single worst-day insolation for the year (R factor) can be an order of magnitude worse than the next-worse day.

FIGURE IV-12: IRRIGATION (RELIABILITY-AREA)

FIGURE IV-13: IRRIGATION
BATTERY SIZE VS. AREA OF ARRAY FOR 100% RELIABILITY

Secondly, for uses that are sun-dependent for their deployment, such as irrigation and the portable power pack, usually, if there is no sun, there is no need. Therefore, worst-day conditions may not be the real basis for worst-case calculations, thereby easing the area requirements for the array.

The program structure and schematic representation both provide that the battery is run in a constant charge (float) mode, which implies that minimum regulation is needed. This results in minimum deep discharge favoring both cost and reliability.

For all cases studied, it is assumed that the system storage starts with full charge on day one. This, by its nature, eliminates randomization effects on the system startup.

In evaluating the output data of the program, a number of points should be kept in mind:

- 1) Accuracy of the output data generated is about one percent.
- 2) Randomization produced correlates well with actual weather patterns observed.
- 3) Isotropic radiation only is considered in this project.
- 4) For simplicity and uniform comparison, all of the runs were made at these angles. Tilts other than 0° and latitude can be evaluated. For partial year usage, tilt must be averaged for time of year, i.e., irrigation.
- 5) Values in the first program are absolute worst-case values (see Section F-b). If risk of none or partial operation is allowable, then array size may be cut using next worst-case-day data.

e.g. days totally lost:	$\frac{1}{365}$	$\frac{2}{365}$	$\frac{3}{365}$
% "up time":	99.726	99.452	99.178

6) Orientation can be entered as input data but has not been done for this program run; only south facing data are given.

i. Irrigation

Array area required for worst-case operation (see Table IV-19) is about 2,500 m² with battery capacities on the order of 331 kilowatt-hours. By increasing the battery capacity to 662 kilowatt hours, the area requirement for the array becomes a 510 m². If half this area is used, one need only increase the battery capacity to 728 kilowatt-hours to maintain 100-percent reliable operation. Using these data coupled with the ERDA cost projections for solar arrays at 13-percent array efficiency, one obtains a series of cost tradeoffs (Figure IV-14) showing that until the array cost drops below \$2/peak watt, it is more economical to add battery capacity and decrease array area for the irrigation application as calculated.

In order for this application to be really economical, the system must be utilized on a year basis--probably for electric vehicles or space heating for animals or humans.

On days of excess loss (unused insolation), pumped water storage (tower) should be used--an overall 66-percent efficient recovery of losses. Depending on capacity, this can be used entirely in place of a battery storage.

By using smaller horsepower motors, e.g. 5, 10, 25 in groups, these individual motors can be turned on dependent upon soil needs resultant from lower evaporation rates or poor sun-days.

ii. Remote Repeater

As can be seen from the analysis (Table IV-20), the constant load of 200 watts increases the system size appreciably. Reduction of days of storage required also directly affects the size of the system. Using a

FIGURE IV-14: ARRAY AREA/BATTERY CAPACITY TRADEOFF, IRRIGATION
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lower-power repeater with better terminal receiver detectivity would make the system more economical.

Worst-case areas are untenable in the light of present system costs. However, one-half mean area considerations coupled with lower-power repeaters would make the application quite viable.

Quarterly adjustments for tilt would lower the area requirement by 15-percent and so should be employed as part of a regular maintenance check.

iii. Outside Lighting

From the data generated, one can see that the cloudier weather areas, such as New York, do not lend themselves readily to such installations. However, certain procedures can alleviate some of these difficulties.

If direct current can be used, the elimination of the converter lowers the area requirement appreciably.

The use of five flood lamps (11.8 v @ 33.6 watts) instead of one 175-watt bulb would give more coverage and higher system reliability.

By using photoelectric turn on/off, the real on time and power consumption can be reduced. Using feedback from storage monitors, one can phase-modulate SCR power controllers to storage remaining thereby reducing both area and storage needs dictated by worst-day considerations.

iv. Corrosion Protection

This application is seriously affected by worst-day considerations. If storage requirements can be relaxed, the system cost can be appreciably reduced.

Modular design dictated by area of corrosion to be protected would provide add-on protection capability.

Tilt and orientation adjustments could reduce array area by 20 percent.

Considerations of mean and half-mean array area are the most promising approaches to viability for this system. The economics are proper for implementation of this system.

v. Refrigerator

If the refrigerator is to be portable, the analysis would appear to show a lower-than-expected viability of the application. However, the advent of newer and better insulation and more efficient refrigeration could help this application greatly.

Secondly, top-lid refrigeration makes best use of the convection flow and yields less loss in refrigeration.

Thirdly, batteries could be eliminated or dropped to a single backup battery if, during the "sun" hours, ice could be made and stored for both cooling and ice use. Approximately ten pounds of water can be cooled per hour to form ice at the 1,400 watts specified. This would yield a maximum utilized cycle with minimum loss and waste of insolation.

vi. Portable Power Pack

Little needs to be said regarding this application other than the fact that the system should fully charge one battery before moving on to the next.

The southern climates are ideal showing changing rates five to seven batteries per month/m² of array. Even New York with lower insolation charges three to six batteries per month/m² of array.

Modularizing the system according to capacity and applying standard electronic switching (at full charge) to the next battery make this application a very viable system.

TABLE IV-19
IRRIGATION

Assumptions

50 h.p. pump, constant load,

1 day storage; 2 1/2 hrs/day; El Paso, Tx. test case; April to August;

some crop drying mid-September through mid-October.

Worst Case

Tilt (°) =	0	Latitude	Lat - Decl
Area (m ²)	2525	2524	2500
Batt. Cap. (watt-hrs)	3.31×10^5	3.31×10^5	3.31×10^5
Number of Batt.	276	276	276

Mean Array Area

Tilt (°) =	0	Latitude	Lat - Decl
Mean Area (m ²)	510	510	508
Batt. Cap. (days lost) (watt-hours)	3.31×10^5 (2)	3.31×10^5 (2)	3.31×10^5 (2)
Batt. Cap. (no days lost) (watt-hours)	6.62×10^5	6.62×10^5	6.62×10^5
Number of Batt.	552	552	552

1/2 Mean Array Area

1/2 mean area (m ²)	255	255	254
Batt. Cap. (days lost) (watt-hours)	3.31×10^5 (26)	3.31×10^5 (20)	3.31×10^5 (18)
Batt. Cap. (no days lost) (watt-hours)	7.28×10^5	7.28×10^5	7.28×10^5
Number of Batt.	607	607	607

TABLE IV-20
REMOTE REPEATER

Assumptions:

Edmonton, Alberta, Canada, load constant, 2, 3, 4 day storage - 200 watt continuous load.

Worst Case

Batt. Stg. (Days)	2		3		4	
Tilt (°) =	0	Latitude	0	Latitude	0	Latitude
Area (m ²)	2836	2836	4254	4254	5672	5672
Batt. Cap.	1.44x10 ⁴	1.44x10 ⁴	2.16x10 ⁴	2.16x10 ⁴	2.88x10 ⁴	2.88x10 ⁴
	12 batt.		18 batt.		24 batt.	

Mean Array Area

Batt. Stg. (Days)	2		3		4	
Tilt (°) =	0	Latitude	0	Latitude	0	Latitude
Mean Area (m ²)	652	635	978	952	1304	1270
Batt. Cap. (days lost) (watt-hrs)	2.88x10 ⁴ (5)		2.16x10 ⁴ (5)		2.88x10 ⁴ (5)	
Batt. Cap. (no days lost) (watt-hrs)	2.88x10 ⁴		4.32x10 ⁴		5.76x10 ⁴	
Number of Batt.	24		36		48	

TABLE IV-20 (CONTINUED)

<u>1/2 Mean Array Area</u>						
1/2 Mean Area (m ²)	326	318	489	476	652	635
Batt. Cap. (days lost) watt-hrs)	1.44x10 ⁴ (10)		2.16x10 ⁴ (10)		2.88x10 ⁴ (10)	
Batt. Cap. (no days lost) (watt-hrs)	2.88x10 ⁴		4.32x10 ⁴	-	5.76x10 ⁴	
Number of Batt.	24		36		48	

TABLE IV-21
OUTSIDE LIGHTING

Assumptions:

1 night plus 1 night storage; El Paso, Tx. and New York, N.Y.; light runs every day of the year; 175 watt bulb (or multiple smaller wattage bulbs).

Worst Case

<u>El Paso, Tx.</u>	<u>With Converter</u>		<u>Without Converter</u>	
Tilt (°) =	0	Latitude	0	Latitude
Area (m ²)	66	60	47	42
Battery Cap. (watt-hrs)	7000	7000	4900	4900
	6 batt.		4 batt.	

Worst Case

<u>New York, NY</u>	<u>With Converter</u>		<u>Without Converter</u>	
Tilt (°) =	0	Latitude	0	Latitude
Area (m ²)	825	826	578	578
Battery Cap. (watt-hrs)	7000	7000	4900	4900
	6 batt.		4 batt.	

TABLE IV-21 (CONTINUED)

Mean Array AreaNew York, NYTilt ($^{\circ}$) =Mean Area (m^2)Batt. Cap (days lost)
(watt-hrs)Batt. Cap (no days lost)
(watt-hrs)

Number of Batteries

Without Converter

0

Latitude

510

510

 4.9×10^3 (2) 4.9×10^3 (2) 9.8×10^3 9.8×10^3

8

8

1/2 Mean Array Area1/2 Mean Area (m^2)

Batt. Cap (days lost)

Batt. Cap (no days lost)

255

255

 4.9×10^3 (4) 4.9×10^3 (4) 9.8×10^3 9.8×10^3

TABLE IV-22
CORROSION PROTECTION

Assumptions:

.El Paso, Texas and Oklahoma City; every day of the year at constant or near constant load - 6 V @ 5A; 3, 10, 25 day storage.

Worst Case

El Paso

Batt. Stg.	3		10		25	
(Days)						
Tilt (°) =	0	Latitude	0	Latitude	0	Latitude
Area (m ²)	22.4	22.5	74.7	75.0	186.7	187.5
Batt. Cap.	2.88x10 ³	2.88x10 ³	9.6x10 ³	9.6x10 ³	24x10 ³	24x10 ³
(watt-hrs)						
	3 batt.		8 batt.		20 batt.	

Worst Case

Oklahoma City

Batt. Stg.	3		10		25	
(Days)						
Tilt (°) =	0	Latitude	0	Latitude	0	Latitude
Area (m ²)	699	699	2330	2329	5025	5022
Batt. Cap.	2.88x10 ³	2.88x10 ³	9.6x10 ³	9.6x10 ³	24x10 ³	24x10 ³
(watt-hrs)						
	3 batt.		8 batt.		20 batt.	

TABLE IV-22 (CONTINUED)

Mean Array Area

Batt. Stg.	3		10		25
(Days)					
Tilt (°) =	0	Latitude	0	Latitude	0
Mean Area (m ²)	81.4	80.5	271.3	268.3	678.3
Batt. Cap. (days lost)	2.88x10 ³ (1)		9.6x10 ³ (1)		24x10 ³ (1)
Batt. Cap. (no days lost) (watt-hrs)	5.76x10 ³		1.92x10 ⁴		4.8x10 ⁴
Number of Batt.	6		16		40

1/2 Mean Array Area

Batt. Stg.	3		10		25
(Days)					
Tilt (°) -	0	Latitude	0	Latitude	0
1/2 Mean Area (m ²)	40.7	40.2	135	134	339
Batt. Cap. (days lost)	2.88x10 ³ (2)		9.6x10 ³ (3)		24x10 ³ (3)
Batt. Cap. (no days lost) (watt-hrs)	5.76x10 ³		1.92x10 ⁴		4.8x10 ⁴
Number of Batt.	6		16		40

TABLE IV-23
REFRIGERATOR

Assumptions:

1 day storage; 1400 watt-hrs/day; Phoenix, Arizona; tilt = lat and horizontal

Worst Case

Phoenix, Arizona

Tilt (°) =	0	Latitude
Area (m ²)	19.8	15.3
Batt. Cap. (watt-hrs)	3890	3890
Number of Batteries	3	3

Mean Array Area

Tilt (°) =	0	Latitude
Mean Area (m ²)	13.4	12
Batt. Cap. (days lost) (watt-hrs)	3.89×10^3 (11)	3.89×10^3 (8)
Batt. Cap. (no days lost) (watt-hrs)	7.78×10^3	7.78×10^3
Number of Batteries	6	6

1/2 Mean Array Area

	6.7	6
Batt. Cap. (days lost) (watt-hrs)	3.89×10^3 (30)	3.89×10^3 (28)
Batt. Cap. (no days lost)	9.73×10^3	9.73×10^3
Number of Batteries	8	8

TABLE IV-24
PORTABLE POWER PACK

Assumptions:

Battery: 6 V. @ 360 amp - hrs. or

12 V. @ 180 amp - hrs.; charge one battery fully before proceeding to the next.

Locations: Tampa, Florida and New York, N.Y.

Solar Array: Tilt = latitude - declination angle for month.

Orient = 0° (south)

Definitions:

$BM = (\text{Batteries}/M^2 \text{ of array})/\text{month}$

$A = (M^2 \text{ of array})$ Required to charge one battery on worst day of month.

$B = (\# \text{ of batteries})/\text{month}$ when area of solar array is equal to A for the entire month.

Values used for these quantities are on the next page.

TABLE IV-24 (CONTINUED)

Tampa, Florida

<u>Month</u>	<u>BM</u>	<u>A</u>	<u>B</u>
1	6.33	26.48	167
2	5.96	35.20	209
3	6.50	25.95	168
4	6.47	17.79	115
5	7.20	16.13	116
6	6.74	14.70	99
7	6.45	1364.52	8799
8	6.03	104.32	629
9	5.73	22.88	131
10	6.08	23.94	145
11	6.39	21.83	139
12	6.08	24.84	150

New York, NY

1	3.30	129.93	428
2	3.78	72.75	275
3	4.79	61.20	292
4	4.78	318.56	1521
5	5.65	27.00	152
6	6.16	39.29	241
7	6.24	99.50	621
8	5.41	83.12	449
9	5.02	88.42	443
10	4.73	93.18	440
11	3.36	157.99	531
12	3.12	2205.05	6883

2. Final Product Design

Concurrent with sizing and optimization analyses for final product specifications, specific design features were developed for the four selected applications: irrigation pumping, portable refrigeration, outside lighting and battery charging. Design criteria were set by the computer program previously described (D.1) and marketability was based on the reaction of manufacturers and users obtained through the survey process.

These products' designs go beyond the simple addition to an existing product of a solar cell array and associated circuitry and storage. Innovations, styling, flexibility and portability were incorporated into the designs to provide lower first cost and buyer appeal in the current market. In addition, materials and manufacturing techniques were taken into consideration during the design process.

The design for the irrigation system is an example of the use of modularity to increase product flexibility. The modular (Figure IV-15) system may be based on a smaller sized pump, say 25 horsepower, to provide a product for users having smaller irrigation requirements or to allow for variations in pumping requirements. In addition, modules may be phased into the system as finances become available. For the requirements of corporate-owned farms, predicted by interview respondents as the most likely first market in the United States, the 50-horsepower pump might be augmented by additional 50-horsepower modules to meet the demands of different kinds of operations. Furthermore, the irrigation assembly with its self-contained array transport case provides for changes in the location within a given farming situation.

FIGURE IV-15
MODULARIZED IRRIGATION PUMPING SYSTEM

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Several styling and functional improvements were incorporated into the final design of the photovoltaically powered battery charger (Figures IV-18 and IV-19). All components of the system - charging unit and array - are self-contained and protected in two packages. Two changes in their designs increased the system's portability: the sides of the charger unit fold down to serve as platforms for batteries and can be closed for transport. The array panels are also foldable. The capability of the system was increased to permit charging two 12-volt batteries at the same time. Plus, a third, small-battery charging compartment was incorporated into the design, giving the system greater flexibility.

The modular concept was also used in the design of the photovoltaic outdoor lighting system. To increase the system's effectiveness as a security device, use of more than one high-intensity, low-voltage lighting unit has been specified. This change makes it possible to have some lighting at all times, even when energy from the day's insolation falls short of the requirement for illuminating the full system (Figure IV-20).

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SELF-CONTAINED ARRAY
AND TRANSPORT CASE

ARRAY TRANSPORT CASE

FOLD-UP SUPPORTS
(STORE IN WELL
IN TRANSPORT CASE)

FIGURE IV-18
FOLDING PHOTOVOLTAIC ARRAY FOR
BATTERY CHARGER

FIGURE IV-19
PORTABLE BATTERY CHARGER UNIT

FIGURE IV-20
MODULAR OUTSIDE LIGHTING SYSTEM

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V. PRODUCT/MARKET SCENARIO

A. Introduction

In the preceding section of this study, four photovoltaic products were identified as products likely to generate significant markets: the 12-volt battery charger, small refrigerator, outside lighting system, and 50-horsepower pump for irrigation. The high market potential assigned to these products was based upon estimates of capture potential or engineering judgments or both. The reactions of potential manufacturers and users during the product/market study, as well as the estimated demand for these products indicated that isolation of these four products for in-depth study would be desirable.

Based on the marketing promise of these four products and potential uses, then, the assignment in the final phase of this market analysis was to develop detailed product descriptions of each of the four products above and to develop detailed product/market scenarios. The scenarios were to include identification of markets for each product, market penetration estimates, sales forecasts, probable marketing barriers and various methods of innovating upon or improving existing marketing strategies. The results of the work during this task is presented below.

B. Detailed Product Description

Verbal and pictorial descriptions of the battery charger, refrigerator, outdoor lighting system and irrigation pump system were developed in Task III and may be found in Appendix III-A and in Section IV-D of this report.

Specifications for the products are summarized in Tables V-1 through V-4. The solar cell panel size is given for six constant performance insolation regions of the United States. These are described in more detail in Section V.C below.

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TABLE V-1
BATTERY CHARGER

Physical Specifications

Insolation Region	<u>Size</u>	<u>Weight</u>	
	(ft ²)	Solar Array (lb)	Array Support (lb)
Region I	34	97	48
Region II	28	81	39
Region III	25	73	35
Region IV	23	67	32
Region V	21	61	29
Region VI	18	52	25

Electrical Specifications

Component	Basic Specifications			Average Continuous Load	Annual Energy Output	Peak Watt Rating
	<u>(Volt)</u>	<u>(Amp)</u>	<u>(Amp-Hr)</u>	<u>(W)</u>	<u>(kWh)</u>	<u>(W_p)</u>
Solar Array	12	3.8	90	50	600	288
Secondary Battery	NA	NA	NA	NA	NA	NA
Charger Unit	12	3.5	90	50	600	288

NA: Not Applicable

TABLE V-2
SMALL REFRIGERATOR

Physical Specifications

Insolation Region	<u>Size</u>	<u>Weight</u>		Total
	(ft ²)	Solar Array (lb)	Array Support (lb)	
Region I	34	97	48	145
Region II	28	81	39	120
Region III	25	73	35	108
Region IV	23	67	32	99
Region V	21	61	29	90
Region VI	18	52	25	77

Electrical Specifications

Component	Basic Specifications			Average Continuous Load	Annual Energy Output	Peak Watt Rating
	(Volt)	(Amp)	(Amp-Hr)	(W)	(kWh)	(W _p)
Solar Array	12	3.8	-	50	600	288
Secondary Battery	12	3.8	90	50	600	-
Refrigerator Unit	12	3.8	-	42	-	-

TABLE V-3
OUTSIDE LIGHTING

Physical Specifications

Insolation Region	<u>Size</u>	<u>Weight</u>		Total
	(ft ²)	Solar Array (lb)	Array Support (lb)	
Region I	68	197	95	292
Region II	56	162	78	240
Region III	50	145	70	215
Region IV	46	133	64	197
Region V	42	122	59	181
Region VI	36	104	50	154

Electrical Specifications

Component	Basic Specifications			Average Continuous Load	Annual Energy Output	Peak Watt Rating
	(Volt)	(Amp)	(Amp-Hr)	(W)	(kWh)	(W _p)
Solar Array	12	15.0	-	175	766	576
Secondary Battery	12	15.0	175	175	766	-
Lighting Unit	-	-	-	175	-	-

TABLE V-4
IRRIGATION PUMP

Physical Specifications

Insolation Region	<u>Size</u>	<u>Weight</u>		
	(ft ²)	Solar Array (lb)	Array Support (lb)	Total (lb)
Region I	2127	6168	2978	9146
Region II	1742	5051	2439	7490
Region III	1580	4582	2212	6794
Region IV	1480	4292	2072	6364
Region V	1355	3930	1897	5827
Region VI	1134	3288	1588	4876

Electrical Specifications

Component	Basic Specifications			Average Continuous Load	Annual Energy Output	Peak Watt Rating
	<u>(Volt)</u>	<u>(Amp)</u>	<u>(Amp-Hr)</u>	<u>(W)</u>	<u>(kWh)</u>	<u>(W_p)</u>
Solar Array	96	500	-	48000	38000	18240
Secondary Battery	96	400	1000	-	-	-
Irrigation Pump	-	-	-	46000	35000	-

C. Segmentation of the Market

As shown by the marketing survey, the added first cost difference is the key factor in segmenting the market for photovoltaic products. One variable in this added first cost is the distance between the given application and the electrical grid. Similarly, the value of the photovoltaic product to the buyer can also be seen in terms of distance from the grid--the tradeoff in terms of the buyer's independence from conventional power sources and the estimation of operating costs associated with those power sources.

An exhaustive study of how many potential buyers of photovoltaics are removed from the grid, and of the actual distances that separate the buyers from the grid, is beyond the scope of this project. Instead, certain realistic assumptions can be made about the most likely market segments for the given product. For each photovoltaic product, it is probable that, as the distance from the grid increases, market penetration will also increase. But, the number of users of the product will decrease as the distance from the grid increases. So, the number of potential sales of photovoltaic products will be expected to reach a maximum depending on the shape of the distribution curve (describing the increasing penetration and decreasing number of users with distance). This concept can be described very generally by the qualitative curves shown in Figure V-1. Scenarios for several likely applications of photovoltaics follow.

1. Scenarios for Applications of the Four Products

a. Battery Chargers

A likely market for 12-volt photovoltaically powered battery chargers could develop for carpentry, gardening and automotive projects in which power tools, garden or automotive equipment could be run off the battery charger instead of electricity or a gasoline generator.

FIGURE V-1

QUALITATIVE OVERVIEW OF RELATIONSHIP BETWEEN
SALES FORECASTS AND DISTANCE FROM GRID

If, for example, the power tools were run by a 3.5 horsepower gasoline generator, a first cost of \$300 would be encountered. The use of photovoltaics instead of the generator would save approximately \$250 per year in operating costs (maintenance, energy, etc.) Were the location of the tool shed 200 feet away from an electrical outlet, the initial cost of running an underground cable to the shed would be about \$580, based on a cost of \$1.89 per foot of cable plus a \$175 fixed cost for connection and installation. The use of the photovoltaically powered charger would then save about \$25 in annual energy costs ($\$.05/\text{kwh} \times 500 \text{ kwh}$).

b. Outside Lighting

A likely market for a photovoltaically powered outside lighting system would be security lighting for construction and industrial offices in remote locations. For an office located 1,000 feet from electrical power, the cost of installing an electric cable would be \$2,100, based on a cost of \$1.89 per foot of cable plus \$175 for fixed installation charges. Using the photovoltaic system would save approximately \$20 annually in operating expenses ($175 \text{ W} \times 10 \text{ hrs/day} \times 365 \times .05$). Or, if the office were located only 200 feet from the grid, the cost of installing the cable would be approximately \$550 and the photovoltaic system would still save \$20 annually.

c. Refrigeration

One of the better markets for a photovoltaically powered refrigerator of four-to eight-cubic foot capacity would be remote vacation houses and cabins. If the cabin were located 500 feet from the grid, the cost of running cable to the cabin would be about \$1,200 based on the cost of \$1.89 per foot of cable plus the fixed installation charge of \$175. Using the photovoltaic system would produce annual operating savings of \$20 based on the figure of $\$.05/\text{kwh}$.

d. Irrigation

The most promising market for photovoltaically powered irrigation pumps was judged to be the corporately owned factory farm with a managerial

staff. Since in 1974, for example, 86% of the power for irrigation was derived from electricity, natural gas and diesel fuel (7), the scenarios summarized in Exhibit V-1 were developed.

2. Regional Differences in Cost of Photovoltaic Systems

Photovoltaic system costs for the four products, 12-volt battery chargers, outside lighting, refrigeration and irrigation, were calculated for six constant-performance solar regions of the United States.* Figure V-1 maps these regions. Relevant insolation and weather data for representative cities in these six regions are summarized in Table V-5.

Sizing of the photovoltaic panels was adjusted according to insolation in the six regions starting with the basic sizes listed below. Battery storage requirements are listed as well. As mentioned in Section IV.2a, a panel efficiency of 13% was assumed.

	Product			
	Battery Charger	Small Refrigerator	Outside Lighting	Large Irrigation
Panel Size (ft ²)	24	24	48	1520
Battery Storage (kWh)	0	1	2.5	125

Initial cost was calculated for each of the applications as follows.

EQUATION V-1:

$$\text{COST (I)} = [\text{COST PER PEAK WATT (I)} * \text{PEAK WATTS} * \text{DEALER MARKUP} + \text{STRUCTURAL COST PER SQUARE FOOT} * \text{AREA} + \text{BATTERY COST PER KILOWATT-HR} * \text{KILOWATT-HR OF STORAGE} + \text{POWER CONDITIONING COST PER PEAK WATT} * \text{PEAK WATT}]$$

End-of-the-year ERDA price goals of Table IV-2 were used to obtain the cost per peak watt over the required time span.

*InterTechnology Corporation, Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat. ERDA C00/2829-76/1, February 1977.

INTERTECHNOLOGY CORPORATION
Box 340
Warrenton, Virginia 22186, U.S.A.

REGION I II III IV V VI

FIGURE V-2: CONSTANT PERFORMANCE SOLAR REGIONS OF THE U.S.

TABLE V-5

WEATHER DATA AND PANEL SIZING BY CONSTANT PERFORMANCE
SOLAR REGION

Region	Representative City	Annual Insolation* (kBtu/ft ² /yr)	Annual Average Ambient Temperature (°F)	Product			
				Battery Charger	Small Refrigerator	Outside Lighting	Large Irrigation
I	Schenectady, NY	393	50.3	34	34	68	2127
II	Madison, WI	480	45.5	28	28	56	1742
III	Lincoln, NE	529	55.8	25	25	50	1580
IV	Stillwater, OK	565	64.2	23	23	46	1480
V	Fort Worth, TX	617	65.8	21	21	42	1355
VI	El Paso, TX	737	63.3	18	18	36	1134

* For fixed collector tilted at latitude angle.

In all cases, the following parameters were used in Equation V-1.

Structural Cost per Square Foot = \$1.50/ft²

Battery Cost per Kilowatt-Hour = \$50/kWh

Dealer Markup = 1.20

Power Conditioning Cost per Watt = \$0.05/Wp

The initial cost differences between the photovoltaic systems and selected power systems are presented in Appendix III-H (Table III-H-2). For each alternative power system for a given application there is a value for annual operating cost savings.

FIGURE V-3

PV POWERED 12 VOLT BATTERY CHARGER SYSTEM COST
BY U.S. INSOLATION REGION

FIGURE V-4

PV - POWERED
OUTSIDE LIGHTING SYSTEM COST
BY U.S. INSOLATION REGION

FIGURE V-5

PV - POWERED
REFRIGERATOR SYSTEM COST
BY U.S. INSOLATION REGION

FIGURE V-6

PV - POWERED
LARGE IRRIGATION SYSTEM COST
BY U.S. INSOLATION REGION

D. Market Penetration Predictions

As noted in Section IV.C.2.d, Methodology for Market Penetration, demand functions expressing the consensus of interview responses from industry decision-makers form the basis of market penetration estimates. For quantitative estimates, values for initial solar costs and operating cost savings over alternative power sources must be projected since the demand functions are dependent upon these factors. The projected values of X_i (initial cost differences) and the values of Y_i (operating cost savings) used to estimate the market penetration curves were calculated for the scenarios described in Section V.C.1, Scenarios for Applications of the Four Products. See Table III-H-1 of Appendix III-H for these values.

Additionally, the product life-cycle must be included in the analysis. In Appendix III-E, a mathematical model which merges the demand functions with the typical product life-cycle curve is detailed. This model incorporates into the market penetration function a function which describes the introductory period of the product life-cycle in terms of the time from introduction to the displacement time or time at which late growth, early maturity is reached (see Figure IV-8). To provide a flexible methodology, the displacement time is defined across a range of minimum to maximum, chosen so as to reasonably include the true value of the displacement time. The values of $t_{\min}$ and $t_{\max}$ for the four products are presented in Appendix III-H (Table III-H-2).

Plots of market penetration projections for the total United States market weighted by regional market size estimates are presented in Figures V-7 through V-11. Table V-6 summarizes the data for the curves. Regional weighting factors are based on the relative proportion of population in the six constant-performance insolation regions. For battery chargers and outside lighting rural population ratios were used

as the basis; for small refrigerators total population ratios used as the basis; and for irrigation applications, acreage under irrigation was used as the basis of choosing the weighting factors. Table III-H-3 of Appendix III-H summarizes the data used.

The predicted saturation year varied not only by application, but also by region; thus showing the effect of varying insolation characteristics. Time to saturation ranged from 4.2 years after 1976 for PV battery chargers replacing a gasoline generator in Region VI to 9.4 years for PV powered irrigation pumps replacing electrically powered pumps in Region I. Variation in saturation time for most applications is one to two years. Predicted saturation years are summarized in Table V-6A.

The resulting market penetration projections shown in the following tables and curves indicate a sharp take-off when break-even cost is reached. These steep curves might be expected in light of the rapid drop in cost goals. Additionally, the curves indicate that penetration is relatively insensitive to tax credits in the case of lighting and irrigation.

TABLE V-6A
UNITED STATES MARKET PREDICTIONS BY APPLICATION

Year	LIGHTING				BATTERY CHARGERS	
	Application 1		Application 2		Application 1	Application 2
	<u>No Tax Credit</u>	<u>Tax Credit</u>	<u>No Tax Credit</u>	<u>Tax Credit</u>		
1	0.0	0.0	0.0	0.003	1.285	0.0
2	0.0	0.275	0.0	0.0645	5.256	0.0
3	0.904	0.756	0.003	0.311	11.808	0.0015
4	1.776	3.641	0.117	0.852	20.510	0.1005
5	17.295	21.119	0.881	2.105	43.878	1.897
6	95.758	99.484	2.712	4.452	93.0	10.165
7	100.0	100.0	6.495	8.909	100.0	50.340
8	100.0	100.0	13.685	17.026	100.0	99.830
9	100.0	100.0	27.761	32.616	100.0	100.0
10	100.0	100.0	42.680	48.846	100.0	100.0

TABLE V-6A (CONT'D)

IRRIGATION

<u>Year</u>	<u>Application 1</u>			<u>Application 2</u>		
	<u>Tax Credit</u>			<u>Tax Credit</u>		
	\$0.00	\$2000	\$4000	\$0.00	\$2000	\$4000
1	0.34	0.34	0.34	0.30	0.31	0.39
2	1.36	1.36	1.37	1.27	1.28	1.29
3	3.04	3.10	3.15	2.76	2.81	2.86
4	5.30	5.47	5.62	4.72	4.88	5.04
5	8.19	8.60	8.60	7.10	7.50	7.91
6	11.65	12.50	13.35	9.77	10.59	11.40
7	15.84	17.22	19.01	12.67	14.15	15.62
8	20.75	23.42	26.09	15.69	18.07	20.61
9	26.24	30.36	34.48	18.59	23.28	25.47
10	28.65	33.46	38.27	20.19	24.33	28.47

TABLE V-6A (CONT'D)

IRRIGATION (CONT'D)				REFRIGERATION
	Application 3			Application
<u>Year</u>	<u>Tax Credit</u>			
	\$0.00	\$2000	\$4000	
1	0.46	0.46	0.46	0.015
2	1.87	1.88	1.90	0.423
3	4.15	4.28	4.33	2.208
4	7.17	7.43	7.68	7.411
5	11.01	11.63	12.25	31.922
6	15.62	16.88	18.14	80.528
7	21.39	23.75	26.11	100.0
8	28.82	32.92	37.01	100.0
9	39.84	46.78	53.71	100.0
10	50.10	59.69	69.29	100.0

TABLE V-68
PREDICTED SATURATION YEAR BY APPLICATION AND REGION

<u>APPLICATION</u>	<u>REGION</u> (SATURATION YEAR AFTER 1976)					
	I	II	III	IV	V	VI
Battery Chargers, App. 1	6.7	5.4	5.2	5.0	4.8	4.2
Battery Chargers, App. 2	8.5	8.2	7.6	7.3	7.2	6.6
Lighting, App. 1	5.9	6.3	5.4	5.1	5.3	4.9
Lighting, App. 2	9.8	9.8	9.7	9.6	9.6	8.7
Irrigation vs Elec.	9.4	8.6	8.6	8.6	8.1	7.7
Irrigation vs Gas.	7.1	9.0	9.0	9.0	8.9	8.9
Irrigation vs Oil	9.3	9.3	9.3	9.3	9.5	9.3
Refrigeration	6.7	6.3	5.7	5.7	5.3	4.6

FIGURE V-7
MARKET PENETRATION PROJECTION FOR TOTAL U.S. MARKET
BATTERY CHARGERS

FIGURE V-8
MARKET PENETRATION PROJECTION FOR TOTAL U.S. MARKET
LIGHTING, APPLICATION 1

FIGURE V-9
MARKET PENETRATION PROJECTION FOR TOTAL U.S. MARKET
LIGHTING, APPLICATION 2

FIGURE V-10
MARKET PENETRATION PROJECTION FOR TOTAL U.S. MARKET
SMALL REFRIGERATORS

FIGURE V-11A
MARKET PENETRATION PROJECTION FOR TOTAL U.S. MARKET
PV IRRIGATION DISPLACING DIESEL

TC = Tax Credit

FIGURE V-11B
MARKET PENETRATION PROJECTION FOR TOTAL U.S. MARKET
PV IRRIGATION DISPLACING GASOLINE

TC = Tax Credit

FIGURE V-11C
MARKET PENETRATION PROJECTION FOR TOTAL U.S. MARKET
PV IRRIGATION DISPLACING ELECTRICITY

TC = Tax Credit

E. Sales Forecasts

Forecasting the ultimate purchaser's willingness and ability to buy requires an integration of many variables. Demand at a given time is affected by a multitude of factors such as individual socio-economic status, value attitudes, life-style and geographic location. Moreover demand is not unalterable, being affected by such factors as perceptions of the buyer, the communication of information, the political and cultural environment and domestic and foreign policy and regulations. An additional factor to be considered in the case of photovoltaically powered products is buyer reaction to novelty.

In spite of the heterogeneous factors which affect buyers, groups of buyers share attitudes, opinions, reactions, desires and needs. The survey information and penetration analysis have established some common denominators based on the business experience of the respondents.

Using the information garnered about end-uses of the products (but limited by the trade-off between useful data available about end-users and a judgment as to market significance of specific end-user sectors), user segments for each product were identified.

While this study does not include completely segmented sales forecasts for each of the four products, the basic data and methodology for obtaining such forecasts are provided. Using information from manufacturers who must make decisions regarding product marketing based on how customers make purchasing decisions, penetration curves have been constructed for the scenarios identified in Section V.B. For these scenarios we shall develop a sales forecast for a likely segment of the market.

1. Small Refrigerators for Remote Cabins

In 1976, 359,000 compact refrigerators (4 to 8 ft³) were sold.⁽¹⁾

Primary uses for these small units includes remote cabins, recreational

vehicles, college dormitories and second refrigerators for private residences. Among these segments defined by user needs, the segment selected as most likely to provide a near-term market is the remote cabin. According to the proposed scenario, the likely buyer will be one who has an unelectrified cabin. There will be about 207,000 unelectrified cabins in 1986.⁽²⁾ Among these cabin owners there will be a group who will want to preserve environmental integrity and live independently of society for thirty to sixty days of the year. Let us assume that this group shares the socio-economic status and psychogenic characteristics of "innovators" or buyers who first accept new products⁽³⁾. For a conservative estimate we shall assume that this group of buyers constitutes the entire market, rather than simply the early market. This group constitutes 2.5% of the potential purchasers⁽³⁾. Thus we would have a cumulative market for compact refrigerators in small cabins of $207,000 \times 0.025 = 5175$ units or about 1.5 Mwp.

Using an estimated annual total for such unelectrified cabins and the United States market penetration predictions for the refrigeration application of Table V-6, sales for photovoltaically powered compact refrigerators to this market segment may be generated (Table V-7).

2. Small Refrigerators Recreational Vehicles

Another segment of end-users of the compact refrigerator is the owner of the fully self-contained recreational vehicle. The estimated 250,000 to 300,000 recreational vehicles sold each year may be categorized as follows: truck-campers; motor-homes which may be conventional, van conversions or mini-motor homes; fold-down camping trailers and travel trailers, both a conventional type towed by a regular vehicle and a fifth-wheel type towed by a specially designed truck. Among these, conventional motor-homes (known as Type A in the trade), the mini-motor homes (Type C) and travel trailers are self-contained. Conservatively we would expect the more luxurious R/V's such as conventional motor-

TABLE V-7

FORECAST SALES OF PHOTOVOLTAICALLY POWERED COMPACT REFRIGERATORS
FOR REMOTE CABINS

<u>Year</u>	Total Cabins, Unelectrified <u>(Units)</u>	PV Powered Compact Refrigerators			
		Annual Sales		Cumulative Sales	
		<u>(Units)</u>	<u>(MWp)</u>	<u>(Units)</u>	<u>(MWp)</u>
1977	131,000	0	0	0	0
1978	140,000	15	0.004	15	0.004
1979	149,000	80	0.023	95	0.027
1980	158,000	285	0.082	380	0.109
1981	167,000	1210	0.348	1590	0.458
1982	176,000	2260	0.651	3850	1.109
1983	184,500	750	0.216	4600	1.325
1984	192,500	212	0.061	4812	1.386
1985	200,000	188	0.054	5000	1.440
1986	207,000	175	0.050	5175	1.490

FIGURE V-12
CUMULATIVE SALES OF PHOTOVOLTAICALLY POWERED
COMPACT REFRIGERATORS FOR REMOTE CABINS

homes and fifth-wheel travel trailers to constitute the near-term photovoltaic product market. Since the recent annual sales have fluctuated around 45,000 conventional motor homes and 22,000 fifth-wheel type travel trailers⁽⁵⁾, an estimate of annual sales of photovoltaically powered refrigerators will be based on 67,000 luxurious and semi-luxurious R/V units being added each year. A further assumption for this sales forecast is that the potential market will be compact refrigerators for new self-contained recreational vehicles rather than a replacement market. A sales forecast for the recreational vehicle segment of the photovoltaically powered compact refrigerator market is presented in Table V-8 and Figure V-13. This figure also shows the total market for the two compact refrigerator segments: recreational vehicles and remote cabins.

3. Security Lights for Farms

Security lights for farms represent an end-use for outside lighting that can provide a viable near-term market for photovoltaically powered mercury vapor lights. The usual security light is a mercury vapor light installed by the local power company. The customer is charged a flat monthly rate per light (at rates ranging from 10¢ to 14¢ per kilowatt hour) and he may elect to pay the installation cost in a lump sum or pay an additional monthly charge to cover installation costs over a number of years. The wattage selected is based on the area required to be illuminated: a 175 watt light, for example, will illuminate an area with a radius of 55 feet. Poles must be set no more than 150 feet apart. Thus if the security light is 200 feet from the utility line at least one pole must be set at an initial charge of \$125. (This cost is dependent on locality.) Though the initial cost of \$125 is lower than the \$380 cost set for the scenario used for market penetration predictions, the yearly cost of energy is \$72 rather than \$25. No attempt has been made to estimate the proportion of customers who might elect to use underground cable rather than overhead pole-supported lines.

TABLE V-8
FORECAST SALES OF PHOTOVOLTAICALLY POWERED COMPACT REFRIGERATORS
FOR RECREATIONAL VEHICLES*

Year	Recreational Vehicles*	PV-Powered Compact Refrigerators			
	Cumulative Total, (Units)	Annual Sales		Cumulative Sales	
		(Units)	(MWp)**	(Units)	(MWp)**
1977	67,000	10	0.003	10	0.003
1978	134,000	280	0.08	290	0.08
1979	201,000	1,480	0.43	1,770	0.51
1980	268,000	4,965	1.43	6,735	1.94
1981	335,000	21,390	6.16	28,125	8.10
1982	402,000	53,950	15.54	82,075	23.64
1983	469,000	67,000	19.30	149,075	42.93
1984	536,000	67,000	19.30	216,075	62.23
1985	603,000	67,000	19.30	283,075	81.53
1986	670,000	67,000	19.30	350,075	100.82

*Recreational vehicles for this application are limited to conventional motor-homes and fifth-wheel travel trailers.

**Calculated for a photovoltaic array of 288 Wp.

FIGURE V-13
 CUMULATIVE SALES FOR PHOTOVOLTAICALLY POWERED COMPACT REFRIGERATORS
 FOR RECREATIONAL VEHICLES & REMOTE CABINS

Figures for the total number of security lighting units were obtained from the Rural Electrification Administration (REA) for the five-years 1972 through 1976. There is no breakdown of security lighting for farm and non-farm use. However, the distributing companies that report to REA are such that one can assume the vast bulk are farm installations.

<u>Year</u>	<u>Cumulative Total, Security Lights</u>
1972	1,349,952
1973	1,486,200
1974	1,633,451
1975	1,715,000
1976	1,815,176

Regression analysis of these data led to a linear equation with regression coefficient = 99.36.

$$\text{Total units} = 115,925 (\text{year}-1971) + 1,252,181$$

Assuming that new security light installations constitute the potential market, Figure V-14 and Table V-9 were generated.

TABLE V-9

FORECAST SALES OF PHOTOVOLTAICALLY POWERED
SECURITY LIGHTING FOR FARMS

<u>Year</u>	Cumulative Total Farm Security Lights	PV Powered Farm Security Lights Cumulative Sales 200 feet from Grid			
		No Tax Credit		Tax Credit	
	(Units)	(Units)	(MWp)	(Units)	(MWp)
1977	1,947,731	0	0	3	0.002
1978	2,063,656	0	0	78	0.046
1979	2,179,581	3	0.002	438	0.298
1980	2,295,506	138	0.081	1428	1.121
1981	2,411,431	1155	0.746	3868	3.349
1982	2,527,356	4295	3.219	9028	8.549
1983	2,643,281	11825	10.030	19358	19.70
1984	2,759,206	27685	25.977	39098	42.22
1985	2,875,131	59865	60.459	76908	86.52
1986	2,991,056	109365	123.453	133533	163.43

FIGURE V-14
ANNUAL SALES OF PHOTOVOLTAICALLY POWERED
SECURITY LIGHTS FOR FARMS

F. Barriers

The survey of potential manufacturers and users of photovoltaic products summarized in Section IV.C.3 showed that the one overriding concern to be dealt with in gaining market acceptance of photovoltaics is that of high initial cost. Almost as significant were two other barriers: risk that the system might not be reliable or work well and lack of reputable suppliers who will guarantee and/or maintain their products. Of less concern but still identified as barriers were the space consumed by solar units and the risk of vandalism.

Generally, these concerns about photovoltaic products reflect a lack of confidence stemming from the fact that few manufacturers or potential buyers have had access to field test data or demonstration program results. In fact, most respondents to the survey said such information was essential if they were to consider buying or including photovoltaics in their product line. Without test or demonstration program data, potential buyers and manufacturers lack performance data, maintenance histories and requirements, quality control standards, pricing criteria, etc. And, without such programs, there are fewer opportunities for product improvement and price reduction.

Other kinds of barriers to market acceptance were also suggested which have to do with the current climate or attitude toward the "energy problem." Many respondents to the survey noted the public's continuing skepticism about energy conservation and energy costs; the need for alternative energy sources such as photovoltaics has yet to be "sold" to the consumer. Further, some respondents expressed doubts about the projected ERDA price goals for photovoltaics and the Department of Energy's short-and long-term energy development programs; realization of the price goals requires participation in photovoltaic product development now; however, a large portion of potential manufacturers and buyers may wait until peak-watt prices come down before entering the market. Still another problem in gaining acceptance of photovoltaics is institutional.

Communication with those in the financial sector is needed so that adequate capital for initial investment in the products can be made available to the potential manufacturer or buyer. There is probably a need to widen channels for government-sponsored loans, tax credits and benefits for manufacture and installation of the photovoltaic devices.

G. Marketing Strategies and Innovations

For practical reasons, this study is primarily concerned with product development and market growth of photovoltaics. However, the successful entrance of photovoltaics into the marketplace will hinge on careful preplanning for all stages in the life cycle pattern of the products under study. Consideration of the barriers to market acceptance just presented, and analysis of and innovation in photovoltaic product lines and marketing processes are essential for development of the photovoltaic market.

a. Overcoming Market Barriers

As stated in the previous section, the dissemination of field test data and demonstration program results is the key to eliminating consumer skepticism about photovoltaic products, apprehension about their performance and maintenance requirements, and doubts as to their cost/benefits compared with lower-priced and proven alternative power sources.

Information provided by demonstration programs and field tests should not only include technical performance criteria, maintenance requirements, and cost/benefit ratings, but also data on the operation of photovoltaic systems under both normal and extreme conditions. Then, as experience with these systems increases, emphasis should be placed on providing the potential buyer with technical performance standards and quality control guidelines, as well as intelligible instructions for maintenance and repair personnel.

The current photovoltaic experiment with irrigation in Mead, Nebraska, which is being conducted jointly by the Lincoln Laboratory of MIT and the University of Nebraska-Lincoln and funded by ERDA, is the type of demonstration project that should produce a wealth of data and experience useful to potential manufacturers and consumers. Similar programs should be mounted for other photovoltaic systems of interest, such as the outside lighting system, refrigeration units and battery chargers, and the results of these

programs made readily available to members of the suggested market segment.

Once demonstration programs and field experiments with photovoltaics have been mounted, they should play a significant role in creating a climate of acceptance for photovoltaics by increasing the "visibility" of alternate energy programs. Thus, these programs can exert influence upon the more abstract barriers, such as the buyer's current disposition not to purchase photovoltaics, which is controlled by such factors as external environment, lifestyle, perception of the product, expected satisfaction, and purchasing constraints.

b. Product Innovations

Each of the four prime products studied during the final phase of this project is generically linked to several other products, as shown in Appendix III-A. Once the market has been established for 12-volt battery chargers for power tools, for example, expansion of the product line can be explored to include such products as the battery charger for small electrical appliances (radios, tape recorders, calculators, dictaphones), the battery charger for small boats (corrosion protection, radio transceiver, navigational instruments, lights, starter motor preservation), photovoltaic small electric vehicles (forklifts, vehicles for the elderly, recreation carts). Possibilities for expanding the product line for the small refrigeration unit, the pumping units for irrigation, and outside lighting systems, are also suggested by the products included in Appendix III-A.

The modular array concept employed in the design of the irrigation pumping system, for example, should also permit adaptation of the photovoltaic units to meet several needs. The user is permitted a choice of scale of the product, and able to add on to the photovoltaic system as his experience with the system and needs increase.

c. Process Innovations

Several kinds of marketing process innovations are possible to accelerate the growth of the photovoltaic market. One possibility is to provide a new forms of credit to the purchaser of a photovoltaic system, as has been done in the housing industry. Credit with graduated loan payments might be given to the corporate farm, for example, linked with the energy savings produced by the use of photovoltaics, so as to provide the initial capital required for the investment.

Another possible innovation would be to establish rental and leasing opportunities for the user of photovoltaic systems. Such products as the battery charger could easily be rented to the user along with the power tools needed. The leasing arrangement would attract to the market those who are not in a position to buy the equipment, such as a building contractor who needs a construction trailer for a remote building location. Rather than buying or renting a generator, the contractor could lease the photovoltaically powered construction trailer.

Also, consideration should be given to including provisions for photovoltaic installations to such financial mechanisms as construction and operating grants, tax credits to the manufacturer, benefit-in-kind allowances and other forms of government credits.

Finally, experimentation with the larger industrial and agricultural photovoltaic systems, such as irrigation pumps, should generate large-scale production of solar arrays and systems components, reducing the cost over time. Concurrently, introduction of smaller products into the commercial market, such as photovoltaic chargers for electronic gadgets, could sensitize the consumer and expedite commercialization of photovoltaics generally.

d. Summary

As has been shown, the existing barriers to acceptance of photovoltaic systems are classic but not insurmountable. Moreover, the characteristics of the current market indicate potentially high production and sales volumes based on photovoltaic systems' energy-saving capacity and usefulness in remote locations.

For example, photovoltaically powered compact refrigerators for recreational vehicles may represent a cumulative market of over 100 MW_p by 1986. In general the approach suggested in this section toward the stimulation of manufacture of photovoltaic products is to encourage consumer demand for specific products.

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APPENDIX I - ECONOMIC CALCULATIONS FOR FOREIGN MARKET ESTIMATES

A. Desalination Economics

In many parts of the world desalination is becoming increasingly important to the supply of potable water and sometimes to the supply of irrigation water. In light of this need and the possibility of using photovoltaics with electrodialysis (ED) desalination units, an economic analysis of this application is presented. This is seen as an excellent application of photovoltaics in Saudi Arabia. One important point to be considered is that this analysis assumes that the water to be desalinated is surface water.

Product flow for 100% load = 6,000 gal/day

Total dissolved solids = 3500 ppm

Temperature = 80°F

Electric consumption (solids removal) = 6 kWh/1000 U.S. gal.

Feed pump = .84 kW

Concentrate pump = .56 kW

Insolation = 25 mW/cm² (typical for Saudi Arabia)

Load factor = .65

Operating time = 15.6 hours/day

$$\begin{aligned}\text{Power required} &= \left(\frac{6 \text{ kWh}}{1000 \text{ gal}} \right) \left(\frac{6000 \text{ gal}}{\text{day}} \right) \left(\frac{1}{24 \text{ hr/day}} \right) + .84 \text{ kW} + .56 \text{ kW} \\ &= 2.9 \text{ kW}\end{aligned}$$

$$\begin{aligned}\text{Energy} &= (2.9 \text{ kW})(15.6 \text{ hrs}) \\ &= 45 \text{ kW} \cdot \text{hrs}\end{aligned}$$

$$\begin{aligned}\text{Average load} &= (2.9 \text{ kW}) \left(\frac{15.6 \text{ hr}}{24 \text{ hr}} \right) \\ &= 1.9 \text{ kW}\end{aligned}$$

PV System Costs

Battery efficiency = .70

Maximum discharge = .70

Battery life = 5 years

Battery cost = \$50/kWh

Water delivered = $(6,000 \text{ gal}) \frac{15.6}{24} = 3900 \text{ gal/day}$

Panel cost = X (\$/W)

Panel size = $\frac{1.9 \text{ kW}}{(.70 \text{ batt. eff.})} \left(\frac{100 \text{ mw/cm}^2 \text{ peak}}{25 \text{ mw/cm}^2 \text{ ave}} \right) = 10.9 \text{ kW}$

Battery size = $\frac{(2.9 \text{ kW})(15.6 \text{ hr} - 5 \text{ hr no storage})}{(.70 \text{ batt. discharge})} = 44 \text{ kW} \cdot \text{hrs}$

Present value (i = 2%, n = 20 years) =

$$= 10,900 X + \$10,900 + (44 \text{ kWh})(\$50/\text{kWh}) \left[1 + (1.02)^{-5} + (1.02)^{-10} + (1.02)^{-15} \right]$$

$$= 10,900 X + \$18,500$$

Generator Costs

Load factor for generator = .58

5 kW generator required

Operating cost = \$.74/kWh

Initial cost = \$1000

4 year replacement

Load = $(2.9 \text{ kW})(15.6 \text{ hr/day})(365 \text{ days/year}) = 16,500 \text{ kWh}$

Present value (i = 2%, n = 20 years) = $(16,500 \text{ kWh})(\$0.74/\text{kWh}) \left[\frac{(1.02)^{20} - 1}{(.02)(1.02)^{20}} \right]$

$$+ 1000 \left[1 + 1.02^{-4} + 1.02^{-8} + 1.02^{-12} + 1.02^{-16} \right] = \$204,000$$

Breakeven cost = \$17 peak watt

B. Electric Cooking Economics

Due to the rapid depletion of the forests for use in heating and cooking in many areas of the world, the use of photovoltaics for cooking has been assessed. The analysis has been made on the basis of first cost since firewood is regarded as a free commodity in most areas of the developing world. This estimate has been made on the basis of firewood use in India. ⁽¹⁶⁾

Annual firewood used = 515×10^9 kWh

Cooking use = 25%

Firewood efficiency = 9%

Electric stove efficiency = 40%

Population = 439×10^6 (rural)

Rural population with electricity = 40%

$(515 \times 10^9 \text{ kWh/yr})(.25) = 129 \times 10^9 \text{ kWh/yr}$ for cooking

Wood energy required =

$$\frac{(129 \times 10^9 \text{ kWh/yr})(5 \text{ people/household})}{(439 \times 10^6 \text{ people})(.40 \text{ with electricity})(365 \text{ day/yr})} = 10 \text{ kWh/household/day}$$

$$\text{Electric energy required} = \left(10 \frac{\text{kWh}}{\text{day}}\right) \left(\frac{9\%}{40\%}\right) = 2.2 \text{ kWh/day}$$

$$\text{Average load} = \frac{2.2 \text{ kWh/day}}{24 \text{ hr/day}} = .09 \text{ kW}$$

$$\text{Panel size} = (.09) \frac{100 \text{ mW/cm}^2}{24 \text{ mW/cm}^2} = 380 \text{ watts}$$

C. Electric Lighting Economics

The need for light for building interiors after the sun sets is universal. In many sections of the developing world kerosene lighting is used for this purpose. Kerosene lighting is very inefficient in comparison with fluorescent lighting. Also, if the kerosene must be imported it produces a drain on the foreign exchange of the country. For these reasons the use of photovoltaics to replace kerosene lighting has been assessed.

The analysis shows that a breakeven cost of \$11.50 per watt of photovoltaics can be achieved with a 20-year life at 10% interest rates. On a first-cost comparison when the price of photovoltaics falls to \$.50 per watt the payback period is less than one year and a half. Although this is still beyond the means of many households in developing countries, government subsidies or loans may be worthwhile to reduce the national dependence on foreign oil.

Even at \$.50 per watt the initial cost of panel, batteries, and stove or hotplate would be higher than the vast majority of families could afford in developing countries. Consequently, this does not seem to be a good market for photovoltaics.

Example: Electric Lighting - Kerosene Replacement

Kerosene use for lighting = 4.56×10^6 tons⁽¹⁶⁾

Population = 439×10^6 people⁽¹⁶⁾ (rural)

Household size = 5 people

Electrified villages = 40%

Kerosene cost/barrel = \$27,000

Interest rate = 10%

$$\begin{aligned} \text{Annual kerosene cost} &= \frac{(4.56 \times 10^6 \text{ tons})(5 \text{ people/household})(12.8 \times 10^3 \text{ kWh/ton})(\$0.16/\text{kWh})}{\text{household} \quad (439 \times 10^6 \text{ people})(.40 \text{ with electricity})} \\ &= \$26.60 \end{aligned}$$

$$\text{Present value } (i = 10\%, n = 20 \text{ years}) = 26.60 \left[\frac{(1.10)^{20} - 1}{(.10)(1.10)^{20}} \right] = \$226$$

PV System Costs

Two 8 watt fixtures used 4 hours nightly

Battery efficiency = .70

Storage = 4 days

Power conditioning = \$2

Light fixtures = \$12

$$\text{Energy requirements} = (2)(8 \text{ watt})(4 \text{ hrs/day}) = 64 \text{ watt} \cdot \text{hrs/day}$$

$$\text{Average load} = 2.67 \text{ watts}$$

$$\text{Panel size} = \frac{(2.67 \text{ watts})}{(.70 \text{ batt. eff.})} \left(\frac{100 \text{ mW/cm}^2 \text{ peak}}{24 \text{ mW/cm}^2 \text{ ave}} \right) = 16 \text{ peak watts}$$

$$\text{Present value } (i = 10\%, n = 20 \text{ years}) =$$

$$\begin{aligned} &16X + (.25 \text{ kWh})(\$50/\text{kWh}) \left[1 + (1.1)^{-5} + (1.1)^{-10} + (1.1)^{-15} \right] + \$2 + \$12 \\ &= 16X + \$42 \end{aligned}$$

Breakeven cost = \$11.5/watt

FIRST-COST COMPARISON--PAYBACK PERIOD

<u>PV Cost (\$/W)</u>	<u>Payback Period (years)</u>
5	4.0
4	3.4
3	2.8
2	2.2
1	1.6
.5	1.3

D. Water Pumping Economics

Water pumping is regarded as a promising option for the use of photovoltaics. An economic analysis shows that photovoltaics are indeed attractive for pumping low volumes of water such as that for household use in a small community. An example of a small water pumping system to be used year-round in Saudi Arabia follows. The system analyzed is assumed to be typical for a small Saudi village which overlies one of the shallow aquifers. Efficiencies of the various system components are as shown. The 8% interest rate is a result of the low cost of money for the Saudi government. The breakeven cost of \$24 per watt indicates that photovoltaics are presently viable for such an application.

Example:

Location: Saudi Arabia

Capacity = 5000 gallons (U.S.)/day

Lift = 400 feet

Pump efficiency = .65

Battery efficiency = .70

Motor efficiency = .90

Piping efficiency = .97

Storage = .5 hours

Interest rate = 8%

Inflation rate = 6%

Real (uninflated) interest rate = 2%

Support structure and power conditioning = \$1/W_p

$$\begin{aligned}\text{Power}_{\text{PV}} &= \frac{(5000 \text{ gal/day})}{(.65 \text{ pump})} \frac{(400 \text{ ft})}{(.70 \text{ batt.})} \frac{(8.34 \text{ lb/gal})}{(.90 \text{ motor})(.97 \text{ pipe})} \\ &= 4.20 \times 10^7 \text{ ft. lb/day} \\ &= 15.8 \text{ kWh/day} \\ &= .659 \text{ kW continuous for photovoltaics}\end{aligned}$$

Power for generator = power for photovoltaics x .70 (because there are no battery losses)

Photovoltaic Costs

$$\text{Panel size} = (.659 \text{ kW}) \left(\frac{100 \text{ mW/cm}^2 \text{ peak}}{25 \text{ mW/cm}^2 \text{ average}} \right) = 2.64 \text{ kW}$$

$$\text{Panel cost} = X (\$/W)$$

Present value panel cost (i = 2%, 20 years) =

$$(2640 \text{ watts})(X) + \$2640 + (2.64 \text{ kW})(.5 \text{ hr})(\$50/\text{kW} \cdot \text{hr})[(1+(1+i)^{-5} + (1+i)^{-10} + (1+i)^{-15})] = 2640 X + \$2869$$

Generator Cost

$$\text{Generator size} = 3 \text{ kW}$$

$$\text{Annual cost} = (.659 \text{ kW})(.7)(24)(\$1.63/\text{kW} \cdot \text{hr})(365 \text{ days/yr}) = \$6587$$

$$\text{Generator life} = 4 \text{ years}$$

$$\text{Generator cost} = \$ 293$$

$$\text{Present value (i = 2\%, 20 years)} = \$65,791$$

$$\$65,791 = 2640 X + 2869$$

$$X = \$23.83$$

A general computer program has been developed which determines breakeven costs for various pumping depths and rates. The program uses generator costs as shown in Table D-1.⁽²⁵⁾ The program also offers the option of inflating the real cost of fuel in future years. Due to the uncertainty

TABLE D-1
GENERATOR COSTS

	Generator Size (kW)				
	<u>3</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>
Cost (\$/kWh)	1.63	0.93	0.74	0.47	0.35
Initial Cost (\$)	293	1011	1246	2048	2655

of fuel costs, escalation was included in this analysis. One table of generated output is shown in Table D-2. It should be noted that the analysis has greater room for error at high flow rates and large pumping depths since other alternatives such as power line extensions become much more attractive for high power applications.

The analysis yields much less promising results for high-volume irrigation systems which are only used for a small fraction of the year. Since users of electric-powered pumps pay only for the electricity used, the winter months of inactivity represent very low cost for power. In comparison, the photovoltaics are paid for at the outset and any inactivity results in wasted power which has already been paid for. The example given for a private well in India demonstrates the low breakeven cost. The representative well chosen pumps 30 liters per second from 30 meters deep.⁽²¹⁾ This pump has a much lower power requirement than a government-installed pump which usually pumps 120 liters per second from 70 meters. Thus, the example presented represents a comparatively more favorable case for irrigation via photovoltaics.

The analysis considers both gasoline-powered pumps and pumps powered by the utility grid. Grid-powered pumps are the more common of the two. The analysis indicates that low interest rates, and low costs of photovoltaics are necessary to compete with gasoline generators or long extensions of the utility grid. Studies at M.I.T. Lincoln Labs indicate that if the cost of irrigation rises too high the farmers may stop irrigating rather than switch to photovoltaics.⁽²⁶⁾

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PUMP.FOR
00100 C THIS PROGRAM FINDS BREAK-EVEN ARRAY COSTS FOR WATER PUMPING
00200 DIMENSION BE(10)
00300 TYPE 2
00400 ACCEPT 1,C,FI
00500 1 FORMAT (3G)
00600 2 FORMAT(' ENTER INTEREST PERCENTAGE RATE AND FUEL INFLATION.
00605 2 ,5X,$)
00610 TYPE 3
00620 3 FORMAT(//,' ENTER THE MAXIMUM NUMBER OF GALLONS PER DAY.',5X,$)
00630 ACCEPT 1,2
00700 CA=(C-FI)*.01
00750 CS=(C-FI)*.01+1.
00800 C=C*.01+1.
00900 DO 20 I=1,20
01000 DO 15 J=1,10
01100 A=I*2/20. ! GAL/DAY
01200 B=J*100. ! FEET OF LIFT
01300 D=A*B*1.32E-6 !PEAK KILOWATTS
01400 E=D*.5 !KWHRS STORAGE
01500 F=D*1000. ! PEAK WATTS
01600 PVC=F+E*53.*(1.+C**5+C**10+C**15)
01700 G=1533.*D !ANNUAL KWHR FOR GENERATOR
01800 R=((CS)**20-1.)/CA/(CS)**20 !FUEL INFLATION FACTOR
01850 RA=1.+C**4+C**8+C**12+C**16 ! PURCHASE DISCOUNT FACTOR
01900 IF(D.LT.2.) GC=293.*RA+1.63*R*G
02000 IF(D.GE.2.0.AND.D.LT.4.) GC=1011.*RA+.93*R*G
02100 IF(D.GE.4.0.AND.D.LT.6.67) GC=1246.*RA+.74*R*G
02200 IF(D.GE.6.67.AND.D.LT.13.3) GC=2048.*RA+.47*R*G
02250 IF(D.GE.13.3.AND.D.LT.20.)GC=2655.*RA+.35*R*G
02300 IF(D.GE.20.)GO TO 10
02350 C GC IS GENERATOR COSTS
02500 GO TO 12
02600 10 GC=5000.*(1.+C**5+C**10+C**15)+.2*G*R
02700 12 BE(J)=(GC-PVC)/F
02800 15 CONTINUE
02900 IF(I.EQ.1) TYPE 16
03000 16 FORMAT (///,12X,'100',5X,'200',5X,'300',5X,'400',5X,
03100 C '500',5X,'600',5X,'700',5X,'800',5X,'900',5X,'1000',//)
03200 TYPE 17,A,BE
03300 17 FORMAT(2X,F6.0,2X,10(F6.2,2X),/)
03400 20 CONTINUE
03500 STOP
03600 END

```

FIGURE D-1

LINK: Loading
 [LINKACT FROM Execution]
 ENTER INT ST PERCENTAGE RATE AND FUEL INFLATION. 2. 0.

ENTER THE MAXIMUM NUMBER OF GALLONS PER DAY. 50000

	LIFT (FEET)									
	100	200	300	400	500	600	700	800	900	1000
2500.	43.58	41.67	41.04	40.72	40.53	40.40	24.10	23.86	23.68	23.54
5000.	41.67	40.72	40.40	23.86	23.54	23.32	18.62	18.47	18.36	18.27
7500.	41.04	40.40	23.68	23.32	18.54	18.36	11.96	11.80	11.68	11.58
10000.	40.72	23.86	23.32	18.47	18.27	11.80	11.64	11.52	11.43	11.36
12500.	40.53	23.54	18.54	18.27	11.76	11.58	11.45	11.36	8.45	8.37
15000.	40.40	23.32	18.36	11.80	11.58	11.43	8.50	8.40	8.32	8.26
17500.	24.10	18.62	11.96	11.64	11.45	8.50	8.39	8.30	4.76	4.67
20000.	23.86	18.47	11.80	11.52	11.36	8.40	8.30	4.74	4.65	4.58
22500.	23.68	18.36	11.68	11.43	8.45	8.32	4.76	4.65	4.57	4.51
25000.	23.54	18.27	11.58	11.36	8.37	8.26	4.67	4.58	4.51	4.45
27500.	23.42	11.90	11.50	8.47	8.31	4.72	4.60	4.52	4.45	4.40
30000.	23.32	11.80	11.43	8.40	8.26	4.65	4.55	4.47	4.41	4.36
32500.	18.70	11.71	11.37	8.35	4.73	4.60	4.50	4.43	4.37	4.33
35000.	18.62	11.64	8.50	8.30	4.67	4.55	4.46	4.39	4.34	4.30
37500.	18.54	11.58	8.45	8.26	4.62	4.51	4.42	4.36	4.31	4.27
40000.	18.47	11.52	8.40	4.74	4.58	4.47	4.39	4.33	4.29	4.25
42500.	18.41	11.47	8.36	4.69	4.54	4.44	4.36	4.31	4.26	4.23
45000.	18.36	11.43	8.32	4.65	4.51	4.41	4.34	4.29	4.25	4.21
47500.	18.31	11.39	8.29	4.61	4.47	4.38	4.32	4.27	4.23	4.20
50000.	18.27	11.36	8.26	4.58	4.45	4.36	4.30	4.25	4.21	4.18

BREAKEVEN COST
 (\$/W)

GALLONS/DAY
 352

STOP

END OF EXECUTION
 CPU'S: 15 ELAPSED TIME: 1:14.02
 EXIT

TABLE D-2

E. Irrigation Pumping Economics

Example: Private Well

Location: India

Capacity = 30 liters/second

Lift = 30 meters

Insolation = 24 mW/cm^2

Operation = 1000 hr/yr (195 days)

Pump efficiency = 0.65

Battery efficiency = 0.70

Motor efficiency = 0.90

Piping efficiency = 0.97

Storage = 0.5 hours

Interest rate = 10%

Inflation rate = 6%

Real (uninflated) interest rate = 4%

Support structure and power conditioning = $\$.50/W_p$

$$\begin{aligned}\text{Power}_{PV} &= \frac{(1 \text{ kg/l})(30 \text{ m})(30 \text{ l/sec})(60^2 \text{ sec/hr})}{(.65)(.90)(.70)(.97)} \\ &= 8.16 \times 10^6 \text{ kg} \cdot \text{m/hr} \\ &= 22.2 \text{ kW (continuous)}\end{aligned}$$

Power for generator = power for photovoltaics X .70 (because there are no battery losses)

$$\text{Power}_{\text{GEN}} = 15.5 \text{ kW}$$

Photovoltaic Cost

8 hours pumping/day

$$\text{Power}_{PV} = \frac{(22.2 \text{ kW}) \left(\frac{1.00 \text{ mW/cm}^2 \text{ (peak)}}{24 \text{ mW/cm}^2 \text{ (average)}} \right) \left(\frac{24 \text{ hr}}{8 \text{ hr}} \right)}{1} = 30.8 \text{ kW}$$

Present value panel cost ($i = 4\%$, 20 years)

$$= 30,800 X + ($.50)(30,800) + (.5 \text{ hr})(30.8 \text{ kW})(\$50/\text{kWh})$$

$$\left[1 + (1.04)^{-5} + (1.04)^{-10} + (1.04)^{-15} \right]$$

$$= 30,800 X + 17,750$$

Generator Cost

Generator size = 20 kW

$$\text{Annual cost} = (15.5 \text{ kW})(1000 \text{ hrs})(\$0.20/\text{kWh}) = \$3100$$

Generator life = 4 years

Generator cost = \$6,000

Present value ($i=4\%$, $n = 20$ years) = \$64,570

$$X = \$1.52/\text{watt}$$

Powerline Extension

Electricity cost = \$.05/kWh

$$\begin{aligned} \text{Annual cost} &= (15.5 \text{ kW})(1000 \text{ hr})(\$0.05/\text{kWh}) \\ &= \$775 \end{aligned}$$

Present value = \$10,530

Extension cost = \$2,000/mile

Miles Extension	\$/W Breakeven
5	0.09
10	0.41
15	0.74
20	1.06

APPENDIX II

Appendix A: Creativity Session Among Selected InterTechnology Employees

The first creativity session was of the "brainstorming" type with six staff members of InterTechnology/Solar. The group consisted of Mr. David Doyle, then vice president with a background in foreign service and construction; Mr. Christopher Harmer, chemical engineer; Dr. Jean Henry, physical chemist; Dr. Henry Liers, physicist; Mr. Paul Culbertson, manager of administration and Dr. Frederick Costello, vice president of engineering, who led the session.

The session opened with a description of the goal, to generate 100 new ideas for solar cell applications, along with the assumptions to be made. The most critical assumption was the price of \$500 per peak kilowatt, which would be competitive with the prices of electricity in less than the ten-year span of interest. As a consequence, most of the session was spent simply listing uses of electrical energy. Also, because the group assumed that solar-supplied energy would be very cheap, uses of solar photovoltaics where they are not currently economical were justifiably proposed.

The staff agreed that there would be far too many ideas if the scope of discussion were not limited. The first area considered comprises all uses of solar a householder might encounter. The ideas generated are listed in Table A-1. Several prompters were used because the group became tired after approximately one hour of meeting. The prompters included: all uses that are essential to the householder's living; uses that depend on the silence of the photovoltaic cells; and "If you were a photovoltaic cell, what would you want to give to mankind?" These prompters were reasonably successful; however, the sessions should probably have been limited to one hour at a time. In a second subsession, the scope was limited to foreign householders. In the third subsession, the scope was limited to engineers and how they would use photovoltaic cells. The ideas for the foreign householders are shown in Table A-2; for the engineers in Table A-3.

The session suffered because it was not lighthearted enough, because it was too long, and because of the abundance of ideas made possible by the extremely low cost of the cells at \$500 per peak kilowatt.

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Table A-1

Applications Pertaining To The Home Occupant

Electric toilets	Complete climate control
Electronic filtering	Barbecue pits
Adjustable chairs	Adjustable beds
Conveyors	Electric car
Garden appliances	Well pump
Communications	Greenhouses
Controlled tractor	People movers
Hair removers	Kitchen appliances
Intrusion defense	Electric fencing
Beauty appliances	Electric toys
Electric underwear	Pool pump
Power tools	Electric scarecrow
Outside lighting	Driving solar thermal system
Electric towel rack	Door opening
Pavement warming	Vent fan
Roof snow removal	Heating
Weather station	Switching devices
Pumping oil to furnace	Garbage compactor
Septic tank	Solar heated seat
Garden tilling	Growth control
Sterilization	Night lights
Radio	Television
Phonograph	Mood lights
Chimney cleaning	Electrostatic precipitator
Closed water system	Clothes dryer
Pipe tracing	Trash classification
Refining metals	24-hour greenhouse
Trash removal	Wood conveyor
Wood chips	Power auxiliary
Power system	Clocks
Window opacity control	Automatic voltage control
Ventilation control	Laundry
Expansion contraction control	Transferring sunlight all the way around the house
Preventing coloring fading	Air conditioning
Household memory	Electronic dirt catcher
Electric window cleaner	Ordering systems
Unlimited power	Earthquake compensator
Air purifier	Intrusion protection
Shock machine	Portable power pack
Hydrogen production	Cathodic protection
Electric clothing	Ice maker
Beer cooler	DC to electronics
DC for better lights	Cells as a building material
DC battery charger	Outdoor lights
Cells as windows	Panels on track or belt
Roll out panels	
Boat power	

Camper power
 Tents made of cells
 Shoe cleaning
 Camp heater
 Awnings made of cells
 Make everything smaller
 Caulerizer
 Animal guard in camp
 Electric games
 Powering citizen's band radios
 Portable saw
 Cold water wash
 Robot cleaner
 Water removal
 Waste removal
 Washing and drying
 Better cleaning
 Electrostatic cleaning
 Ultrasonic cleaning
 Food drying
 Back up to utility
 DC for motors
 DC for battery charging
 DC for microwave cooking
 Supplying the grid
 Use as wallpaper
 Use as combined shade

Camper lights
 Camping, cooking
 Painting
 Portable toilets
 Clothes made of cells
 Camping freezer
 Purify camp water
 Fish attractor
 Electric hammer
 Portable clothes washer
 Ozonizer
 Electricity without fire hazard
 Heat
 Light
 Refrigeration
 Cook in the daytime
 Oven cleaning
 Dry cleaning
 Deodorizer
 Food chilling
 DC for bells
 DC for electronics
 Smaller wires
 LED printout
 Power controls
 Power supply for lawnmower or tractor

Table A-2

Applications For Home Occupant In Developing Countries

Irrigation pumps
 Food preservation
 Medical needs
 Transportation
 Education
 Food sterilization
 Bug removing
 Using perspiration
 Electric fence
 Make fertilizer from sewage

Communications
 Machinery
 Medical refrigeration
 Water treatment
 Cooking
 Combining with solar heating
 Humidifier in desert
 Pacemaker
 Wild animal protection
 Lengthen growing season

Table A-3

Applications For The Engineer

Portable time card	Distance meter
Closed circuit television	Non-destructive testing
Testing equipment	Soil testing
Brick facing alignment	Hat communications equipment
Wild animal detection	Vibration-free experiments
Place on dam face and use pumped storage	Combustion-free and spark-free electricity for mines
Coring	On-site, computer-aided design
As-built drawings as you go on site	Detecting crop harvesting time
Harvest by a hot wire	Remote activation of explosions
Remote switching	Run computers
Run calculators	Exerciser
Locating surveying stakes	Communications
Portable power supply	Portable field-testing equipment
Corrosion control	Surveying
Powering the construction trailer	Portable toilets
Cleaning plans	Micro-film projector
DC welder	Portable tools
Quiet jack hammer	Hat light
Music in hat	Air-conditioned suit
Safety equipment	Safety suits
Safety attachments	Voice reader for calculators
Measuring distances	Leveling
Measuring right angles	Computer-designed stairs
Pencil sharpener	Powering a people bubble
Road profile calculator	Concrete heater
Asphalt heater	Site inventory
Intrusion protection	Data transmission

Appendix B: Creativity Session With Two Members of the Mobil Tyco Staff

The second creativity session, was a focused interview. Dr. Frederick Costello of InterTechnology/Solar interviewed Dr. A.I. Mlavsky and Mr. Hugh Chilton of Mobil Tyco. Since Dr. Mlavsky is an expert in foreign application of solar photovoltaics, the interview focused primarily on foreign markets. The interview itself lasted approximately one hour and fifteen minutes.

The first focal point was the selection of the twenty most promising applications of photovoltaics. The second focal point centered on the uses of solar cells which are attractive because their output is direct current. The third focal point comprised uses that would counteract the undesirable aspects of the sun. The results of the interview are listed in Tables B-1, B-2, and B-3 for the three foci. All three members of the session contributed ideas, although Dr. Mlavsky certainly dominated.

The session was reasonably successful. Those ideas which might be considered novel are indicated on the tables with an asterisk. As in the session described in Appendix A, this session was too serious also. Unlike the first session, minor criticisms were raised during the ideation process, although they were not serious enough to inhibit the other two. In light of Dr. Mlavsky's expertise in solar photovoltaics, incorporating him into the creativity process was probably most effective. Dr. Mlavsky, however, was disappointed that more members didn't participate.

Table B-1

The 20 Best Worldwide Applications

Irrigation pumping	Lighting
Electric tractor with batteries or without	Refrigeration
Purify water using ozonizer	Pumping drinking water
Educational television	Fixation of atmospheric nitrogen
Power for simple industries	Heating
Electric flywheel bus*	Electrolytically grown food
Communications	Sewage treatment
Military	Telephone systems
Environmental sensors, including nuclear radiation	National alert network
Pumps, fans	Controls for biogas plants
Electrolysis of water for eutrofication control and hydrogen production	Methanol plants
Portable medical machines	Electric motorcycles
Rural airports	Anodic protection
Hand tools for construction	Cathodic protection
Cauterization*	Electric fences
Railroad signals and controls	Roofing material
Battery powered school buses	Pesticide protection
	Electric bug electrocutor
	Remote medical centers

Table B-2

Worldwide Applications That Do Not Require Storage

Peak load for utilities	Air conditioning load for utilities
Pumped storage	Making wood chips
Producing chlorine by electrolysis	Driving solar heating systems
Nitrogen fixation	Generating and storing coolness
Precious metal recovery	Garden tools
Electroplating	Greenhouse controls
Grain drying	Wood drying
Electric airplanes	

Table B-3

Applications Based On The Attribute That The
Power Produced Is Direct Current

Powering electronics	Traction motors
Warning flashing lights	Toys
Educational devices	Recreational equipment

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*Possible novel idea.

Appendix C: Creativity Session at the University of Delaware

The participants in this traditional "brainstorming" session were Dr. Jerome Scott, associate professor, College of Business and Economics, and an expert in the marketing of solar systems; Mr. Joseph Slikowski, industrial engineer in the electronics field; Dr. Allen Barnett, director, Institute of Energy Conversion, and an electronics engineer with a background in the development of new businesses in the light-emitting-diode area; Dr. Vic Dalal, a material scientist with a considerable practical experience in the fields pertaining to solar; and Dr. George Warfield, assistant director of the Institute of Energy Conversion with a background in solid state electronics. Dr. Frederick Costello of Inter-Technology/Solar Corporation conducted the session.

In an attempt to introduce some levity into the situation, the first session spent five minutes in generating fifteen outrageous applications of solar cell. The results of this period are given in Table C-1. Some of the ideas don't seem too outrageous but the initial session did help put the participants in the proper mood. In an attempt to get past the most common ideas, the second effort of the session focused on those applications most likely to succeed. The results of this five-minute session are shown on Table C-2. The ideas which might be novel are shown with an asterisk. A third five-minute period was devoted to those applications which depend on the output of the photovoltaic cells being direct current. The results of this session are shown on Table C-3. At the end of this five-minute session the participants were asked for another attribute of the solar cell which might serve as a basis. "No moving parts" was chosen. As indicated by the asterisks on Table C-4, which shows the results of this session, the difficulty of this task was instrumental in generating novel ideas. Other stimulants used were negative aspects of the sun and contributions of photovoltaic cells to mankind. The results are summarized in Tables C-5 and C-6. The next attribute used as a basis was "lack of price elasticity." The results of this session proved useful,

although nothing new was uncovered, as indicated in Table C-7. The final five-minute session focused on how the president of General Motors might use solar cells. The ideas generated center around his use of the photovoltaics as a conversation piece. Several new submarkets associated with mobile communications are identified in this session, as shown in Table C-8.

At the end of this series of sessions, which took 1.5 hours, the participants were asked to criticize the session. One criticism was that no allowance was made for relaxation during the prolonged period. It is evident that the session should be kept to approximately 45 minutes with an allowance for approximately 15 minutes between subsessions. It would be better to have the sessions end with an informal luncheon, but the only time available for Delaware's participation was late in the afternoon. Possibly the most serious criticism was that the egos of the people involved were not stimulated, nor were they allowed to pursue any of their ideas in sufficient depth to work out some of the more interesting details. As a consequence the participants did not get satisfaction as would a product developer. In future sessions some allowance will be made in the schedule to permit participants to achieve some sense of satisfaction.

Table C-1

Concepts Least Likely to Succeed

Central power	Heating oil sands
Automobiles	Flying airplanes
Space heating	Lighting glider lights
Heating remote sites	Refining metals
Nuclear fuel reprocessing	Manufacturing furnaces
Water desalination	Running pulp mills
Heating stadiums	Heating inaugural platforms
Aircraft launchers	Aircraft carriers

Table C-2

Applications Most Likely to Succeed

Remote repeaters	Irrigation pumping
Rural lighting	Heating and cooling
Powering solar furnaces	Food refrigeration
Medicine refrigeration	Parole monitors
Supplying peak electricity	Desalination
Pollution processing	Electrostatic precipitators
Domestic electricity	Aerospace applications
Traffic and train signals	Military
Remote telephones	National park power
Buoys	Animal monitor power
Camper power	Sailboats
T.V. and radio	Watches
Calculators	Battery chargers
Electric chairs	Cooking
Photo plotters	Using sunlight to provide light
Powering electronics	Electric cars
Environmental monitors	Corrosion control

Table C-3

Applications Based on the Attribute
That Direct Current is Supplied

Electrolytic refining	Electrolytic plating
Motors	Electronics
Medical electronics	Resistance heating
Tungsten lighting	Battery chargers
Anti-corrosion	Hydrogen generation
Oxygen generation	Paint spraying
Painting the enemy during warfare	X-rays
Lasers	Charging capacitors
Charging Van de Graaff generators	Electric fences
Electric probes	Smoke detectors
Electrostatic precipitators	

Table C-4

Applications Based on the Attribute
That There Are No Moving Parts

Electronic calculators	Watches
Medical telemetry	Spacecraft
Military applications involving high impact	Powering animal monitoring stations
Permanent installations in roads, billboards and runways*	Reliable remote power
Lasers	Cells as building material*
Detectors	Vibration sensitive instruments*
Cordless jack hammers	Process control
Powering thermo-electrics*	Cordless appliances
Dirigibles	Submarines
	Ultrasonic intrusion detectors

*Possible novel idea.

Table C-5

Applications Based on the Negative
Aspects of the Sun

Powering electro-field-sensitive glass	Driving air conditioners
Powering skin coating to avoid sunburn	Extending the day with lights
Regulating greenhouse lighting	Regulating hydroponic temperatures

Table C-6

Applications Based on the Stimulant:
If You Were a Photovoltaic Cell, What Would You Give to Mankind?

Independence	Electrons
Work savers	Money savers
Less pollution	Bionic control
National security	Balance of payments
Resource conservation	Stability of earth heat balance
Clean environment	Fast industrialization
Jobs	Power for labor intensive devices
Reliable power	A foreign policy tool

Table C-7

Applications Based on the Attribute
Lack of Price Sensitivity

Remote communications	Educational television
Space power	Pollution control
Gadget market	Gift market
Novelty market	Recreation market
Sailboats	Explorer's power
Human and animal telemetry	Toys
Battery charger	Crop dryers
Hunter ultrasonic detector	Rural lighting

Remote alarms
Sonar for fisherman
Drilling rig
Conversation pieces
Medical devices

Electronic art
Safari power
Jewelry
Educational demonstrations

Table C-8

Applications for the President of General Motors

Gifts
Electronic watch
Radio
Boats
Remote communications
New-idea stimulator
Calendar power
Portable water cooler
Portable refrigerator
Covering for golf ball
Electric car for retirement community

Conversation pieces
Calculators
Television
Public relations
Remote television
Powering shades for car or office
One-upmanship: golf, hunting
tennis, etc.
Golf ball detector (powers beeper)
Foot warmer for athletic events

Appendix D: Interview of Dr. Charles Weiss of the World Bank

A focused interview was conducted with Dr. Weiss, who has written several papers on the use of photovoltaics in developing countries. Since most of Dr. Weiss's ideas are already documented, as summarized in Table D-1, most of the interview was spent discussing the reason for using photovoltaics in developing countries. Table D-2 summarizes Dr. Weiss's favored applications.

The daily and seasonal load factors on any electric power source is especially important in determining the economic system for developing countries. For example, if the photovoltaics are devoted to irrigation pumping, they will be used only approximately three months out of the year except for rice farming or double cropping which increase the usage period. If the photovoltaics are used for educational television, they will be used approximately five hours per day, five days per week, nine months per year. As a consequence, an array costing \$20.00 per square foot with a ten-percent efficiency, with a life of ten years and a ten-percent discount rate, will result in a cost of energy of \$4.00 per kilowatt hour. The computations are shown on Table D-3. The effect of load factor will be especially important when comparing the solar cells with their competitors, such as gasoline and diesel generators. Engine-driven generators are low in first cost and high in operating cost, so they are less severely affected by poor load factors. The other serious competitors are primary batteries and man-pedaled generators. To offset the poor load factor, consideration must be given to serial uses of solar cells. For example, the solar cells might be used for irrigation pumping in the summer and for educational television during the remainder of the year.

Mr. Weiss believes that pumping of irrigation and drinking water, educational communications and rural television are the most promising applications of photovoltaics. He believes that desalination will be economical only if population centers are in coastal areas. Libya is one country particularly interested in irrigation pumping, since it desires to be food-independent. The ministers of education in each of the countries would be particularly

interested in the rural communications applications. Of particular importance to them would be the simple maintenance procedures that could be used with the photovoltaics since maintenance of engines in remote areas is a serious problem in most developing countries.

An example of current technology for providing rural power in developing countries is the Freon-Brayton cycle engine being marketed by Ormat, an Israeli company. Applications include use as a backup to solar energy.

Dr. Weiss also indicated that photovoltaics would be useful in forest camps, especially in driving the small machine shop. These forest camps frequently have houses clustered around the shop, forming a small community. The same can be said for mining and exploration camps.

In Nepal, where the main industry is tourism, electric power is needed for tourist camps located in the remote parts of the country, especially in the mountains. This electric power would be needed for light, communications, pumping, heat and as a backup to wind-power systems. Powering of repeater stations, police and railroad stations and campers' backpacks are also cited by Dr. Weiss. Telephones and hand radios would be included in the communication equipment powered by photovoltaics.

The methods of financing solar systems in the various countries would cover a considerable range of interest rates. For example, three- to five-year loans are common in some countries at an interest rate of 100 percent per year. Interest rates from the World Bank range from 0 percent to 15 percent, with 10 percent being common. In Nepal, 3/4 percent might be used. Some funds for the World Bank are obtained from bonds sold in the market place, so reasonable interest rates would be realized with these funds. Other funds are available by direct contributions from member countries, including \$275 million per year from the United States. No return is expected on these latter funds, so they are available for interest-free loans to deserving countries. The typical lending cycle for the World Bank is four years. No factor is added to the interest rate to account for risks, although some consideration is given to risk in judging the worthiness of a project.

Table D-1

Developing Country Applications of Photovoltaic Cells*

Educational TV receivers
Audio-visual equipment for rural schools
Refrigerators for clinics
Small appliances for remote tourist centers
Pumping potable water
Pumping irrigation water (in combination with off-season uses)

Table D-2

The Most Promising Applications

Irrigation pumping
Drinking-water pumping
Educational communications
Rural television
Shops in forest camps
Communications equipment
Repeater stations
Mining camps
Exploration camps
Camper backpacks
Tourist camps
Police stations
Railroad stations
Telephones
Hand radios
Lighting in the community center (but not in individual homes)
Refrigeration for medicine (but not for food)
Medical sterilization
Water sterilization (at present water is not sterilized)

*Charles Weiss, "Developing Country Applications of Photovoltaic Cells",
Proceedings of the Second ERDA Semi-Annual Solar Photovoltaic Conversion
Program Review," Lake Buena Vista, Florida, January 1976.

Appendix E. Photovoltaic Cell Brainstorming Session with Foreign Representatives
(Group 1)

1 February 1977
10:45 AM to 12:30 PM
ITC Conference Room

Attendees

Mr. Ferenc Jarmer
First Secretary (Scientific)
Embassy of the Hungarian People's Republic

Mr. Kiichiro Nagara
Counselor
Embassy of Japan

Dr. Josef Soldaczuk
Economic Counselor
Embassy of Polish People's Republic
Office of Economic and Commercial Counselor

Dr. Wladyslaw Czulno
Scientific & Technological Counselor
Embassy of the Polish People's Republic

From ITC/Solar

Dr. Frederick A. Costello
Dr. George C. Szego
Mr. David W. Doyle
Mrs. Pauline P. Brooks

Ideas Generated

Lead question: Consider flatbed truck 40 ft. long by 7.5 ft. wide which is equipped with a panel of photovoltaic cells, 3 kW peak, 2/3 kW average over 24 hours. What are some applications of this mobile unit?

Propel itself	Local movie, TV production
Battery charger	Demonstrator
Mobile icemaker	School picnic
Remote communications	Controller
Drive drawbridge	Cool beer
Construction work (remote operation of tools)	
Emergency power	Test telephone lines
Irrigation	Keep time
Sharpen knives	Mobile dentist, doctor, hospital
Desalinization	Water purification
Chimney cleaner	Prepare food - peeling

Sawing wood	Start nuclear plants
Hydroseeding power	Broadcasting
Spotlight (accident, fire, police)	
Emergency communication	Corrosion control
Power wheel chair	Portable Hi-Fi
Speech amplifier (PA system)	Remote telemetry
Military command (radar, laser, detectors)	
Ski lift	Hoist
Fish herding & feeding	Buoys
Beacons (airfield)	

Lead question: Who feels deprived in your country?

Light	Heat
Refrigeration	Plating
Electrochemistry	Yacht Power
Movie studio on location	Warm septic tanks
Warm dipstick	Electric underwear
Electric handwarmer	Defrosters (home, car)
Execution	Pacemaker
EDM	X-ray
Cattle fencing	Photoflash
De-icing sidewalk	Road de-icing
Drive train	Pump solar collector (water/fan)
Office machinery	Ventilation of buildings
Household appliances	Water picks, electric toothbrushes
Hibachi ignition	Electric sail on boat
Electric blanket	Mine ventilation
Respirator	Prospecting equipment
Set off explosives	

Lead question: How about applications beginning with the letter "A"?

An intrusion detector/ repeller Controller	A model airplane

Lead question: How about applications beginning with the letter "B"?

Brewing	Bird chaser (starlings)

Lead question: How about applications beginning with the letter "C"?

Mosquito (insect) trap	Anticoagulate
Sterilization (of medical equipment, ozone, UV)	
Compressor	Calculator
Elevator	Escalator

Lead question: How about applications beginning with the letter "D"?

Drill

Lead question: How about applications beginning with the letter "Z"?

Zebra probe	Mobile (TV camera)
NDT equipment	Worm trap (zapper)
Ziel-phot: (photo-finish races)	Watches
Warning systems	Electric musical instruments

Lead question: What are the five most ridiculous uses?

Electric backscratcher	Food dispensers
plane	Farming machines
metronome	Building material
computer	Raincoat
Sunvisor	Fountain (rainbows)
Change glass color	Raisin dryer
Shaving	Electric necktie rack
Hat spinner	Auto theft warner
Merry-go-round	Desk-top
Soft drink dispenser	Dodge-em car (Disneyland)
Electric broom for sweeping	Electrostatic precipitator
ice for Curls game	Card sorter
Carving knife	Mobile circus
Telephone bugger	Shoe cleaner
Laundry	Mobile laundry
Gas liquefaction	O ₂ production
H ₂ production	Fixing N ₂
Powering pole to remove light bulb	
Roulette wheel	Pin-ball machine
Carnival	

Lead question: What are the uses which don't require storage?

Grind wood for fuel	Lumbering
Dry crops	Laundry
Preserve food	Office machines
Institutional cooking	Mine lighting
Pump water	Electric cars
Compress air	Farm machines
Magnetic storage	Garden tools
Electrostatic storage	Construction tools
Pumped storage	Air conditioning
	Opacity control

After Incubation Period:

Phonograph record	Power transmission (receiver)
Power trains	Transform wavelength of solar light
Magic carpet	IR windows that produce electricity
Gas balloon with cells	Electric roller skates
Put on mountain	Power off switch on gas light (or electric)
Phosphor-coat cells	Gas transmission line pumping

Group II

3 February 1977
10:20 AM to 12:20 PM
ITC Conference Room

Attendees

Mr. Mohammad M. Al-Falah
Cultural Attache
Embassy of the State of Kuwait

Dr. Luigi Massimo, Scientific Advisor
European Economic Community

Mlle. Eliane Morin, Scientific Advisor
Office of Scientific Counselor
Embassy of France

Mr. Klaus Wiendieck
Counselor, Science and Technology
Embassy of the Federal Republic of Germany

From ITC/Solar

Dr. Frederick A. Costello
Mr. David W. Doyle
Mrs. Pauline P. Brooks

Ideas Generated

The framework for stimulating and guiding ideas was the morphological diagram (see Figure 1). Cells of this matrix were selected at random.

12A: Human Need: Love; Attribute: Current

Robot
"Feely"
Baby sitter

3J: Human Need: Warmth; Attribute: Low Technology and Maintenance

Fireplace replacement (elec. resistance heating)
Sun bathing
Electric underwear (blanket)
Hot water
Hibernation
Space heating
Combine with thermal

4K: Human Need: Oxygen; Attribute: Temperature Dependence

If PV's get too hot will degrade

Extracting O₂ from ice

Greenhouse (night illumination, combine with solar thermal)

Heat to liberate O₂ from H₂O

Corrosion protection

1A: Human Need: Shelter; Attribute: Current

Electric fence

Electric fan

Carve out underground igloo

Kill bugs, etc.

Charge rain to repel

Electromagnetic field

Metal detectors in remote airport

Skin of shelter provides electricity

24M: Human Need: Variety of Experience; Attribute: Rugged

Kaleidoscope

Camping power

Space power

Remote power

Water pumps, rugged area

Heating ski lift

Power skier's radio

Compressing air for mountain
climbers

Air drills

Toys

Pressurize football

Transportation

Mountain climbing

Counting migrating lemmings

Electronic targets for rifle range

Construction (remote)

Jogging machine

Electric controlled comb

Inflight recorder

Power recovery beacon

Electric chair

Prosthesis

Fishing (electric shock)

Energy independence (personal power pack)

Life-saving equipment

Navigational

Pacemaker

Watch

Animal telemetry

Power kayak

Power during car crash

Electric sailboat

Typhoon or earthquake emergency power

Electric polo pony

Walking machine

Electric wheelchairs

Trash compacting

Electric sails

Windmill blades

High vibration environment (sorters)

Concentration camps

Electric glider

Portable foot warmer

34T: Human Need: Social Control; Attribute: Undetectable

TV propaganda (subliminal)	Herding the blind
Bugging devices	Behavioral conditioning
Anti-theft	Speed traps (no radar)
Speed controls	Intrusion detector (self-powered)
Lights for birth control	Hidden monitors
Communication	Mark (cars, people) with beacon
Power for bug catcher	Warming pews
Prodding sluggish	Voting booth surveillance
Cooling by filtering	Direct use of e-m radiation

23U: Human Need: Salvation; Attribute: Non-polluting

Garden of Eden	Controlled environment meditation
Religious activities in sacred area	chamber
Salvation Army weapons	
Communication	

Rest period

Lead Question: Where do photovoltaic cells fit best in your country?

France:

Remote power
Ship emergency power
Airship (skin)
Safe hot-air airship or balloon.

Germany:

Remote power
(where insolation permits)
Weather station
Communication

Kuwait:

Remote power
Water purification
Water desalinization
and irrigation
Water recycling
Electricity for cooling and heating
Combined with electrical separation for cooling

All:

Medical sterilization equipment
Ventilation
Greenhouses
Solar umbrella
Navigational equipment

Looking at one of the above uses (communication) led to selection of cell 28D as a brainstorming target.

28D: Human Need: Communication; Attribute: Power Source

Telephone
TV
Telegraph
Radio
News print
Repeater stations
Photocells to modulate filtered sunlight

Lead Question: Are there any new ways to use electricity because we have photocells?

Electricity without wire for remote uses.

Hybrid system: Windmill coupled with panels of cells (augmenting wind)

Noted in discussion:

1. Present remote power source in Western Europe: Diesel generator (oil transported to site).
2. African thermal systems close to economic feasibility for power in remote places.
3. Remote applications and small fixed energy needs appear to be the recommendable uses.

Group III

4 February 1977
10:20 AM to 12:20 PM
ITC Conference Room

Attendees

Mr. Chairul Anwar
Industrial Attache
Embassy of the Republic of Indonesia

Lieutenant Colonel Claude Cholin
Assistant Air Attache
Offices of the Military, Naval and Air Attaches of France

Major Mohamed El Kostali
Assistant Military, Air and Naval Attache
Embassy of Morocco

Major G. Roa
Embassy of Spain

Dr. James Harrington Whittem
Scientific Attache
Embassy of Australia

From ITC:

Dr. Frederick Costello
Mr. David W. Doyle
Mrs. Pauline P. Brooks

Initial Discussion:

Photovoltaic cell characteristics, state-of-the-art, monetary and energy costs were discussed based on questions from the participants. Models were demonstrated. The framework for the stimulation and guidance of ideas was once again the morphological diagram. Cells of this matrix were selected at random from the cells not used in the 3 February session.

Approach

Morphological Diagram

11C: Human Need: Safety; Attribute: Direct Current

Navigation aids
Instrumentation (sensors)
Electrocution
Thermistors
Thermocouple sensing/DC amplifier
Ignition of flares
Flashers
Seat Belt
Snow removal

15E: Human Need: Self Respect; Attribute: Intermittent

Psychedelic lights
Resourcefulness enhanced
Darkrooms

17H: Human Need: Clothing; Attribute: Low Price

Raincoat
Electric heaters
Electric sewing equipment (scissors)
Dyeing
Electrostatic dust removal
Repellant clothes
Anti-static device
Drier, clothes

19W: Human Need: Material Goods; Attribute: Utility-Free

Lead Question: What new material goods can you have if PV's were on your roof?

Electric appliances

Lead Question: What three things would you add that you don't have now?

Refrigerator (Morocco)
Freezer, large-scale (U.S.)
Air conditioner (Spain, Indonesia)
Desalting (Spain)
Cooking
Drive heater pump
Sewage treatment
Water recovery
Electric car charger
Electric motorized bicycle

7L: Human Need: Sleep; Attribute: Thin

Blanket (electric) for shift worker, siesta
Hammock
Run boring TV, music
Mosquito net
Monotonous tones
Curtain, drapes

8M: Human Need: Health; Attribute: Rugged

Medical call
Mobile medical equipment
Off road   Cauterizers   Pacemakers
Sterilizers   Instruments   Rescue vehicles
Beacon   Personal   Telemetry/monitor
locator

10Q: Human Need: Sanitation; Attribute: Modular

Sewage treatment (home, camping, boat, plane, portable toilet)
Solar lamp (UV) applied in meat packing plants or country slaughterhouse
Portable ozone generator
Electrostatic precipitator (smoke)

20F: Human Need: Peace of Mind; Attribute: Backed up

Constant power
Computer (as personal memo device)

25G: Human Need: Creative Opportunities; Attribute: Storage System

Recharging station

16R: Human Need: Power; Attribute: Flexible

Superman suit
Whip
Wrap up the opposition
Fire ray gun or laser gun from hip
Net

290: Human Need: Production; Attribute: Quiet

Avoid noise to improve productivity
Music
Recording
Hospital power
Anechoic chambers
Optical equipment
Electron microscopes

29P: Human Need: Production; Attribute: Lightweight

Portable machine shops
Portable A/C
Portable lights
Harvest equipment
Small towns
On-site food processing
Irrigation pumping
(seasonal, follow food chain)
Modular power unit
Serial applications (dependent on need of time period)

All-weather umbrella

2X: Human Need: Light; Attribute: Light-Sensitive

Transfer light indoors
Adjust shutters
Tracking solar collectors
Adjust illumination
Power LED
Sunlight telltale
Insolation meter
Timer
Automatic headlight dimmer
Dim building lights
Night lights on fences

How can we relate this to chemi-luminescence? Light beacons

How can we relate this to optical fibers? Combine with lighthouse for timing dimming, large ships, trigger chemical lighting, light traps, entomological controls

11F: Human Need: Safety; Attribute: Backed up

Constant power

34J: Human Need: Social Control; Attribute: Low-Technology Maintenance

Discussion: What is social control? Varies from society to society. Low technology maintenance is important in industrialized, as well as under-developed nations because of high cost and unavailability of repairmen.

Unskilled police
Smuggling detection
Theft detection
Intrusion detection
Low-skill employment
Do-it-yourself applications
TV, surveillance camera
Public address system
Cross-culture enhancement
Tape recording
Bugging devices
Alarm for cars, bldgs
Automatic sidewalks

32Y: Human Need: Defense; Attribute: IR Transmitting

IR window for IR detectors (filter), self-powered
Line furnaces (field uses)
Heating airplane hangars
Radiant heating plus electric uses: tools, automotive equipment
Solar concentrators with cells on mirror
Heat barriers for bugs
Mouse trap
Mosquito trap
IR decoy
IR screen
Coat tanks to reduce IR radiation & tow emitter to act as decoy
IR sensor - self powered

Ideas and Comments Generated During Rest Period:

Military applications: ruggedness with respect to explosions discussed
Australia uses coal and hydropower for electricity at present
Spain going to nuclear in western provinces
Float on ocean banks of PV's
Australia: Transmissions (telemetry) from stream gauges
Many remote places: airfield, desalination, recharge storage batteries
(presently use transceivers initially charged by bicycle)
Described low-density population, many self-contained ranch houses

Appendix F: Creativity Session As Part of Ruritan Club Meeting

16 February 1977
9:00 PM to 9:45 PM
Meeting of Baldwin Ridge Ruritan Club
Vint Hill Station Chapel

Attendees

Members of the Baldwin Ridge Ruritan Club

From ITC/Solar

Mr. Douglas R. Eaton
Mr. Norris L. Beard
Mrs. Pauline P. Brooks

Twenty-three members of the local Ruritan Club participated in a creativity session as part of the program for their regular monthly meeting. The session was of the brainstorming type with use of the morphological diagram used in previous sessions to limit the scope of applications. Mrs. Brooks led the session.

Members of the Baldwin Ridge Ruritan Club represent a variety of occupations: electrician, printer, farmer, barber, flight controller, electrical engineer, minister and gas station owner, for example. Ideas generated in this session are presented in Table F-1.

Table F-1

Ideas Generated at Ruritan Club Meeting

Clothing Lightweight

Heated socks	Hearing aid
Electric jackets	Handwarmer
Blankets	Illuminated clothes
Wiper for glasses	Thermal clothing
Thermal construction boots	Halo
Lighted jewelry (strobe)	Watches
Beany spinner	Nose mitten

Safety, Non-polluting

Electric boat (sail)	Traffic signal
Electric generator (no smog)	Anti-corrosion
Replace gas pilot light	

Social Control Low Price

Buoys	Earthquake detector
Stop lights	Alarm systems
Home appliance	Emergency power (hospitals)
Cattle prod	Autos

Other Ideas

Electric dryer (30 amp)	CB radio
Electric hot water heater	Light
Range	Beacon
Beer cooler (portable)	Road ribbon of cells
Ice-maker	Ice melter
Electric shaver	Hatchery heat
Toothbrush	Game control (tagging)
Coffee pot	Fence (electric)
Television	Radio
Pumps (irrigation, oil pumps)	Sonar buoy
Intercom	Electric organ

Appendix G: Most Promising Applications of Photovoltaics

Ideas for applications of solar cells, generated in the brainstorming session and recorded in Appendixes A through F, were ranked with respect to overall market potential by teams at the University of Delaware; Mobil Tyco and InterTechnology/Solar Corporation. Members of the teams participating in the rankings were V. Dalal, J. Masi, A. Barnett, and J. D. Meakin from the University of Delaware; H. Chilton, A. I. Mlavsky, Messrs. Scharlack, Tornstrom, Ravi, and J. M. McNeil from Mobil Tyco and G. C. Szego, D. W. Doyle, and J. H. Paster from ITC/Solar.

Groupings in these three tables give a general picture of the rankings within the list of approximately 100 promising applications. Pairs of numbers in parentheses in Tables G-1 and G-3 show the total number of 2's and 1's received by an application (first numbers) and the number of ratings of 1 (second number). In Table G-2, groups are described by a single number in parentheses which indicates the total number of ratings of 1 and 2.

TABLE G-1

MOST PROMISING APPLICATIONS OF PHOTOVOLTAICS
CONSOLIDATED RATING OF UNIVERSITY OF DELAWARE GROUP

Group 1 (4,4)

DC battery chargers
Educational devices
Communications (regular, emergency)
Irrigation pumping
Pumping potable water
Telephone systems
Buoys
Reliable remote power
Space power
Rural television
Refrigerate medicine

Group 2 (4,3)

Electric toys
Portable power pack
Medical needs (emergency, mobile)
Educational television
Refrigerate food
National park power
Anti-corrosion
Driving air conditioners

Group 3 (4,2)

Generating and storing coolness

Group 4 (3,3)

Outside lighting

Weather station

Back-up for utility

DC for motors

Environmental sensors

Railroad signals and controls

Peak load for utilities

Pumped storage

National alert network

Traffic signals

Boats, sailboats, yachts

Driving solar thermal system

Electric car (for general use, for retirement community)

Emergency power

Cathodic protection

Military

Intrusion detectors

Group 5 (4,1)

Garden appliances

Remote medical centers

Greenhouse controls

Group 6 (3,2)

Intrusion defense

Data transmission

Water purification

Group 8 (3,1)

Food preservation

Clocks

Group 9 (2,2)

Radio

Phonograph

Power system

People movers

Electric fencing

Pool pump

Vent fan

Night lights

Electrostatic precipitator

Testing equipment

Electronic calculators

Remote switching

Anodic protection

Flashers, highway

Central power

Rural lighting

Medical telemetry

Installation in roads, billboards, runways

Gadget market

Portable water cooler

Portable refrigerator

Community center lighting

Water pumps, rugged area

Power remote construction tools

Bugging devices

Anti-theft devices

Group 9 (cont'd)

Telegraph

Mountain-top placement

Tracking solar collectors

Group 10 (3,0)

Controlled tractor

Power for construction trailer

Power for simple industries

Group 11 (2,1)

Electronic filtering

Greenhouses

Portable saw

Make fertilizer from sewage

Daytime cooking

Wild animal protection

Remote activation of explosives

Surveying

Battery-powered school bus

Electric flywheel bus

Electrolysis of water

    O₂ generation

    H₂ generation

Heating

Controls for bio-gas plants

Precious metal recovery

Desalinization

Using sunlight to provide light

Power animal-monitoring stations

Power shades for car or office

Group 11 (cont'd)

Fixing N₂

Personal locator (hikers, etc.)

Recharging stations

Ventilation of buildings

Automatic illumination adjustment

Dim lighting for buildings

Model airplanes

Electric bicycle

Pump for solar collector

Water recovery

TABLE G-2
MOST PROMISING APPLICATIONS OF PHOTOVOLTAICS
CONSOLIDATED RATING OF MOBIL TYCO GROUP

Group 1 (6)

- Cathodic protection
- Irrigation pumps
- Remote repeaters
- Pumping drinking water
- Buoys

Group 2 (5)

- Communications
- Portable powerpack
- Military
- Lighting, rural
- Educational television
- Lighting, general
- Weather station
- Closed water system
- Warning flashing lights

Group 3 (4)

- DC battery charger
- Corrosion control
- Combining w/solar heating
- Pumped storage
- Educational devices

Driving solar thermal systems
Refrigeration
Water treatment
Power for simple industries
Portable medical machines
Remote telephones
Watches
Sterilization
Pool pump
Railroad signals & controls

Group 4 (3)

DC for better lights
Back-up to utility
Food preservation
Television
Power auxiliary
DC to electronics
Medical needs
H₂ production
Powering citizen's band radios
Environmental monitors

Electric toys
Switching devices
Air conditioning
Electric games
Purify camp water
Food sterilization
Electric tractor with batteries

Group 5 (2)

Power system

Unlimited power

Offshore drilling rig

Radio

Boat

Complete climate control

Electrolysis of H_2O for eutrophication control and H_2 production

Rural airports

Grain drying

A/C load (peak) for utilities

Central power

H_2O desalination

Refining metals

Domestic electricity

Garden appliances

Controlled tractor

Power tools

Roof snow removal

Pumping oil to furnace

Clocks

Ice maker

Camper lights

Camping freezer

Power controls

Make fertilizer from sewage

Hand tools for construction

N₂ fixation

Telephone systems

Generating and storing coolness

Heating remote sites

Gadget market

Group 6 (1)

People movers

Electric fencing

Water removal

Food drying

Data transmission

Purify H₂O using ozonizer

Electroplating

Precious metal recovery

Electric bug electrocutor

Smoke detectors

Seismic activity detection

Sailboats (auxiliary power)

Educational demonstrations

Beacons (airfield)

Group 6 (continued)

Electric toilets
Electronic filtering
Ventilation control
Air purifier
Roll-out panels
Electric scarecrow
Vent fan
Night lights
Laundry
Electronic dirtcatcher
Intrusion protection
Camp heater
Use as combined shade
Cook in the daytime
DC welder
Pencil sharpener
Combustion-free, spark-free electricity for mines
Battery-controlled school buses
Heating
O₂ generation
Electric blanket

TABLE G-3

MOST PROMISING APPLICATIONS OF PHOTOVOLTAICS
CONSOLIDATED RATING OF INTERTECHNOLOGY/SOLAR CORPORATION GROUP

Group 1 (3,3)

Communications (general)
DC battery charger
Clocks
DC to electronics
Testing equipment
Remote switching
Corrosion control
Safety equipment
Remote activation of explosions
Powering electronics
Warning flashing lights
Educational devices
Lighting, general
Telephone systems
Remote repeaters
Lighting, rural
Remote telephones
Environmental monitors
Watches
Reliable remote power
Remote communications
Remote alarms
Calculators
Police stations
Railroad stations
Lighting, community center
Navigational equipment

Radio
Instrumentation (sensors)
Thermistors
Insolation meter

Group 2 (3,2)

Electronic filtering
Intrusion defense
Portable power pack
DC for bell
Power controls
Measuring distances
Road profile calculator
Haf communication equipment
Detecting crop harvesting time
Surveying
Leveling
Data transmission
Military
Portable medical machines
Pumping potable water
Powering electronics
Medical telemetry
Human and animal telemetry
Conversation pieces
Educational TV receivers
Pumping irrigation water (in combination with off-season uses)
Emergency power
Medical needs

Power skier's radio

Anti-static device

Power LED

Group 3 (3, 1)

Locating surveying stakes

Tracking solar collectors

Pumps (oil)

Group 4 (2, 2)

Automatic voltage control

Ordering systems

Cathodic protection

Educational devices

DC for microwave cooking

DC for electronics

Railroad signals and controls

National alert network

Controls for biogas plants

Toys

Buoys

Traffic signals

Sailboats

Detectors (smoke, ultrasonic, other)

Regulated greenhouse lighting

Space power

Novelty market

Rural lighting

Educational demonstrations

Public relations
Refrigerators for clinics
Refrigeration for medicine
Remote communications
Spotlight (accident, fire, police)
Beacons (airfield)
Portable hi-fi
Remote telemetry
Opacity control
Combine with solar/thermal
Power recovery beacon
Life-saving equipment
Speed controls
Hidden monitors
Electricity without wire for remote use
Personal memo computer
Electron microscopes
Modular power unit
Timer
Television
Intercom

APPENDIX III

APPENDIX III-A

32 PHOTOVOLTAIC PRODUCT DESCRIPTION SHEETS

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PHOTOVOLTAIC BATTERY CHARGER FOR SMALL BOATS

DESCRIPTION: A marine battery charger, powered by a photovoltaic panel, charges a standard marine battery and is of interest for many marine and navigational uses.

APPLICATIONS:

1. Corrosion protection.
2. Radio transceiver.
3. Navigational instruments.
4. Lights.
5. Preservation of engine starter battery during storage.

PERFORMANCE AND SIZE: The solar panel, about 2 ft. by 1-1/2 feet in size, is mounted on an exposed upper surface of the vessel and covered with tough plastic to protect it from the weather and damage. The edges of the panel blend evenly with the mounting surface to prevent tripping or stumbling.

The photovoltaic charger provides corrosion protection, for example, by passing a small current between an inert electrode and the exposed underwater metal parts of the vessel, such as the propeller. This method gives better protection than ordinary zinc electrodes and is particularly important if a radio transceiver is used on-board.

The corrosion protection and trickle charge for the battery continue even when the vessel is stored for a long time and help the operator get underway quickly.

ALTERNATIVE POWER SOURCES: At present, a conventional marine battery must be removed from the vessel to be charged, or the vessel's electrical system must be connected to an electrical outlet at the dock. Vessels with engines on board can charge their batteries while the engine is running but not during storage. Furthermore, it is not economical to run a sailboat's auxiliary engine solely to charge the battery.

The cost of electricity with conventional marine chargers is not a serious concern, but the inconvenience and loss of sailing time are. The amount of electricity provided by the panel is about 50 kilowatt-hrs. per year.

The cost of running the solar charger is, at present, quite high, but with increased usage and mass production, the cost will come down considerably.

PHOTOVOLTAICALLY POWERED REFRIGERATOR

DESCRIPTION: A small, five-cubic-foot refrigerator is powered by solar-cell panels which can be mounted on a roof and connected to the refrigerator by cable.

APPLICATIONS

1. Preserving food in campers, trailers, and tents.
2. Refrigeration for remote cabins and work camps.
3. Preserving food in developing nations
4. Preserving medicines in remote areas
5. Preserving medicines in emergency mobile clinics

PERFORMANCE AND SIZE: Three 2 ft. by 4 ft. panels are mounted on a south-facing roof and tilted at an angle approximately equal to the latitude. On sunny days, in addition to keeping the contents of the refrigerator cold, the power from the panels charges a battery and freezes extra ice to carry the unit through the night and up to three overcast days. The solar cells will last up to 20 years and require little maintenance. The panels can provide about 500 kilowatt hours of electricity per year.

ALTERNATIVE POWER SOURCES: Other ways such a refrigerator might be run include running a small gasoline generator or extending utility power lines out to the site. If utility power is available, it is the cheapest way to run a refrigerator because the power needed is only about 400 kilowatt hours per year. However, if the electrical lines need to be extended more than a few hundred yards, the cost will exceed the cost of either a gasoline power plant or the solar panels.

A gasoline generator costs about \$300 and can run a few lights and small appliances in addition to the refrigerator. However, it requires daily attention, lasts only two to three years, and is a maintenance problem in remote areas. Typically, the cost of the fuel and oil for this generator would be about \$340 per year, including delivery.

Currently, the solar cells are expensive, but the price will be dramatically reduced by mass-production in the near future.

PHOTOVOLTAICALLY POWERED 12-VOLT BATTERY CHARGER

DESCRIPTION: A solar-powered, general-purpose battery-charger for 12-volt batteries will recharge a standard battery in one day. The device is simple, requires little maintenance, and has a long lifetime.

APPLICATIONS:

1. Small battery-assisted vehicles.
2. Lawn mowers and garden tractors.
3. Garage and service stations.

PERFORMANCE AND SIZE: This battery charger consists of a photovoltaic panel, totaling 24 square feet, which may be mounted on a roof or in an open yard. The device is simple, has no moving parts and should last about 20 years. The panel provides approximately 600 kilowatt hours of electricity per year.

ALTERNATIVE ENERGY SOURCES: A battery charger can, of course, be powered either from the electrical grid, or by a small gasoline generator. In the case of the electrical grid it is not the cost of the electricity that is the important consideration but the cost of installing the electrical outlet. For a simple function such as charging a battery, only a modest expense for the initial installation would be appropriate. The cost of installing even a few hundred yards of electrical line, for example, out to a farm shed in which battery-powered tools were stored might equal the cost of the photovoltaically powered system. Once the electrical connection is installed, however, it could be used for other purposes such as lighting, in addition to the battery-charging function.

If a gasoline generator is used, it would cost initially about \$300 and would require about \$100 worth of fuel per year plus about \$30 in maintenance and oil. The device would last two or three years but would require considerable maintenance. The gasoline generator would be portable, however, and could be used for other tasks, such as operating power tools. The total cost for operating such a generator would be about \$250 per year.

The cost of the solar panels is currently quite high, but as usage and mass-production increase the cost will come down dramatically.

PHOTOVOLTAICALLY POWERED SOLAR COLLECTOR SYSTEMS

DESCRIPTION: Modular photovoltaic panels mount alongside the flat-plate collectors of a water or space heating system and provide power for electrically driven components.

APPLICATIONS:

1. Power for the fluid circulation pump.
2. Power for the control system.
3. Corrosion protection for collectors, pipes and storage tanks.

PERFORMANCE AND SIZE: If the pump which circulates the fluid through the collectors is to be powered, then about one square foot of photovoltaic panel is required for each six square feet of flat-plate collector. Each square foot of photovoltaic panels can provide about 20 kilowatt hours of electricity per year.

The pump only needs to run when the sun shines so a battery may not be required.

This system can also provide the power for a solid state control system which would include a small rechargeable battery.

Both the flat-plate and photovoltaic panels can be expected to last for twenty years with little maintenance.

These solar powered units can be used to advantage on space heating or water heating systems in remote areas or where independence from other power sources is desirable.

ALTERNATE ENERGY SOURCES: Where utility power is available, electricity may be used both for pumping and controls. A principal advantage of the solar powered pump is that it cannot be interrupted by power failures.

The present cost of the solar panels is high, but dramatic price reductions are expected with the introduction of mass-production in this industry.

PHOTOVOLTAIC POWER FOR SMALL ELECTRICAL APPLIANCES

DESCRIPTION: A small portable solar power unit will be useful for small electrical appliances. It either charges nickel-cadmium batteries or drives the appliances directly. It may be placed in a window at home or in the office, used in a car, or used on a beach or in the field.

APPLICATIONS:

1. Radios, record players, tape recorders.
2. Calculators, dictaphones, pagers.
3. Flashlights.
4. Grass trimmers and shears.

PERFORMANCE AND SIZE: Consider, for example, a compact device which contains a photovoltaic panel measuring 6 inches x 8 inches, the base of which holds batteries for recharging. The device also can be plugged into small appliances so that they may be operated directly off sunlight. A switch on the base allows the panel to provide the correct voltage for several different appliances. The recharger unit can be separated from the actual appliance, so it is unnecessary to leave the electronic appliance in the sun, which can cause damage by overheating. If protected from mechanical damage, the device should last 20 years and provide about 5 kilowatt hours of electricity per year. This charger contains circuits to prevent overcharging the batteries.

ALTERNATE ENERGY SOURCES: The batteries for such appliances could also be charged from electrical outlets in the house or primary, non-rechargeable batteries could be used. A battery charger operating on house current cannot be used in many of the places that the photovoltaic can, such as the beach or in the car, but it can be used at night. Primary batteries can be used, particularly on devices that do not draw very much current, but they are expensive and need to be replaced periodically. The cost of using the primary batteries would depend on how heavily the device is used.

The present cost of the solar device is high, but dramatic price reductions are expected with the introduction of mass production in this industry.

PHOTOVOLTAICALLY POWERED EMERGENCY RADIO BEACON

DESCRIPTION: A small photovoltaically powered radio can be switched on in emergencies to summon aid. It gives a radio signal, allowing searchers to home in on the transmitter both day and night for up to seven overcast days.

APPLICATIONS:

1. Private airplanes.
2. Private boats.
3. Hunters, hikers, skiers.

PERFORMANCE AND SIZE: A solar-powered radio is a small unit weighing about 8 pounds and having a photovoltaic panel 20 inches square which folds up. To summon aid, the solar panel is unfolded and faced toward the sun. The signal put out by the radio may be picked up by search aircraft at a considerable distance and will continue for as long as sunlight is available to recharge the batteries.

The entire unit may be stored indefinitely and requires no maintenance beyond a yearly inspection for proper operation. If protected from mechanical damage, the solar power supply should last in excess of 20 years.

ALTERNATE ENERGY SOURCES: Radio beacons may also be operated from a primary battery, which costs about \$25. If necessary, the battery will operate the radio for seven days. These batteries must be replaced every year and a half even if the transmitter is not used for they lose power in storage.

The present cost of solar panels is high, but dramatic price reductions are expected with the introduction of mass production,

PHOTOVOLTAICALLY POWERED HOUSE

DESCRIPTION: Photovoltaic panels located on the roof provide power for household appliances, lighting, and refrigeration. In addition, heating and cooling can be provided by a small heat pump working with roof-mounted solar-thermal as well as photovoltaic panels and an insulated energy storage tank. The entire house including appliances needs to be designed carefully to conserve energy. Power would be stored in a battery bank to give independence from the power grid.

APPLICATIONS:

1. Houses in remote sites.
2. Self-sufficient living units.
3. Locations where grid power is overloaded during summer days.

PERFORMANCE AND SIZE: A 1500 square-foot American home could be fitted with a solar system for providing almost all of the energy requirements. Household thermal energy requirements for heating space and hot water would be provided by 200-400 square feet of roof-mounted solar-thermal panels. In addition, an array of photovoltaic panels located on the roof, totaling 400 square feet, would provide electrical power for lighting, refrigeration, a microwave oven, other household appliances, control systems and a 24,000 Btu/hr heat pump which could provide cooling as well as heating. These photovoltaic panels could provide 10,000 kilowatt hours of electricity per year. A battery string located in the basement would be used to provide up to three days of power during extended overcast periods. A power conditioning unit converts the DC of the photovoltaic panels and batteries into standard AC power for normal household appliances.

The photovoltaic and solar-thermal panels and control circuits will last about twenty years. The battery bank, however, would need to be replaced after about fifteen years. The maintenance for the entire system would be quite low. However, on long winter days and during overcast periods, careful conservation of energy would be needed.

ALTERNATE ENERGY SOURCES: Where utility power is available, it would be the first choice for providing power to the house, since it requires far less capital investment than the solar-powered system. However, in locations where a power line must be brought in, the cost of installing the new power line can equal the cost of the photovoltaic system (power lines cost \$3,000 to \$10,000 per mile). Also, in areas where the grid power is overloaded on hot summer days, the photovoltaic system could give considerably more dependable service than the utility grid.

The present cost of solar panels is high, but dramatic price reductions are expected with the introduction of mass production in this industry.

PHOTOVOLTAICALLY POWERED HEAVY AGRICULTURAL UNITS

DESCRIPTION: A large but portable photovoltaic power source could provide power for driving a 50 horsepower irrigation pump. This same unit could be used during non-irrigation periods for a variety of uses such as crop handling and drying.

APPLICATIONS:

1. Agricultural irrigation, crop drying, crop handling.
2. Aquaculture.
3. Remote industries such as ore concentration.

PERFORMANCE AND SIZE: A solar powered agricultural unit may consist of 10 trailer-mounted photovoltaic panels totaling about 1500 square feet and a separate trailer containing a heavy battery bank and control circuits. If used in irrigation, the unit will power a 50-horsepower pump capable of providing 1000 gallons per minute against a 10 foot lift and 5 pounds per square inch outlet pressure for 2 1/2 hours per day. This is a total of approximately 144,000 gallons per day. The amount of electricity which can be provided by the panel is 38,000 kilowatt hours per year.

The batteries can store enough power to operate the pump at its rated capacity for 2 1/2 hours. The controls prevent the batteries from becoming overcharged and shut the motor off when the voltage level of the batteries is too low. Any number of photovoltaic panels may be connected to the control circuit depending upon the amount of power required for the job. During various seasons of the year, the power unit may be moved to different portions of the farm to provide power for such operations as blowing air for crop drying or running conveyor systems for loading produce.

If properly maintained, the photovoltaic panel should last in excess of 20 years. However, the battery pack would have to be replaced after 10 years.

ALTERNATE ENERGY SOURCES: Agricultural power of this magnitude could be provided either by connection with the electrical power grid or by installation of a diesel engine. If electrical power from the grid is to be used, the primary consideration is the cost of running the electrical subtransmission line out to the site where the power is needed. The cost of such subtransmission lines is about \$10,000 a mile for average terrain but can be much higher if the terrain is difficult. This often requires a substantial investment to obtain power at a single fixed location.

If a diesel engine is used, it will cost about \$10,000 initially, and require about \$2,000 worth of fuel a year. The cost of this fuel, however, is expected to rapidly increase and in some areas there may be restrictions on supply. The maintenance required for a diesel engine is much higher than for the photovoltaic system and the diesel motor can be expected to last about 10 years.

The cost of the photovoltaic panels is currently quite high, but with increased usage and mass production the cost will come down considerably.

PHOTOVOLTAICALLY POWERED WATER PUMPS

DESCRIPTION: A 1/2-horsepower water pump, powered by solar cells, has several features that will interest members of the farming industry, in addition to other small industries. Small in size and lightweight compared with conventional pumping devices, it is portable and operates automatically.

APPLICATIONS:

1. Watering livestock.
2. Irrigating small plots.
3. Providing drinking water.
4. Pumping liquids in small industries (wineries, tanneries).

PERFORMANCE AND SIZE: The pump is powered by two photovoltaic panels, which measure a total of 32 square feet and can produce about 800 Kilowatt hours per year. The pump is easily transported from one location to another since the solar panels fold to open and closed positions and because the panels, controls and batteries are mounted on a portable cart.

Two automobile batteries are used to store the sun's energy. If the panels are exposed to the sun all day, the pump will operate for about 2 1/2 hours. The batteries store enough energy to allow the pump to run during one overcast day. If more storage or longer daytime operation is needed additional batteries and modular solar panels can be added.

When used to pump water from a shallow well for irrigation or watering livestock, the pump will provide 36 gallons per minute, or about 5400 gallons for each sunny day. If used on a pressurized system, such as for drinking water, it will provide 4 gallons per minute, or about 600 gallons per day.

The panels will last about 20 years if kept clean and protected from mechanical damage. Maintenance is expected to be low. The batteries will need replacement after four years.

ALTERNATIVE POWER SOURCES: A power grid is the best power source at present; but in addition to the energy cost for 550 kilowatt hours per year, the cost of running electrical wire, even a few hundred yards, is more than the cost of the solar system. A windmill system, which costs about \$6,000 to install, has approximately the same life-expectancy and maintenance cost as the solar pump, but is limited to a fixed location.

The pump could also be run by a small gasoline motor, which costs about \$100 initially plus \$140 per year to operate. The motor will last two to three years but requires frequent maintenance and runs on flammable fuel, the price of which is expected to rapidly increase.

The cost of the solar pump is currently quite high, but as usage and mass-production increase the cost will come down dramatically.

PHOTOVOLTAICALLY POWERED WATER PUMP

DESCRIPTION: A five-horsepower water pump can lift 200 gallons per minute from a depth of 5 feet into a discharge pressure of 10 psi. It is powered by photovoltaic panels which may be stored and carried on a cart which also houses the batteries.

APPLICATIONS:

1. Irrigation of small plots.
2. Aquaculture.
3. Small industries such as sea-salt recovery.

PERFORMANCE AND SIZE: The entire unit including pump, hoses, photovoltaic panels, battery and control circuits mount on a small cart or wagon for ease of transport and moving from site to site. The pump may be quickly set up and the panels unloaded and adjusted to face the sun. The panels total 240 square feet of photovoltaic cells and can provide 6000 kilowatt hours of electricity per year. This is enough power to run the pump for 2-1/2 hours each day in which time it can pump 29,000 gallons of water.

The cart also contains a battery capable of running the pump for 2-1/2 hours and control circuits which prevent the battery from being overcharged and shut the pump off when the batteries reach their low voltage level.

The photovoltaic panels and batteries can also be used as a power supply for other farm implements, such as crop dryers.

The photovoltaic system is simple and requires little maintenance. If the panels are protected from mechanical damage they will last about 20 years. The battery, however, will have to be replaced after 10 years.

ALTERNATE ENERGY SOURCES: Pumping of this type could also be done by a small gasoline-powered pump or by an electric pump connected to the power grid. The gasoline-powered unit costs only about \$150 but would require a higher level of maintenance and attention than the photovoltaic unit. It would burn about \$470 worth of fuel a year to provide the same amount of pumping as the solar unit. The price of this fuel is expected to rapidly increase. The maintenance on these small gasoline engines is also problematic as they can be counted on to last only 3 or 4 years.

If power from the electric grid is to be used, then an electrical line to the pumping site must be available. The cost of installing such power lines can be as high as \$10,000 a mile.

The cost of the solar panels is at present quite high, but with increased usage and mass production the cost will come down considerably.

PHOTOVOLTAICALLY POWERED CROP DRYING UNITS

Description: This portable photovoltaic power source provides power for a number of agricultural requirements including crop drying, crop handling, and irrigation. The unit shown is for crop drying and will provide 10 horsepower for 12 hours on each sunny day to power air blowers. The blown air is also warmed slightly by a simple solar collector.

APPLICATIONS:

1. Crop drying.
2. Agricultural irrigation.
3. Crop handling.

PERFORMANCE AND SIZE: This unit consists of 10 trailer or skid-mounted photovoltaic panels totaling 1500 square feet and a separate trailer containing a large battery bank and control circuits. When set up for crop drying this unit can provide 10 horsepower to air blowers for up to 12 hours per day. The air is blown through a simple solar collector which warms the air a few degrees thereby reducing its relative humidity and speeding the drying process. The panel provides about 40,000 kilowatt hours per year.

The batteries can store enough power to operate the blowers at their rated capacity for about 2-1/2 hours. The controls prevent the batteries from becoming overcharged and shut the motor off when the voltage level of the batteries reaches its low level. During various seasons of the year, the power unit may be moved to different portions of the farm to provide power for such operations as irrigation or running conveyor systems for loading produce.

If properly maintained, the photovoltaic panel should last in excess of twenty years. However, the battery pack would have to be replaced after ten years.

ALTERNATE ENERGY SOURCES: The required power could be provided by connection with the electrical power grid or by installation of a diesel engine. If electrical power from the grid is to be used, the primary consideration is the cost of running the electrical subtransmission line out to the site where the power is needed, particularly since the power is needed only a few weeks of the year. The average cost of such transmission lines is about \$10,000 a mile.

If the diesel engine is used, it will cost about \$2,200 initially and require about \$200 worth of fuel and maintenance a year. The cost of the fuel, however, is expected to rapidly increase and some areas may have restrictions on supply. The maintenance on a diesel engine is much higher than on the photovoltaic system and the engine can be expected to last about fifteen years.

The cost of the photovoltaic panels is currently quite high, but with increased usage and mass production the cost will come down considerably.

PHOTOVOLTAICALLY POWERED OUTSIDE LIGHTING

DESCRIPTION: A 175-watt mercury-vapor lamp powered by solar energy may be used out of doors. This system includes a light which may be pole-mounted or mounted on the side of a building, a photovoltaic panel, and a battery to allow night-time operation.

APPLICATIONS

1. Lighting farmyards.
2. Security lighting around remote buildings.
3. Lighting for signs.
4. Lighting for parking areas.

PERFORMANCE AND POWER: A solar-powered 175-watt mercury lamp puts out the light of a 300-watt incandescent lamp, but requires only about half as much electrical power. The power comes from an array of photovoltaic cells totalling 48 square feet which may be mounted on the roof of the building or have their own separate structure. On sunny days the solar panels charge a battery which may be housed either inside a building or in a weatherproof box beneath the solar array. The light is turned on automatically as the light fades in the evening and turned off again in the morning. The battery stores enough power to operate the light at night for up to three nights during overcast periods. The panels will last about 20 years protected from mechanical damage. The batteries and light bulb will need replacement approximately every five years. The entire system is fully automatic and requires low maintenance.

ALTERNATIVE POWER SOURCES: Such a light can be powered by connection to the commercial power grid and is an inexpensive, low-maintenance source of power where it is available. The only problem is that the cost of extending the electrical wires out to the site where the light is needed can be more expensive than the cost of the light or energy it uses. The cost of the photovoltaic system can equal the installed cost of only a few hundred yards of power connection. If such a power line is installed, however, it can provide power for other uses as well as lighting.

The cost of solar cells is currently quite high but as usage and mass production increase the cost will come down dramatically.

PHOTOVOLTAICALLY POWERED CONSTRUCTION TRAILER

DESCRIPTION: This self-contained trailer provides temporary office space for new construction sites and for other temporary or remote sites. The unit has 192 square feet of office space and features photovoltaic panels to provide electrical power for lighting, small appliances and a small air conditioner. Heating and hot water requirements are provided by solar-thermal collectors also included in the design.

APPLICATION:

1. Temporary office space at construction sites.
2. Temporary office or living space for remote industries.

PERFORMANCE AND SIZE: This unit consists of a conventional trailer office space unit which is well insulated with the addition of solar panels totaling 100 square feet of photovoltaic cells and up to 72 square feet of solar-thermal collectors. The unit functions independently of conventional electrical power lines and allows for the use of normal office lighting and electrical equipment such as typewriters, while keeping the temperature in a comfortable range except under the most extreme conditions. The unit contains batteries capable of providing electrical power for up to three consecutive overcast days and an insulated hot-water tank to store heat for overcast winter days. The amount of electricity provided by the panels is about 2,000 kilowatt hours a year.

If more office space is needed several units may be used at the same site. The units require very little time to install at a new site, and have low maintenance requirements. Both types of solar panels are expected to last 20 years or more.

ALTERNATE ENERGY SOURCES: Such temporary office space could of course be powered from the electrical grid which requires establishing temporary electrical connections. For sites where electrical power is available this is the most economical method to provide power. However, in situations where there is no nearby electrical power at the site and the space is needed quickly, the independence of the photovoltaic system may justify the additional cost. The cost of running an electrical line would be about \$1,000-\$3,000 a mile depending on the terrain.

A small gasoline-powered electrical generator might also be used. These units cost about \$300.00 and cost an additional \$350 a year to operate. They require substantial maintenance and can be counted on to last only two to three years. These units are noisy and require expensive and perhaps unavailable fuel.

The cost of the photovoltaic panels is currently quite high but with increased usage and mass production the cost will come down considerably.

PHOTOVOLTAICALLY POWERED REPEATER STATIONS

DESCRIPTION: Repeater stations for the telecommunications industry are often located in remote places and require highly dependable DC power. Photovoltaic panels working with batteries are well-suited to provide power for this application.

APPLICATIONS:

1. Microwave repeater stations.
2. Telephone cable repeater stations.
3. Satellite ground stations.
4. Radio-telephone interlink units.

PERFORMANCE AND SIZE: Consider a small 200-watt microwave relay station mounted on a remote mountain top. Its continuous load can be supplied by photovoltaic panels totaling 110 square feet. These can provide 2300 kilowatt hours of electricity per year. The panels are mounted on metal frames beside the repeater station and can be easily transported to the site by helicopter.

All repeater stations contain a battery bank to power this system during power failures. The battery bank for the photovoltaically powered repeater station would be made of batteries specifically designed for photovoltaic applications, but would not cost much more than the batteries normally provided for repeater stations. The photovoltaic panels are dependable and will last up to 20 years. The batteries would have to be replaced after 10 to 15 years. The photovoltaic system is simple, requiring little maintenance.

ALTERNATE ENERGY SOURCES: Repeater stations may be powered by the electrical grid. The major consideration here is the cost of running the electrical subtransmission line to the repeater site. In cases where the repeater is at a remote location, this cost may be considerable since subtransmission lines cost approximately \$10,000 per mile or more if in poor terrain.

The repeater station could also be run by a diesel generator but such generators are not dependable for unattended operation on repeater sites.

The cost of the solar panels is currently quite high, but the increasing usage and mass production will bring down the price considerably.

LARGE PHOTOVOLTAIC POWER FIELDS

DESCRIPTION: A one-megawatt peak-power photovoltaic field will provide electrical power into the electrical grid. It will provide its full peak power during daylight and, with storage, provides a smaller amount of power at night.

APPLICATIONS:

1. Daytime peak-load power.
2. Power for remote villages and industries.

PERFORMANCE AND SIZE: A one-megawatt photovoltaic power field would consist of 13 square miles of photovoltaic panels, an advanced storage device, a high-wattage power conditioning device and a control system. The field would be installed to maximize the amount of sunlight falling on the panels and to minimize the distance the cables must run between the rows of panels and the storage facility. The power field would produce 44-million kilowatt hours of electricity per year.

The storage facility contains sufficient power to provide one-half the rated load of the facility for six hours. It may consist of either advanced storage batteries, a high-speed flywheel generator storage, or work in conjunction with a hydroelectric dam.

Energy conditioning equipment converts the DC power generated by the electric photovoltaic cells into high-voltage AC power suitable for transmission by high-voltage lines. Working with the control unit, the equipment matches the frequency of the output power to the frequency of the line and balances the load against the incoming power and storage.

This system is particularly suited for meeting large daytime peak loads. It requires low maintenance, a small operating crew, is simple in its operation, and has a life expectancy of at least 20 years.

ALTERNATE ENERGY SOURCES: The alternatives to this solar plant are conventional power plants which burn nuclear fuel, petroleum fuels or coal. The choice for a specific fuel will depend on their relative prices and supply. Also, the amount of capital that must be invested to produce a given capacity of power production must be taken into consideration, along with the environmental effects of the plant. The solar plant will have advantages in locations (1) that have a large amount of incoming solar energy, (2) where the load shows a large peak during daylight hours, (3) where other conventional fuels are expensive or in questionable supply, and (4) where it is favorable to make large capital investments to eliminate fuel costs.

The present cost of solar panels is high, but dramatic reductions are expected with the introduction of mass production into this industry.

PHOTOVOLTAICALLY POWERED GREENHOUSE CONTROL

DESCRIPTION: A photovoltaic panel can be used to power a device which opens and closes the vents in greenhouses in response to temperature. Each automatic unit operates independently and is free of outside power sources.

APPLICATIONS:

1. Greenhouses.
2. Livestock buildings.
3. Solar heated houses.

SELF-CONTAINED CONTROL UNIT
WITH PHOTOVOLTAIC ARRAY AND
BATTERY STORAGE.

PERFORMANCE AND SIZE: The control for each vent is independent and consists of a photovoltaic panel 5 in. by 7 in., a nickel-cadmium battery, a small electric motor, a control circuit and a mechanical opening arrangement. Control circuits may be set to open the vent either at a pre-determined temperature or at a pre-set light level. The photovoltaic panel has a long lifetime and is dependable. The mechanical opening device would, however, require periodic cleaning and lubrication, probably twice a year.

ALTERNATE ENERGY SOURCES: Such a system could be driven by power from the electric utility if it were available at the greenhouse. If it were available, then the cost of installing the electric wires would have to be compared against the price of the photovoltaic system.

Mechanical systems that allow the greenhouse operator to open the vents are now widely used. These, however, do not allow automatic opening of the vents in response to temperature and consequently do not provide the best temperature regulation.

The present cost of solar panels is high, but dramatic price reductions are expected with the introduction of mass production in this industry.

PHOTOVOLTAIC BATTERY CHARGER FOR POWER TOOLS

DESCRIPTION: A battery-tool charger, powered by solar cells, is a convenient device for the homeowner, construction worker and users of electronic equipment. Designed for either stationary or portable use, the charger can mount on the roof of a house, tool shed, larger toolbox or pickup truck and will recharge the nickel-cadmium batteries in a variety of tools.

APPLICATIONS:

1. Power tools--drills, screwdrivers, saws, staplers
2. Lights--flashlights, lamps, cap lights, camera-strobes, and highway flashers.
3. Garden and yard tools--trimmers, edgers.

PHOTOVOLTAIC ARRAY (12 sq. ft.)

PERFORMANCE AND SIZE: The charger collects and stores the sun's energy by means of a 3 ft. by 4 ft. photovoltaic panel, which can provide about 300 kilowatt hours per year and enough power to recharge the batteries for an electric screwdriver or small drill in four hours. If an extra battery pack is charged while the tool is in use, there will be enough power to use the tool continuously. Additional modular solar panels can be used for higher-load tools, such as circular saws, or for charging several tools at the same time. On trucks and trailers, the panels may be hinged to lay flat during transport and tilted up for use.

The solar panels are expected to last for 20 years or more and require little maintenance.

ALTERNATIVE POWER SOURCES: Solar chargers are a convenient alternative to conventional chargers which must be connected to electrical outlets. While conventional chargers are less expensive than the solar panels, electrical outlets are not always available, as, for example, on new construction sites.

A conventional recharging system, which uses the mobile electrical system, costs about \$80 to install. Although this type of charging system will not run down the vehicle's battery, it puts an extra load on the engine and consumes fuel.

The cost of solar cells is presently high, but with mass production, it is expected to come down dramatically, in contrast to the rapidly increasing cost of electricity.

PHOTOVOLTAICALLY-POWERED COMMERCIAL REFRIGERATOR

DESCRIPTION: A 12-ton, solar-powered, commercial refrigerator can provide cooling for meats, crops or fish. It also can provide ice for shipment of perishable goods.

APPLICATIONS:

1. Preservation of fish, meat and crops.
2. Ice for shipment of perishable goods.
3. General refrigeration.

PERFORMANCE AND SIZE: A typical solar refrigeration unit might be located on a fishing pier to provide ice for preserving the catch while the fishing boats are out at sea and packing the fish for transport. A 12-ton system uses 2800 square feet of photovoltaic panels mounted on the roof. These would provide about 60,000 kilowatt hours per year and should provide sufficient ice for a small fishing fleet. The unit would include a battery bank capable of operating the refrigerator for about eight hours. When there is excess power on sunny days, extra ice could be made and stored to be used during cloudy periods. With reasonable maintenance and protection from mechanical damage the solar array should last about 20 years. The batteries, however, would have to be replaced after 10 years.

ALTERNATE ENERGY SOURCES: The refrigeration unit could be provided with power from the electrical grid or be powered by a diesel engine. If power from the electrical grid is used then the grid must be accessible at the site. The main cost consideration in this case is the cost of installing a subtransmission line to the site where the power is needed. At remote locations, this can represent a considerable investment since the cost of the subtransmission line is \$10,000 or more per mile.

If a diesel engine is used, it would cost about \$8,000 initially and would cost about \$7,000 a year to operate. The cost of its fuel, however, is expected to rapidly increase and in some areas it may not be available in the future. The maintenance of a diesel powered unit would be more difficult and require higher levels of skilled technicians for periodic maintenance and repairs. The diesel unit could be expected to last about 10 years.

The cost of the solar system at present is quite high, but with increase usage and mass production the cost will come down considerably.

PHOTOVOLTAICALLY POWERED SECURITY EQUIPMENT

DESCRIPTION: Solar powered security devices can detect the presence of an intruder at a remote location and radio a signal back to a base station. They are independent from electrical power connections, may be mobile and are rugged and dependable.

APPLICATIONS:

1. Security for box cars.
2. Security for truck trailers.
3. Security for remote industrial sites.
4. Security for boats and small craft.

PERFORMANCE AND SIZE: A security unit for a box car, for example, would use a photovoltaic panel, 18 in. x 18 in. mounted on the roof of the box car. A radio antenna is mounted within a fiberglass cover along the ridge of the roof and door sensors are mounted on all entries. If any of the doors are opened without the alarm being properly switched off, or if the antenna or panel is interfered with, the unit sends out an alarm which may be picked up by the railroad security forces or by a properly equipped local police unit. If desired, the system could also use an audible alarm. The unit is dependable, requires little maintenance, and the photovoltaic panel keeps the battery within the transmitter fresh at all times. The panel can provide about 40 kilowatt hours of electricity per year and can be expected to last for 20 years or more.

ALTERNATE ENERGY SOURCES: This unit could also be powered by primary or non-rechargeable batteries. To do so would require a 12-volt, 7-amp battery which costs about \$25. This battery has a shelf-life of approximately 1-1/2 years; to assure operation, the battery would have to be replaced about that often. If the alarms were activated and the battery were to operate the radio for more than a few minutes, the battery would then have to be replaced. The major expense is the labor for checking on and maintaining fresh batteries in a large number of units scattered over a large area. The main advantage of the solar-powered unit is its reduced maintenance requirement and its ability to keep the battery fresh indefinitely.

The cost of the solar panel at present is high, but with increased usage and mass production the cost will come down dramatically.

PHOTOVOLTAICALLY POWERED SMALL ELECTRIC VEHICLES

DESCRIPTION: A photovoltaic battery pack can be used to power small electric vehicles. Two battery packs are used so that one can be charging while the vehicle is being operated. Battery packs may be interchanged at the beginning of each working day.

APPLICATIONS:

1. Industrial vehicles such as forklifts.
2. Vehicles for elderly persons.
3. Security patrol vehicles.
4. Recreation and sports vehicles.

PHOTOVOLTAIC ARRAY (256 sq. ft.)

BATTERY CHARGING STATION

BATTERY POWERED FORKLIFT

PERFORMANCE AND SIZE: A small solar-powered forklift would be suitable for use in handling agricultural produce or in industrial applications at remote sites, such as mining. For this vehicle, an array of 32-2 ft. x 4 ft. panels, totaling 256 square feet, would be needed to charge a battery pack consisting of 12 heavy-duty 6-volt batteries in one day. The panels could either be mounted on the roof of a shed or on a separate structure in an open field. The battery packs would be located on a rack that allows them to be easily slid on and off the vehicle. This device would be most useful in areas where the workload is heaviest during the sunniest portions of the year. An extra battery pack could be kept charged by the array for use on cloudy days.

ALTERNATE ENERGY SOURCES: Such vehicle batteries could also be charged either by power from the electrical grid or by a gasoline-powered generator. If the electrical grid power is to be used then a subtransmission line must be brought in. Since the annual amount of electricity needed for the forklift--about 5,400 kilowatt hours per year--is not large, the cost of initially bringing in the transmission line is the major consideration. Such subtransmission lines cost about \$10,000 per mile, but if the terrain is very difficult, the actual cost may be three or four times this figure. Once the transmission line is brought in, however, it can provide power for a large number of operations.

If a gasoline-powered generator or a gasoline-powered vehicle itself is used, then there is the problem of transporting and storing the flammable fluid. Also, maintenance and operation costs for the gasoline-powered vehicle are much higher than for the electrical vehicle. Fuel and maintenance for a small forklift would run approximately \$525 a year.

The present cost of the solar panels is high, but dramatic price reductions are expected with the introduction of mass production into the industry.

PHOTOVOLTAIC POWERED CORROSION PROTECTION FOR INDUSTRIAL APPLICATIONS

DESCRIPTION: A solar-powered, low-voltage DC power supply can prevent the corrosion of metallic structures which are in contact with ground water, sea water or fresh water by passing a low-voltage DC current between the metal structure and a passive electrode. The electric current prevents oxidation reactions at the surface of the metal structure thereby greatly prolonging its life.

APPLICATIONS:

1. Pipelines, well-casings and tanks.
2. Bridges, piers, docks and locks.
3. Ship hulls, off-shore platforms and buoys.

PERFORMANCE AND SIZE: Corrosion protection, sometimes called cathodic protection, requires a DC power supply which is dependable and often located in remote areas. As an example, consider a photovoltaic power supply rated at 5 amps and 6 volts. This could provide protection for a well-casing of about 25 miles of new one-foot diameter pipe if that pipe is wrapped with protective material. The protective device consists of a photovoltaic panel totaling 20 square feet, a 6-volt battery rated at 360 amp-hours, and a control box. During daylight hours the photovoltaic panel provides the protection and charges the batteries, thus ensuring that the protection continues at night and through as many as three consecutive overcast days.

The photovoltaic panels have a lifetime of 20 years or more and the system requires attention only once or twice a year. The batteries, however, would have to be replaced after 10 years. The photovoltaic panels will provide about 400 kilowatt hours of electricity per year. This is not a large amount of electricity but it is provided exactly where it is needed.

ALTERNATIVE ENERGY SOURCES: Power for cathodic protection is now provided by DC power supplies connected to the electrical grid or by thermal-electric power supplies which run on natural or bottled gas. In the case of using power from the electrical grid, the controlling factor is the cost of new subtransmission lines. If the location of the device to be protected is close to an existing connection to the electrical grid, then this does provide a dependable source of power for the cathodic protection system. However, the cost of the photovoltaic power supply is equal to the cost of only a few hundred yards of subtransmission line and less than the cost of running such a line under a road or across difficult terrain.

When thermal electric generators are used for corrosion protection they must have a supply of high quality fuel. This sometimes takes the form of bottled gas which must be renewed every few months or, in the specific example of natural gas pipelines, the natural gas itself may be used to power the thermal electric generators. Therefore, the generators require a maintenance trip to renew their fuel supply every few months and on occasion they fail to provide the electrical power because wind has blown out their internal flame. The limiting factor is the cost of providing this fuel at the remote locations, rather than the cost of the fuel itself.

The cost of the solar panel is currently high, but as usage and mass-production increase the cost will come down dramatically.

INDUSTRIAL PHOTOVOLTAIC POWER

DESCRIPTION: A photovoltaic array can provide substantial amounts of power for industrial processes in remote areas. It features unattended operation, energy storage for night operation, and low maintenance requirements.

APPLICATIONS:

1. Pipeline pumping stations.
2. Mine ventilation.
3. Well pumping.

PERFORMANCE AND SIZE: A pipeline pumping station may have a 100-horsepower electric pump which must be operated 24 hours a day. The photovoltaic power system would consist of a field of 5,300, 2 ft. x 4 ft. panels with a total area of 42,400 square feet, an energy storage device, and a control system. During sunlight hours, the array would provide a large amount of power both to run the motor of the pump and to charge the energy storage device. At night and on cloudy days, the energy storage would carry the full load for up to three consecutive cloudy days.

Since the energy storage would require about 6.5 million volt-amp-hours of storage, the storage device would probably need to be of an advanced design. Advanced systems should be commercially available in the late 1980's. The photovoltaic system is capable of operating months at a time without attendance and requires low maintenance. Given periodic maintenance, the photovoltaic array should last 20 years and the energy storage system 15 to 20 years. This photovoltaic system could provide about one- million kilowatt hours of electricity per year.

ALTERNATE ENERGY SOURCES: Power for this pump could be provided either from the electrical grid or by a diesel engine. If power from the electrical grid is to be used, a subtransmission line must be run to the location of the pump. These lines cost from \$10,000 to \$45,000 a mile, depending on the terrain, and for remote locations constitute a substantial investment. Use of the grid power would also involve an energy cost, but like the photovoltaic system, it could be operated unattended with low maintenance.

If a diesel engine were used for the power, it would cost about \$8,000 initially and would require fuel. The cost of the fuel would be dependent upon the cost of transportation to the site. Also, diesel units require more maintenance and cannot be operated unattended for long lengths of time. The cost of the fuel for the diesel system is also expected to rapidly increase.

The present cost of the solar panels is high, but dramatic price reductions are expected with the introduction of mass production into this industry.

PHOTOVOLTAIC POWERED EMERGENCY CLINIC

DESCRIPTION: A small medical facility can have power for medical electronic equipment, lighting and communications provided by photovoltaic panels mounted on the roof of the unit. This unit may be stored for long periods without attention, transported easily by air, truck or ship and set up very quickly.

APPLICATIONS:

1. Disaster relief.
2. Epidemic control.
3. Population control programs.
4. Routine clinical uses.

PERFORMANCE AND SIZE: The entire clinic is the size of a standard shipping container and is approximately 8 ft. x 20 ft. at the base. It contains tents which may be quickly set up to provide covered area for receiving patients. The photovoltaic array of about 160 square feet mounted on the roof of the container provides power for electrical lighting, radio communications and for medical electronic equipment. The unit may be used for receiving patients, examining them (for disease or injury), providing first aid or vaccinations and stabilizing the severe patients for transport to better equipped facilities. The unit might also be used for minor surgical procedures such as sterilization or cataract operations. The unit contains a small refrigerator for storage of blood and medical supplies.

The unit contains enough electrical power storage in the form of batteries for one full day of operation. If an overcast period continued for longer than that, then a small gasoline generator would be needed as a backup.

The photovoltaic panels can provide about 4000 kilowatt-hours of electricity per year. These panels are expected to last for 20 years or more and require little maintenance.

ALTERNATIVE POWER SOURCES: This medical clinic could also be powered by a small gasoline-driven generator costing about \$300. However, these generators do not store for long periods as well as the photovoltaic systems and they are difficult to maintain. Storage and transportation of the flammable fuel can also be a problem. If used intermittently for a few weeks at a time, such a generator would cost \$400 a year to operate and would require much more attention by skilled personnel than the solar system and would be noisy.

The cost of solar panels is currently high, but as usage and mass-production increase the cost will come dramatically.

PHOTOVOLTAICALLY POWERED RADIO TRANSCEIVER

DESCRIPTION: A 200-watt radio transceiver can be powered by an array of photovoltaic which can be folded up for transport. A rechargeable battery pack provides enough power to the transceiver to allow operation at night and through three consecutive cloudy days.

APPLICATIONS:

1. Work camps and ranches.
2. Military and police stations.
3. Natural disaster coordination.

PERFORMANCE AND SIZE: The solar transceiver will broadcast two-hundred watts of R.F. power, transmit two to three hours a day, and receive three to twelve hours a day on the energy provided by 24 square feet of solar panels. The panels have no moving parts, are very dependable, and will last 20 years if not damaged. If more hours per day of operation time are needed, additional modular solar panels may be added.

The battery's capacity equals that of three good automobile batteries and is mounted in a sealable transport case. Standard automobile batteries may also be used if the weather remains overcast longer than three days. The panels can also be used to charge the batteries of small, hand-held transceivers which are often used in conjunction with the base stations. The panels can provide about 500 kilowatt hours of electricity per year.

All the components easily pack into their transport cases and can be quickly unpacked and put into operation. The solar panels may be set up either on open ground or permanently mounted on a roof.

ALTERNATIVE POWER SOURCES: The transceiver can also be run by a small gasoline generator instead of the solar panels and batteries. Such a generator would cost about \$300 and could provide some additional power for lights and other small-power electrical devices. If run for the same number of hours per day, it would burn about \$400 of fuel a year and would last two to three years with good maintenance. It would require daily attention and use about \$30 per year of maintenance materials. These units are noisy and have a reputation for maintenance problems.

The cost of the solar panels is currently high, but as usage and mass-production increase, the cost will come down dramatically.

PHOTOVOLTAICALLY POWERED HIGHWAY LIGHTING

DESCRIPTION: Photovoltaic panels can provide power to light highway signs, warning flashers, and highway rest stops.

APPLICATIONS:

1. Power for highway rest stops.
2. Lighting for highway signs.
3. Power for warning flashers.
4. Lighting for commercial signs.

PERFORMANCE AND SIZE: Consider for example, that photovoltaics could be used in a highway rest stop for interior lighting, to run a one-half horsepower water pump which pumps water from a well, and to provide some outside lighting around the entrance. This would require about 144 square feet of photovoltaic panels which could produce about 1700 kilowatt hours of electricity per year. During the day the panels would charge a set of batteries to provide lighting at night and run the well pump, charging a pressurized tank to maintain a constant water supply. The entire system is designed for low maintenance and to deter vandalism. The panels could be expected to last about 20 years and the batteries and pumps about 10 years.

ALTERNATE ENERGY SOURCES: Where utility power is available, electricity could be used both for the pumping and lighting. However, at many locations, electrical connections would have to be brought in from some distance. The cost of subtransmission lines is high, averaging about \$10,000 a mile. In areas remote from the power grid, the cost of installing the power line compared to the cost of the photovoltaic system is a primary consideration.

The present cost of the solar panels is high, but dramatic price reductions are expected with the introduction of mass production in this industry.

PHOTOVOLTAICALLY POWERED VILLAGE POWER SUPPLY

DESCRIPTION: A 5-kilowatt photovoltaic power supply can provide standard AC power to a number of homes, shops and buildings. It receives all its power from the sun and is intended for locations beyond the reach of the conventional electrical power grid.

APPLICATIONS:

1. Villages in developing nations.
2. Remote industries, logging camps, ranches, etc.
3. Schools, community centers, remote clinics.

ENERGY STORAGE FLYWHEEL SYSTEM

PERFORMANCE AND SIZE: The installation consists of a field of approximately 1200 square feet of photovoltaic panels mounted on supports which face the sun. Also, included are a power storage facility and a power conditioning device to transform the DC current provided by the photovoltaic cells into conventional AC current. The photovoltaic field will provide enough power for an average load over a 24-hour period of 5 kilowatts. It will, of course, provide a much larger amount of power during the peak sunshine hours.

The storage system contains enough electrical power to run the system at one-half its rated power for 24 hours, which provides enough storage for normal night operations, plus some storage for overcast days. However, during seasons of the year with a number of overcast days in succession, power use would have to be reduced. At present, the storage consists of a string of large lead acid batteries especially designed for solar applications. These batteries have a lifetime of about 10 years and require very little maintenance.

The system is extremely simple to operate, requires only modest technological skills and should last for 20 years or more. If an electrical power grid is extended to the village during that period, the photovoltaic system may be disassembled and moved to a more remote location.

ALTERNATIVE ENERGY SOURCES: This type of power could also be provided by extending the electrical grid to the location or by installing a diesel generator. In the case of the electrical grid, two things must be considered: (1) does the existing generating plant have excess capacity? and (2) what is the cost of extending the electrical grid? If the electrical generators do have extra capacity then it may be best to use this capacity to the fullest by extending the electrical grid. If extension of the electrical grid is an important consideration, then the terrain over which the electrical lines must pass is an important factor. The cost of subtransmission line can vary from about \$10,000 to as much as \$45,000 per mile if the terrain is very poor.

A 5-kilowatt diesel generator costing about \$7,000 could provide service similar to the photovoltaic system. It would, however, require petroleum fuel which is often an expensive imported item and may have a limited supply. This generator would cost about \$5,400 a year to operate and would require a high level of maintenance skills for dependable operation. A diesel generator can be expected to last about 10 years with proper maintenance.

The cost of the solar installation is currently quite high, but as usage and mass-production increase the cost would come down dramatically.

PHOTOVOLTAICALLY POWERED REMOTE CALL-BOX

DESCRIPTION: When the switch on a remote call-box is thrown by a person needing assistance, it radios a signal to a police command headquarters which then notifies a patrol car. Also, a light on the box lights up in response to a signal from the central control station to signify that the message was received. Power for the radio and light can be provided by photovoltaic cells.

APPLICATIONS:

1. Along highways.
2. On bridges and crossways.
3. On city streets.
4. As fire alarm boxes.

PERFORMANCE AND SIZE: In appearance and size, this device looks much like a fire alarm box often seen on city streets, except that a small radio antenna and photovoltaic array is placed atop the pole. The photovoltaic panel is only 9 square inches, since the radio transmitter is not used often and the main purpose of the panel is to keep the batteries charged. The receiving base station would be incorporated into the local police dispatcher's radio room and would not require additional manpower. If these call boxes were used on roads in remote areas, a repeater box at a high point might be necessary. Repeaters would also be photovoltaically powered. The photovoltaic unit is dependable and requires little maintenance. However, the design of the mount and box would require considerable care to minimize the effects of vandalism.

ALTERNATE POWER SOURCES: These units could also be powered by connection to power lines, but the installation cost would be high, especially if it necessitated ripping up sidewalks or running transmission lines a great distance. The primary advantage of the photovoltaic power source is that it reduces the cost of the installation.

The cost of solar panels are expected to dramatically reduce with the introduction of mass production in this industry.

PHOTOVOLTAICALLY POWERED REMOTE DETECTORS

DESCRIPTION: A photovoltaically powered electronic instrument can measure specific environmental conditions and report those measurements to a base station. The primary purpose of such an instrument is to warn appropriate authorities of dangerous conditions and provide the basic information to allow them to take any required action.

APPLICATIONS:

1. Flood monitors.
2. Forest fire monitors.
3. Earthquake monitors.
4. Pollution monitors.

PERFORMANCE AND SIZE: Consider a flood monitor which upon the receipt of a coded signal from a base station sends back a signal indicating the height of the water level and its location. Several of these positioned upstream from a town could provide the information needed to calculate the time and height of a flood crest. The unit may be pole-mounted and could consist of a box containing the electronics, a photovoltaic panel 18 in. square, and a series of water-level sensors on a cable. The photovoltaic panel provides about 50 kilowatt hours of electricity per year, is durable and requires little maintenance. The proper operation of the unit may be checked without going out to the site, so only one or two maintenance trips a year are necessary. The unit is completely self-contained.

ALTERNATE ENERGY SOURCES: This instrument could also be run from an electrical power line. A battery would have to be included within the unit to ensure its proper operation should the power fail during an emergency period. The amount of the electricity needed is not very large so the energy cost is not a primary consideration; however, the cost of the installation of the electrical wire is a major problem. The cost of this installation would vary with each case, but as these units are often placed in remote areas the cost of installing an electrical line may be high. Primary or non-rechargeable batteries could also be used but in most cases these would be expensive and require frequent trips to the site to replace batteries.

The present cost of the solar power supply is high, but dramatic price reductions are expected with the introduction of mass production in this field.

PHOTOVOLTAICALLY POWERED NAVIGATIONAL AIDS

DESCRIPTION: Photovoltaic panels can provide power for lights, radio beacons, and horns used as navigational aids for maritime and aviation environments.

APPLICATIONS:

1. Navigational buoys.
2. Obstruction lights for aircraft.
3. On-shore marker lights.

PERFORMANCE AND SIZE: A photovoltaic panel, 12 inches square, could be used with a channel marker buoy that carries a light, and allows the buoy to take its power from the sun. The amount of electricity needed is small; about 12 kilowatt hours per year. However, the mounting for the photovoltaic array must be strong and weatherproof. A rechargeable battery would replace the non-rechargeable battery as is now used.

The photovoltaic panels can be expected to last for 10 years or more and require little maintenance. The rechargeable battery would have to be replaced every four years and occasionally checked as part of general maintenance, which could be done aboard a buoy tender.

ALTERNATE ENERGY SOURCES: At present these buoys are powered by a non-rechargeable battery which must be replaced every year. These batteries are large and heavy, which necessitates that the buoy be removed from the water and taken ashore for yearly maintenance. In addition, each battery costs about \$500. In the case of on-shore navigational lights and obstruction lights for aircraft, power from the power lines can be used. However, these devices are usually located in remote areas along coastal promontories or on mountain tops, where the cost of installing electrical lines can be \$10,000 per mile or more.

The present cost of the solar panels is quite high, but dramatic price reductions are expected with the introduction of mass production into this industry.

PHOTOVOLTAICALLY POWERED AGRICULTURAL FIELD DEVICES

DESCRIPTION: Solar powered agricultural devices can be mounted on posts throughout fields and along fence lines. Each device performs a specific task for the farmer or rancher.

APPLICATIONS:

1. Chasing birds away.
2. Monitoring soil moisture.
3. Monitoring frost conditions.
4. Electrifying fences.
5. Locating livestock.
6. Determining harvest time.

PERFORMANCE AND SIZE: Each device performs a unique task. None of them requires connecting wires or batteries which must be periodically replaced. All of them have a panel of solar cells to collect the energy they need on sunny days and, if needed, include a rechargeable battery for nights and cloudy periods.

The fence electrifier, for example, mounts on a fence post in any open area and can electrify 25 miles of wire on insulators. It can provide 30 shocks per minute and operate both day and night for up to five consecutive cloudy days. Its solar panel has an area of 1-1/2 square feet and the entire device will operate for long periods - up to five years - without attention.

The amount of electrical power provided by the panel is not large, only about 32 kilowatt hours per year, but it is provided exactly where it is needed. The cells are dependable and last about 20 years.

Some of the devices measure important quantities, such as soil moisture and periodically report this information to a base-station by radio.

All of these devices need a small amount of power, operate out in the open away from power lines, and provide an economically valuable service.

ALTERNATIVE ENERGY SOURCES: There are conventionally powered fence electrifiers on the market today costing about \$50, but they require connection to a utility power line or replacement of batteries. The power line costs about \$1.25 per foot installed (\$6,600 a mile) which limits the electrifiers' location to fences which run very near power connections. Others require batteries costing \$8 each which must be replaced three or four times a year to ensure continuous operation. Each replacement requires a trip out to the device which results in labor and transportation expenses.

The cost of the solar panel is currently quite high, but as usage and mass-production increase, the cost will come down dramatically.

APPENDIX III-B

SAMPLE INTERVIEW QUESTIONNAIRES
AND
INSTRUCTIONS TO INTERVIEWERS

SOLAR ENERGY SURVEY
INTERVIEWER INSTRUCTIONS

(Read this Manual carefully before conducting any interviews.)

I. PURPOSE AND BACKGROUND

This is a survey which National Analysts is conducting for the Inter-Technology Corporation as part of a contract that they have with the United States Energy Research and Development Agency. The purpose of the survey is to learn more about the likely response of manufacturers, distributors, and buyers to various applications of solar energy.

As you know, our conventional sources of energy are very limited, and the nation is facing an energy crisis that is very likely to become increasingly severe over the next two decades. The federal government, along with private industry, has been working very diligently to develop new energy sources. One of these new sources, which has unlimited potential, involves the direct conversion of sunlight into electricity, using what is known as a photovoltaic cell. It is this new source, and its potential applications, which are the subject of this survey.

II. THE ROLE OF THE INTERVIEWER

As an interviewer, you are part of a small team of experts who have been asked to work on this important study, a study in an area which offers great potential for partially solving this nation's energy problems. Your expertise in properly conducting the interviews is essential to the success of this study. Without a good interviewer to collect accurate data, our final output would suffer; a research team is only as good as the interviewers it utilizes.

Maintaining objectivity in conducting this interview is very important. Please read verbatim all statements and questions in an objective manner. Do not discuss anything that is not directly related to the interview. In particular, do not discuss your opinions on solar energy or on energy-related matters in general.

As a representative of National Analysts, certain criteria must be met. You are to be neat and properly attired. Your approach in the screening and interviewing will be a direct reflection of National Analysts and Booz, Allen & Hamilton. We are counting on you to do a professional and thorough job.

III. APPOINTMENT/CALL RECORD FORM

The Appointment/Call Record Form contains a label which indicates the name of the respondent, along with the name, address, and phone number of his/her company. (In a few cases, the phone number is not given, but you should be able to obtain it easily enough through Directory Assistance.) The respondents were contacted several weeks ago by a member of Inter-Technology's staff and have agreed to an interview. All you should need to do, then, is contact the respondent and set an interview appointment time. A suggested introduction has been included on the Appointment/Call Record Form. If a respondent says that he can not be interviewed before September, tell him that it is very important that the interviews be completed during August, and that if it is at all possible, we would appreciate it if he could provide some time this month. If he still holds out for September, set the appointment for the time and date he desires. If we decide to terminate the field work before that date, we will, of course, indicate this to you so you can cancel the appointment.

Make up to five calls if necessary. Be sure you record the result of call for each call where indicated on the "Appointment/Call Record Form and that you return all of these forms to us, even if you never contact the respondent.

After you have set the appointment, record the respondent code number (given on the Appointment/Call Record Form) on the front page of the questionnaire and on the front pages of the Part B and Part C batteries. (Part B and C will be explained below.)

IV. GENERAL INSTRUCTIONS FOR THE QUESTIONNAIRE

1. Know your work thoroughly. If you have any questions, call our office before you start.
2. Instructions to you, the interviewer, are always in CAPITAL LETTERS. Questions to be asked of the respondent are always in small type like this.
3. Remember that questionnaires are always filled out in lead pencil, never in pen or colored pencil.
4. Do not erase. If the respondent changes her answer or you have made a mistake, strike out the first answer and write in the final one.
5. Follow skip patterns carefully.
6. Try to get an answer to each question you are supposed to ask. If the respondent says "Don't know", you can say "What do you think? We are interested in your opinion", if it is an opinion question. If it is a question requiring a numerical answer (dates, amounts, etc.) say "What is your best guess?"
7. A closed-end or precoded question is one in which alternate responses have been indicated on the questionnaire and code numbers have been assigned to each. When you administer a closed-end question, you indicate the answer by circling or writing in the number or numbers next to the answer given you by the respondent.

Do not read answers to precoded questions unless the instruction "READ" is on the questionnaire or the question ends with a colon (:) rather than a question mark (?).

V. QUESTION-BY-QUESTION INSTRUCTIONS

There are actually four questionnaire versions in this study, one corresponding to each of the four applications of solar energy. The Appointment/Call Record Form will indicate the version which is to be administered to that particular respondent. The four versions are:

<u>Version</u>	<u>Application</u>
#1	Battery Chargers
#2	Lighting
#3	Irrigation
#4	Refrigeration

The corresponding version number is typed on the front page of each questionnaire, and on the front pages of Part B and Part C. Be sure that you administer the correct version to each respondent.

The four versions are very similarly structured. Each contains an application description sheet (explained in more detail below) to be read at the outset by the respondent, and four parts (A, B, C, and D). In each version, Parts B and C are to be filled out by the respondent himself; Parts A and D are to be administered by you.

Part A

Give the respondent the appropriate solar energy description sheet. This is a one-page sheet which describes and illustrates the particular solar application under consideration. Be sure he reads both sides of this sheet.

After the respondent has read the description sheet, you may begin Part A. Part A consists of four open-ended questions, each with a variety of follow-up probes. The first part of each of these four questions consists of an unaided, open-ended question. Beneath this unaided, open-ended question are a series of probes. For each item that the respondent does not mention in response to the unaided question, ask the corresponding open-ended probe. Be sure that you record the respondent's answers clearly in the space provided. In the follow-up probes to Q.2 and Q.3, be sure to record whether the respondent's comments are with respect to manufacturers, distributors or users (buyers) of the particular solar energy application.

Part B (Green Section)

After you have finished Part A, move on to Part B. Part B is self-enumerative, i.e., it is to be read and filled out by the respondents. For ease of identification, Part B is the green section. Your principal role in Part B will be to answer any questions the respondent may have regarding the nature of his task. The nature of this task is discussed below for each question in Part B:

- Q.1: For each potential application listed, the respondent should circle the number from 1 to 5 that best indicates its promise in the respondent's opinion. The higher the number, the better is the application.
- Q.2 and Q.3: For each column in the grid beneath each of these questions, the respondent should circle the number in that row which best indicates the probability that the party named in the column will purchase the solar unit.
- Q.4: The responses should total 100.
- Q.5: Self-explanatory.
- Q.6: For each column, respondents should circle the number which best indicates the market penetration of solar energy, given the initial costs and annual savings listed at the top of the column.
- Q.7-Q.9: Self-explanatory.

Part C

Part C is also self-enumerative. Begin by handing the respondent a copy of the instructions for completing Part C and ask him to take whatever time necessary to read it. If he has any questions regarding the nature of his task, try to answer them.

After the respondent has read the instructions, have him complete the five sample descriptions. These descriptions contain an illustration of the application in the top half of each page and the pricing information in the bottom half. The five sample descriptions are stapled together and the word SAMPLE is printed on the top of each page.

Check that the respondent has completed the samples correctly. On each page, he should have checked the box that best reflects his estimate of market penetration, given the pricing information listed on that page. Be sure the respondent understands the nature of his task before you hand him the main set of descriptions (the BLUE section).

While the respondent is doing Part C, check to see that he answered all the questions in Part B. Be sure the responses in Q. 4 of Part B total 100.

Part D

In Part D, contained on pages 3-8 and 3-9 of the questionnaire, you administer the question as in Part A:

- Q.1-4c: Self-explanatory.
- Q.5a: If yes, continue; if no, skip to Q.7.
- Q.5b: Record number where indicated.
- Q.6: Be sure that the numbers given in response to Q.6 sum to the number given in response to Q.5b.
- Q.7-8: Self-explanatory

Thank you for participating in this study. Remember (1) Be sure you are familiar with each version of the questionnaire before you administer it. (2) If you have any questions, call your supervisor.

NATIONAL ANALYSTS
Philadelphia, Pa.

Study #1-957
August, 1977

SOLAR ENERGY SURVEY
QUESTIONNAIRE

Version 1: General Purpose Battery Charger

Time Interview Began: _____	AM PM
Time Interview Ended: _____	AM PM

RESPONDENT'S NAME: _____

NAME OF RESPONDENT'S ORGANIZATION: _____

ADDRESS: _____

CITY/STATE/ZIP: _____

DATE: ____/____/____ RESPONDENT CODE #: _____

INTERVIEWER'S NAME: _____

PART A: (HAND RESPONDENT THE "PHOTOVOLTAICALLY POWERED 12-VOLT BATTERY CHARGER" DESCRIPTION SHEET AND ASK HIM TO TAKE A FEW MINUTES TO READ BOTH SIDES. AFTER HE HAS FINISHED, ASK:)

1. What information would you as a manufacturer or distributor need before you would consider offering solar-cell-powered battery chargers? That is, what would it take to convince your organization to plan battery chargers that are solar-cell-powered?

(FOR EACH OF THE FOLLOWING FACTORS THAT THE RESPONDENT FAILS TO MENTION, ASK:)

What about cost figures both initial installation considerations and long-term considerations? (RECORD BELOW)

What about reliability tests? (RECORD BELOW)

What about reports on field tests? (RECORD BELOW)

What about market surveys? (RECORD BELOW)

2. What do you think are the major barriers to the acceptance of solar-cell-powered battery charger systems on the part of: (READ EACH AND RECORD.)

Suppliers (MANUFACTURERS AND/OR DISTRIBUTORS)?

Users (BUYERS)?

(FOR EACH OF THE FOLLOWING FACTORS THAT THE RESPONDENTS FAILS TO MENTION, ASK:)

What about high initial solar costs? (RECORD BELOW)

What about vandalism? (RECORD BELOW)

What about the lack of reputable suppliers? (RECORD BELOW)

What about unfamiliarity of the buyer with the equipment?
(RECORD BELOW)

What about beliefs of potential customers about rising energy costs?
(RECORD BELOW)

What about zoning restrictions? (RECORD BELOW)

3. What do you think are the primary reasons why the manufacturer, distributor and buyer will consider solar-cell-powered battery chargers? First, how about the: (READ EACH AND RECORD.)

Manufacturers and/or distributors?

Users (BUYERS)?

(IF RESPONDENT FAILS TO MENTION THE FOLLOWING SPECIAL ADVANTAGES OF SOLAR-CELL EQUIPMENT COMPARED TO CONVENTIONAL EQUIPMENT, ASK:)

What about reduced energy costs? (RECORD BELOW)

What about independence from suppliers of conventional energy?
(RECORD BELOW)

What about the long life of solar powered equipment? (RECORD BELOW)

4. What role do you think the federal, state, and/or local governments should play in stimulating the use of solar powered battery chargers?

(IF RESPONDENT FAILS TO MENTION THE FOLLOWING TYPES OF GOVERNMENT SUPPORT, ASK:)

What about government support of solar research? (RECORD BELOW)

What about tax incentives to manufacturers? (RECORD BELOW)

What about tax incentives to users (BUYERS)? (RECORD BELOW)

What about solar demonstration projects? (RECORD BELOW)

INSTRUCTIONS FOR PART B: (PART B IS SELF-ENUMERTIVE. HAND RESPONDENT A PENCIL AND THE GREEN SECTION LABELED "PART B" AND SAY: Here are several questions regarding solar powered battery chargers. I would like you to read and answer these questions as instructed in these sheets. If you have any problems completing this section of the interview, please let me know and I'll try to be of some assistance.)

(AFTER RESPONDENT HAS COMPLETED PART B, TAKE IT BACK, BE SURE THE RESPONDENT NUMBER IS FILLED IN ON PART B, AND MOVE ON TO PART C.)

INSTRUCTIONS FOR PART C: (PART C IS ALSO SELF-ENUMERATIVE. HAND RESPONDENT THE "INSTRUCTIONS FOR COMPLETING PART C" AND ASK HIM TO READ THEM. WHILE THE RESPONDENT IS DOING THIS, CHECK TO SEE THAT HE ANSWERED ALL OF THE QUESTIONS IN PART B. IF HE DID NOT, HAVE HIM COMPLETE PART B AFTER HE HAS COMPLETED PART C. AFTER HE HAS FINISHED THE PART C INSTRUCTIONS, HAND HIM THE SAMPLES, SAYING: I'd like to begin this section by asking you to complete these five samples.)

(AFTER RESPONDENT HAS FINISHED, COLLECT THE SAMPLES, CHECK FOR ANY OBVIOUS PROBLEMS PER YOUR INSTRUCTION MANUAL. THEN HAND RESPONDENT THE REMAINDER OF PART C (THE BLUE SECTION) AND ASK HIM TO COMPLETE THEM.)

(WHEN THE RESPONDENT IS FINISHED, TAKE BACK THE PENCIL AND THE BLUE SECTION. CHECK THAT THE RESPONDENT NUMBER IS FILLED IN ON PAGE 1-1 OF PART C.)

PART D

(THANK THE RESPONDENT FOR HIS COOPERATION IN THE INTERVIEW, AND SAY:
I have just a few more questions, so that we can get some sort of profile
of our respondents.)

1a. Approximately how many 6 volt battery chargers does your organization
sell per year?

NUMBER: _____

1b. Approximately how many 12 volt battery chargers does your organization
sell per year?

NUMBER: _____

2. What is your present title with this organization?

_____

3. How many years' experience have you had in any aspect of electronics?

NUMBER: _____

4a. Have you had any personal experience in conceptualizing and/or
designing solar powered electronic equipment?

Yes	1
No	2

4b. What about solar cell projects?

Yes	1
No	2

4c. What about solar projects of any kind?

Yes	1
No	2

5a. Is your organization currently engaged in any solar powered electronics
equipment projects?

CONTINUE	Yes	1
SKIP TO Q.7	No	2

5b. How many projects?

NUMBER: _____

6. How many of these projects are presently:

(BE SURE THAT THESE
NUMBERS SUM TO THE
NUMBER GIVEN IN Q.5b.
IF NOT, PROBE AND
CLARIFY.)

(READ AND COMPLETE ONE AT A TIME)

	NUMBER
Only ideas?	
In an advanced research stage?	
In project development?	
Commercial products being used?	

7. Please tell us the solar-powered electronics products you are considering using or presently using.

8. May we have your permission to cite your organization as a participant in this study being undertaken for the Energy Research and Development Administration? That is, your organization's name will appear in the final report -- in a listing of the organizations which participated. No remarks or information will be attributed to you or your organization.

Yes	1
No	2

THANK YOU FOR YOUR COOPERATION

PHOTOVOLTAICALLY POWERED 12-VOLT BATTERY CHARGER

DESCRIPTION: A solar-powered, general-purpose battery-charger for 12-volt batteries will recharge a standard battery in one day. The device is simple, requires little maintenance, and has a long lifetime.

APPLICATIONS:

1. Small battery-assisted vehicles.
2. Lawn mowers and garden tractors.
3. Garage and service stations.

PERFORMANCE AND SIZE: This battery charger consists of a photovoltaic panel, totaling 24 square feet, which may be mounted on a roof or in an open yard. The device is simple, has no moving parts and should last about 20 years. The panel provides approximately 600 kilowatt hours of electricity per year.

Please note that this design is conceptual at this time, and that certain details may be changed as market conditions dictate. In addition, these solar-powered battery chargers are modular, and electrical output can be increased by increasing the number of modules. Assume that the solar-powered battery chargers are as safe to operate as conventionally-powered battery chargers, and the components of the solar-refrigerators, other than the solar panels, are comparable in quality, price, and weight to components of conventionally-powered battery chargers.

ALTERNATIVE ENERGY SOURCES: A battery charger can, of course, be powered either from the electrical grid, or by a small gasoline generator. In the case of the electrical grid it is not the cost of the electricity that is the important consideration but the cost of installing the electrical outlet. For a simple function such as charging a battery, only a modest expense for the initial installation would be appropriate. The cost of installing even a few hundred yards of electrical line, for example, out to a farm shed in which battery-powered tools were stored might equal the cost of the photovoltaically powered system. Once the electrical connection is installed, however, it could be used for other purposes such as lighting, in addition to the battery-charging function.

If a gasoline generator is used, it would cost initially about \$300 and would require about \$100 worth of fuel per year plus about \$30 in maintenance and oil. The device would last two or three years but would require considerable maintenance. The gasoline generator would be portable, however, and could be used for other tasks, such as operating power tools. The total cost for operating such a generator would be about \$250 per year.

The cost of the solar panels is currently quite high, but as usage and mass-production increase the cost will come down dramatically.

Respondent Code#: _____

PART B

1. Several applications where solar-powered 6 or 12 volt battery chargers could be used are listed below. Please circle the number which indicates how promising you think each application is for market acceptance in the Continental United States. Assume the cost of purchasing and installing a solar-powered 6 or 12-volt battery charger is between \$300 and \$450. In making your judgments, remember that if electric power is available very close to where the battery charger is needed, solar power may not be a desirable choice. But if electricity or alternate sources of energy are not nearby, are expensive to extend, or are costly to purchase, solar power may be a reasonable choice. Assume the solar units are very reliable and will perform trouble-free for twenty years.

	POOR APPLICATION			VERY PROMISING APPLICATION	
Today's automobiles and trucks	1	2	3	4	5
Boats	1	2	3	4	5
Battery powered portable tools: drills, saws, impact wrenches	1	2	3	4	5
Two-way communications equipment: ham radios, CB's	1	2	3	4	5
Temporary lighting for construction sites and other industrial purposes	1	2	3	4	5
Small household appliances: radios, stereos, cassette tape players, grass clippers, etc.	1	2	3	4	5

2. Solar-cell-powered 6 or 12-volt battery chargers are more expensive than conventionally powered chargers due to the initial costs of the solar cells. But solar cells save money over a period of time because the power is nearly free. Please indicate what you think the listed types of users will do if the installed purchase cost of a 6 or 12-volt solar-powered unit is \$450 and that of a conventionally powered unit is \$50. Assume the combined costs of installing, buying, and operating the solar-powered unit is equal to the total cost of purchase, installation and operation of a conventional unit over a 10-year period of time. Then the solar unit provides operating costs savings the rest of its life. The solar unit is assumed to be very reliable.

(CIRCLE THE APPROPRIATE CODE NUMBER IN EACH COLUMN.)	Would an Industrial Firm...	Would a Governmental Agency...	Would an Individual Consumer..
Definitely buy the solar unit,	1	1	1
Probably buy the solar unit,	2	2	2
Consider it a toss-up,	3	3	3
Probably use conventional power, or	4	4	4
Definitely use conventional power?	5	5	5

3. Now assume as the industry progresses the solar unit will cost \$200 to buy and install, the conventional electric power unit still costs \$50. Assume the installation cost difference would be recovered by the solar unit within 5 years. Indicate the most likely reactions of the 3 types of buyers under these conditions.

(CIRCLE THE APPROPRIATE CODE NUMBER IN EACH COLUMN.)	Would an Industrial Firm...	Would a Governmental Agency...	Would an Individual Consumer..
Definitely buy the solar unit,	1	1	1
Probably buy the solar unit,	2	2	2
Consider it a toss-up,	3	3	3
Probably use conventional power, or	4	4	4
Definitely use conventional power?	5	5	5

4. Suppose you have 100 points to spread among the five reasons listed below why solar cell battery chargers may not be accepted by the marketplace. Allocate the most points to the factor you think the market will be most concerned about and smaller amounts to those you think the market will be less concerned about. Please read the entire list before assigning any points. Remember the total must be 100 points.

Risk that the system might not be reliable or work well	
Higher initial cost than conventional-powered units	
Lack of reputable solar suppliers who will guarantee or maintain their products	
Risk of vandalism or theft	
Space consumed by the solar units, especially the cells	
Total	100 Points

5. Please indicate whether or not manufacturers and/or purchasers should be granted tax incentives for selling or buying solar powered battery chargers.

(CIRCLE THE APPROPRIATE CODE NUMBER IN EACH ROW.)	Yes	No
Tax incentives should be used	1	2
Manufacturers should receive capital investment tax incentives	1	2
Purchasers should receive tax incentives to reduce the add-on cost of solar equipment	1	2

6. We would like your estimate of market penetration that you believe solar-powered 6 and 12-volt battery chargers, such as that described on the description sheet that you read at the start of the interview, would achieve after an introductory marketing phase under different added initial costs and average annual operating savings. The added cost of the solar system, assumed to be \$350, \$250, or \$150, is the additional initial cost of the solar unit, due to the solar cells, above the cost of buying and installing (including laying electric lines) a conventionally powered battery charger. Low-cost solar cells and remote locations suggest low added initial costs of solar. Average annual operating savings, stated in today's dollars and assumed to be \$30 or \$60, is the reduction in energy costs which result from operation of a solar unit rather than a conventional unit. Greater savings result where alternative sources of energy are expensive.

To estimate market penetration you might assume that your organization is planning to market solar powered 6 and 12 volt battery chargers which are similar to an existing line of conventionally powered battery chargers. Your estimate of market penetration is the percentage of all battery chargers sold that would be equipped with the solar cells.

Assume the solar units are very reliable and will perform trouble-free for twenty years or more. Also assume replacement costs for the batteries of the solar units are included in the estimates of the initial costs.

Place your check mark at the penetration estimate for each column.

ADDED COST DUE TO SOLAR SYSTEM	\$350	\$250	\$150	\$350	\$250	\$150
AVERAGE ANNUAL OPERATING SAVINGS	\$30	\$30	\$30	\$60	\$60	\$60
YOUR ESTIMATE OF	100%	100%	100%	100%	100%	100%
MARKET PENETRATION	90	90	90	90	90	90
AFTER AN INTRO-	80	80	80	80	80	80
DUCTORY MARKETING	70	70	70	70	70	70
PHASE (INDICATE BY	60	60	60	60	60	60
CIRCLING THE	50	50	50	50	50	50
APPROPRIATE NUMBER	40	40	40	40	40	40
IN EACH COLUMN)	30	30	30	30	30	30
	20	20	20	20	20	20
	10	10	10	10	10	10
	5	5	5	5	5	5
	0	0	0	0	0	0

7. Although we realize it may be difficult to estimate, we would appreciate your estimate of how large (in terms of units, not dollars) the market for 6 and 12-volt battery chargers (both solar and conventionally powered) will be in the U.S. during 1977.

Your estimate is _____ 6 and 12-volt battery chargers.

8. Please indicate your impression of the degree of accuracy for the estimate you gave in question 7 above.

(CIRCLE THE APPROPRIATE CODE NUMBER.)

Fairly accurate	1
Questionably accurate	2
Just a guess	3

9. Do you believe the market for 6 and 12-volt battery chargers is growing or declining? Give your estimate of the growth or decline rate expected over the next 10 years:

(CIRCLE THE APPROPRIATE CODE NUMBER.)

Greater than 15% decline per year	1
15% decline per year	2
10% decline per year	3
5% decline per year	4
0% static	5
5% growth per year	6
10% growth per year	7
15% growth per year	8
Greater than 15% growth per year	9

INSTRUCTIONS FOR COMPLETING PART C
(Please Read Carefully)

Similar to Question 6 in Part B, we would like your judgment about how successfully you believe solar-cell-powered 6 and 12-volt battery chargers can be marketed under different economic considerations.

DESCRIPTION OF THE BATTERY CHARGER EXAMPLES

Each page in Part C contains a description of the economic considerations for a specific solar-cell-powered battery charger similar to the one described on the description sheet that you read earlier. Without the solar power system, the base price of a conventionally powered battery charger would be \$50. The economic considerations indicate the additional cost of purchasing and installing a solar system rather than a conventional system under a variety of conditions. The operational savings related to the use of photovoltaic devices are included.

Each example will be described by the following characteristics:

1. The increase in the unit's installed price as a result of including the solar power system. These amounts will be different for each page reflecting possible different costs of the solar cells and of the cost of alternative power at the location.
2. The average annual operational savings a buyer can expect from the system. These savings, stated in today's dollars, are largely dependent upon the price of power.

ESTIMATE OF MARKET PENETRATION

Your task is to estimate the market penetration that you believe the solar-powered units would achieve after the introductory phase. To do this, you might assume that you are planning a relatively large product line that includes several basic 6 and 12-volt models each of which could have conventional power or to be equipped with solar-cell power. The model shown on each page is one example. Your estimate of the market penetration would be the percentage of all 6 and 12-volt battery chargers you sell that would be solar equipped.

In making your judgment please assume that the systems are completely automatic, very reliable and will perform trouble-free for 20 years or longer. Assume that the replacement costs for the batteries of the solar units are included in the estimates of the initial costs.

Please indicate your estimate of post-introductory market penetration by checking the box that most closely represents your opinion. Be sure to read each description carefully before making your judgment.

SAMPLE

1. Price increase if solar cell energy system is added.	<u>\$300.00</u>
2. Average annual operating cost savings due to solar system.	<u>\$ 50.00</u>

Your estimate of market penetration (check one)

☐ 0%   ☐ 5%   ☐ 10%   ☐ 20%   ☐ 30%   ☐ 40%   ☐ 50%   ☐ 60%   ☐ 70%   ☐ 80%   ☐ 90%   ☐ 100%

SAMPLE

1. Price increase if solar cell energy system is added. \$100.00
2. Average annual operating cost savings due to solar system. \$ 15.00

Your estimate of market penetration (check one)

☐ 0%   ☐ 5%   ☐ 10%   ☐ 20%   ☐ 30%   ☐ 40%   ☐ 50%   ☐ 60%   ☐ 70%   ☐ 80%   ☐ 90%   ☐ 100%

SAMPLE

1. Price increase if solar cell energy system is added. \$500.00
2. Average annual operating cost savings due to solar system. \$ 50.00

Your estimate of market penetration (check one)

☐ 0%   ☐ 5%   ☐ 10%   ☐ 20%   ☐ 30%   ☐ 40%   ☐ 50%   ☐ 60%   ☐ 70%   ☐ 80%   ☐ 90%   ☐ 100%

1. Price increase if solar cell energy system is added.	<u>\$200.00</u>
2. Average annual operating cost savings due to solar system.	<u>\$ 15.00</u>

Your estimate of market penetration (check one)

☐ 0%	☐ 5%	☐ 10%	☐ 20%	☐ 30%	☐ 40%	☐ 50%	☐ 60%	☐ 70%	☐ 80%	☐ 90%	☐ 100%

APPENDIX III-B (CONTINUED)

The following 16 pages of this questionnaire, not included here, were based on Table IV-4. They follow the format of the sample pages.

16 possible descriptions (4x4)

Initial Cost Difference	100	200	300	500
Operating Cost Savings	15	30	50	90

APPENDIX III-C

SAMPLE MAILED QUESTIONNAIRES

SOLAR-POWERED REPEATER STATIONS

4/1

Mail Questionnaire

1. Several possible applications where solar cells can provide power for telecommunication equipment are listed below. Please circle the number which indicates how promising you think each application is for market acceptance. Consider the Continental U.S. separate from other markets. Assume the cost of purchasing enough solar cells to provide 200 watts of power ranges between \$3000 to \$5000. The cost of purchasing and installing the batteries and necessary electronic equipment for solar-powered systems is assumed to be equal to conventionally powered systems. Furthermore, assume the solar units are very reliable and will perform trouble-free for twenty years or more. In making your judgments, remember that if electric power is available very close to where telecommunications equipment is needed, solar power may not be a desirable choice. But if electricity is not nearby or is very expensive to extend even a short distance, i.e., electricity is remote, solar power may be a reasonable choice.

Please read down the entire list before circling the promise of each application.

	CONTINENTAL U.S.					FOREIGN COUNTRIES				
	POOR		VERY PROMISING			POOR		VERY PROMISING		
	APPLICATION		APPLICATION			APPLICATION		APPLICATION		
Inter-city microwave stations in urban areas	1	2	3	4	5	1	2	3	4	5
Inter-city microwave stations in rural areas	1	2	3	4	5	1	2	3	4	5
Single channel microwave terminals (on schools, public buildings, etc.)	1	2	3	4	5	1	2	3	4	5
Pole mounted telephone repeaters	1	2	3	4	5	1	2	3	4	5
Inter-city telephone cable repeater stations in urban areas	1	2	3	4	5	1	2	3	4	5
Inter-city telephone cable repeater stations in rural areas	1	2	3	4	5	1	2	3	4	5
Radio telephone relay stations for mobile telephones (along highways)	1	2	3	4	5	1	2	3	4	5
Satellite ground stations	1	2	3	4	5	1	2	3	4	5

2. Solar cell powered telecommunications units may be more expensive due to the initial costs of the solar cells. But they save money over a period of time because the power is nearly free and maintenance costs are low. Consider a case where the installed cost of a 200 watt solar-powered supply is \$10,000 and that of the conventional unit to be \$6,000. Assume the combined costs of buying and operating the solar unit would be equal to the total cost of installing and operating the conventional unit over a 25-year period of time. The solar unit is assumed to be reliable and perform trouble-free for twenty years or more. Please check the box that indicates what you think each of the 2 types of buyers listed would do.

	Would an operating or industrial firm ...	Would a governmental agency ...
Definitely buy the solar unit	—	—
Probably buy the solar unit	—	—
Consider it a toss-up	—	—
Probably use conventional power	—	—
Definitely use conventional power	—	—

3. Now assume as the industry progresses the solar unit will cost \$6,200 to install, the conventional electric power unit still costs \$6,000. Also assume the installation cost difference would be recovered by the solar unit within 4 years.

	Would an operating or industrial firm ...	Would governmental agencies ...
Definitely buy the solar unit	—	—
Probably buy the solar unit	—	—
Consider it a toss-up	—	—
Probably use conventional power	—	—
Definitely use conventional power	—	—

4. Suppose you have 100 points to spread among the five reasons listed below why solar cell telecommunications equipment may not be accepted by the marketplace. Allocate the most points to the factor you are most concerned about and smaller amounts to those you are less concerned about. Please read the entire list before assigning any points. Remember the total must be 100 points.

Risk that the system might not be reliable or work well	—
Higher initial cost than conventional electric	—
Lack of reputable solar firms who will guarantee or maintain their products	—
Space consumed by the solar unit, especially the cells	—
Risk of vandalism or theft	—
Total	100 points

5. Why else, other than the reasons listed in question 4 above, do you feel solar cell telecommunications equipment may not be accepted by the marketplace?

---

6. Please indicate whether or not manufacturers should be granted tax incentives for selling solar powered telecommunications equipment.

Tax incentives should be used	— Yes	— No
Manufacturers should receive capital investment tax incentives	— Yes	— No

7. What, other than tax incentives, should federal and/or state and local governments do to stimulate the use of solar technologies in the telecommunications industry?

---

8. Suppose you have 100 points to spread among the five reasons listed below why utilities and operating companies will accept solar powered telecommunications equipment. Allocate the most points to the factor you feel will be most important and smaller amounts to those of less importance. Please read the entire list before assigning any points. Remember the total must be 100 points.

Reduce bills for conventional power

Availability in remote locations

More dependable than conventional energy

Conservation of scarce energy resources

Enhance public image

Total 100 points

9. Why else, other than the reasons listed in question 8 above, may potential users purchase solar-powered telecommunications equipment rather than conventionally powered equipment?

---

10. We would like your estimates of the market penetration that solar-powered telecommunications units, similar to the unit described on the enclosed sheet, will achieve under different assumed added initial costs and average annual operating savings.

The added cost of the solar system, assumed to be \$2,000, \$1,000, or \$0, is the additional initial cost of a 200 watt solar unit, due to the solar cells, above the cost of buying and installing (including laying electric lines) a conventionally powered telecommunications system. This added cost will vary proportionally with wattage requirements. Low-cost solar cells and remote locations suggest low or no added initial costs of solar. Average annual operating savings, stated in today's dollars and assumed to be \$50 or \$100, are the reduction of power and maintenance costs which result from operation of a solar unit rather than a conventional unit. Greater savings result at locations that are hard to service or where conventional power is expensive.

To estimate market penetration you might assume that your organization is planning to use or sell solar powered telecommunications equipment which is similar to an existing line of conventionally powered telecommunications equipment. Your estimate of the market penetration is the percentage of all telecommunications units purchased or sold that would be equipped with the solar cells.

Assume the solar units are very reliable and will perform trouble-free for twenty years or longer.

Place your check mark at the penetration estimate for each column.

ADDED COST DUE TO SOLAR SYSTEM	\$2000	\$1000	\$0.00	\$2000	\$1000	\$0.00
AVERAGE ANNUAL OPERATING SAVINGS	\$50	\$50	\$50	\$100	\$100	\$100
YOUR ESTIMATE OF MARKET PENETRATION (INDICATE BY PLACING A CHECK IN EACH COLUMN)	100% 90 80 70 60 50 40 30 20 10 5 0	100% 90 80 70 60 50 40 30 20 10 5 0	100% 90 80 70 60 50 40 30 20 10 5 0	100% 90 80 70 60 50 40 30 20 10 5 0	100% 90 80 70 60 50 40 30 20 10 5 0	100% 90 80 70 60 50 40 30 20 10 5 0

11. What information would you need before you would consider offering or using solar-cell-powered communications equipment? That is, what would it take to convince you that your organization should plan programs that will include solar equipped power supply?

---

12. Although we realize it is very difficult to estimate, we would appreciate your estimate of how large the market for telecommunications equipment for each application listed will be in the Continental U.S. during 1977 (both solar and conventionally powered).

Inter-city microwave stations _____ units
 Single channel microwave terminals _____ units
 Radio telephone relay stations for
 mobile telephones _____ units
 Inter-city telephone cable
 repeater stations _____ units

13. Please indicate the degree of accuracy of each estimate of demand you gave in Question 12 above.

<u>Application</u>	ACCURACY OF DEMAND ESTIMATE			
	<u>Highly</u> <u>Accurate</u>	<u>Fairly</u> <u>Accurate</u>	<u>Questionable</u> <u>Accuracy</u>	<u>Just a</u> <u>Guess</u>
Inter-city microwave stations	—	—	—	—
Single channel microwave terminals	—	—	—	—
Radio telephone relay stations	—	—	—	—
Inter-city telephone cable repeaters	—	—	—	—

14. Do you believe each market is growing or declining? Your estimate of the yearly growth (or decline) rate to be expected in each market over the next 10 years is ...

<u>Application</u>	EXPECTED YEARLY RATE OF CHANGE									
	GROWTH					DECLINE				
	More than 15%	15%	10%	5%	0%	-5%	-10%	-15%	More than -15%	
Inter-city microwave stations	—	—	—	—	—	—	—	—	—	—
Single channel microwave terminals	—	—	—	—	—	—	—	—	—	—
Radio telephone relay stations	—	—	—	—	—	—	—	—	—	—
Inter-city telephone cable repeater stations	—	—	—	—	—	—	—	—	—	—

15. Approximately how many remote repeater devices does your organization

_____ sell per year
 _____ install per year
 _____ maintain per year

16. In what states does your organization use and/or sell most of its repeater devices?

_____
 _____
 _____

17. What is your present position with your organization?

_____

18. How many years experience do you personally have in telecommunications?

_____

19. Have you had any personal experience in conceptualizing and/or designing ...

solar powered telecommunications projects	___ Yes	___ No
any solar cell projects	___ Yes	___ No
solar projects of any kind	___ Yes	___ No

20. Is your organization currently engaged in any solar powered telecommunications projects?

___ Yes   ___ No

21. If so, are these projects (please check all the answers which apply to your organization).

___ only ideas at this time
 ___ in advanced R & D
 ___ in product development
 ___ commercial products being used

22. If you can, please indicate the applications in which you are considering (or using) solar power for telecommunications.

_____
 _____
 _____

23. May we have your permission to cite your organization as a participant in this study? That is, your organization's name will appear in a listing of the organization which participated. No remarks will be attributed to you or your organization.

___ Yes   ___ No

Name: _____

Title: _____

Organization: _____

SOLAR-POWERED CORROSION PROTECTION
Mail Questionnaire

1. Several types of structures where solar cells might be useful to provide cathodic protection are listed below. Please circle the number which indicates how promising you think each application is for market acceptance in the Continental U.S. Assume a photovoltaic power supply rated at 5 amps and 6 volts could be purchased and installed by the end user for approximately \$500. Furthermore, assume the solar units are very reliable and will perform trouble-free for twenty years or more. In making your judgments remember that if electric power is available close to where the corrosion protection is needed, solar power may not be a desirable choice. But if electricity is not nearby, is very expensive to extend even a short distance, or natural gas is unavailable or costly to service, solar power may be a reasonable choice.

	<u>POOR</u> <u>APPLICATION</u>			<u>VERY PROMISING</u> <u>APPLICATION</u>	
Pipeline	1	2	3	4	5
Well casings	1	2	3	4	5
Storage Tanks	1	2	3	4	5
Off-shore platforms	1	2	3	4	5
Piers and docks	1	2	3	4	5
Bridges	1	2	3	4	5
Ships	1	2	3	4	5

2. Solar-cell-powered corrosion protection units are more expensive than conventionally powered units due to the initial cost of the solar cells. But they save money over a period of time because the power is nearly free and maintenance costs are low. Consider a case where the installed cost of a solar corrosion protection unit is \$4,000 and a conventional unit to be \$2,000. Assume the combined costs of installing and operating the solar powered unit would be equal to the total costs of installing and operating the conventional unit over a 20-year period of time. Then the solar unit would begin saving money until the end of its life. The solar unit is assumed to be very reliable. Please check the box that indicates what you think each of the two types of buyers listed would do.

	Would an operating or industrial firm	Would governmental agencies ...
Definitely buy the solar unit	—	—
Probably buy the solar unit	—	—
Consider it a toss-up	—	—
Probably use conventional power	—	—
Definitely use conventional power	—	—

3. Now assume as the industry progresses the solar unit will cost \$2,200 to install and the conventional electric unit \$2,000. In addition, the initial cost difference would be recovered by the solar unit within 4 years.

	Would an industrial or operating firm ...	Would governmental agencies ...
Definitely buy the solar unit	--	--
Probably buy the solar unit	--	--
Consider it a toss-up	--	--
Probably use conventional power	--	--
Definitely use conventional power	--	--

4. Suppose you have 100 points to spread among the five reasons listed below why solar cell corrosion protection equipment may not be accepted by the market place. Allocate the most points to the factor you are most concerned about and smaller amounts to those you are less concerned about. Please read the entire list before assigning any points. Remember the total must be 100 points.

Risk that the system might not be reliable or work well	_____
Higher initial cost than conventional power	_____
Lack of reputable solar firms who will guarantee or maintain their products	_____
Space consumed by the solar unit, especially the cells	_____
Risk of vandalism or theft	_____
Total	100 points

5. Why else, other than reasons listed in question 4 above, do you think solar cell corrosion protection equipment may not be accepted by the marketplace?

---

6. Please indicate whether or not manufacturers and/or non-government purchasers should be granted tax incentives for buying solar-powered corrosion protection systems.

Tax incentives should be used	__ Yes	__ No
Manufacturers should receive capital investment tax incentives	__ Yes	__ No
Non-governmental purchasers should receive tax incentives to reduce the add-on cost of solar equipment	__ Yes	__ No

7. Suppose you have 100 points to spread among the five reasons listed below why solar cell corrosion protection equipment may be purchased by the marketplace. Allocate the most points to the factor you feel is most important to potential adoption of solar technology and smaller amounts to those you feel are less important. Please read the entire list before assigning any points. Remember the total must be 100 points.

Reduce bills for conventional power	_____
Availability of solar power in remote locations	_____
More dependable than conventional power	_____
Conservation of scarce energy resources	_____
Enhance public image	_____
Total	100 points

8. Why else, other than the reasons listed in question 7 above, may potential users purchase solar-powered corrosion protection equipment rather than conventionally powered equipment?

---

9. We would like your estimate of the market penetration that you believe solar-powered corrosion protection equipment, such as that described on the enclosed sheet, will achieve under different added initial costs and average annual operating savings.

The added cost of the solar system, assumed to be \$2,000, \$1,000, or \$0, is the additional initial cost of the solar unit, due to the solar cells and the batteries, above the cost of buying and installing (including laying electric lines) a conventional powered corrosion protection device. Low-cost solar cells and remote locations suggest low or no added initial costs of solar. Average annual operating savings, stated in today's dollars and assumed to be \$40 or \$100, is the reduction of power and maintenance costs which result from operation of a solar unit rather than a conventional unit. Greater savings result at locations that are hard to service or where conventional power is expensive.

To estimate market penetration you might assume that your organization is planning major expansion of use of corrosion protection units. Your estimate of the market penetration would be the percentage of all corrosion protection devices that you might use that would be equipped with solar cells.

Assume the solar units are very reliable and will perform trouble-free for twenty years or longer.

Place your check mark at the penetration estimate for each column.

ADDED COST DUE TO SOLAR SYSTEM	\$2,000	\$1,000	\$0.0	\$2,000	\$1,000	\$0.0
AVERAGE ANNUAL OPERATIONAL SAVINGS	\$40	\$40	\$40	\$100	\$100	\$100
YOUR ESTIMATE OF MARKET PENETRATION (INDICATE BY PLACING A CHECK IN EACH COLUMN)	100% 90 80 70 60 50 40 30 20 10 5 0	100% 90 80 70 60 50 40 30 20 10 5 0	100% 90 80 70 60 50 40 30 20 10 5 0	100% 90 80 70 60 50 40 30 20 10 5 0	100% 90 80 70 60 50 40 30 20 10 5 0	100% 90 80 70 60 50 40 30 20 10 5 0

10. What information would you as a user need before you would consider using solar-cell equipped corrosion protection systems? That is, what would it take to convince you that your organization should plan to include solar powered equipment.

---

11. Although we realize it is very difficult to estimate, we would appreciate your estimate of how large the market for corrosion protection devices will be in the U.S. during 1977 (both solar and conventionally powered) for each application listed.

Please express your judgment in terms of units that will provide approximately 30 watts of power.

Pipelines	_____	units
Well casings	_____	units
Storage tanks	_____	units
Off-shore platforms	_____	units
Piers and docks	_____	units
Bridges	_____	units
Ships	_____	units

12. Please indicate the degree of accuracy of the estimate of demand you gave in Question 11 above.

<u>Application</u>	<u>ACCURACY OF DEMAND ESTIMATE</u>			
	<u>Highly</u> <u>Accurate</u>	<u>Fairly</u> <u>Accurate</u>	<u>Questionable</u> <u>Accuracy</u>	<u>Just a</u> <u>Guess</u>
Pipelines	—	—	—	—
Well casings	—	—	—	—
Storage tanks	—	—	—	—
Off-shore platforms	—	—	—	—
Piers and docks	—	—	—	—
Bridges	—	—	—	—
Ships	—	—	—	—

13. Do you believe each market is growing or declining? Your estimate of the yearly growth (or decline) rate to be expected in each market over the next 10 years is .....

Application	EXPECTED YEARLY RATE OF CHANGE								
	GROWTH					DECLINE			
	More than 15%	15%	10%	5%	0%	-5%	-10%	-15%	More than -15%
Pipelines	—	—	—	—	—	—	—	—	—
Well casings	—	—	—	—	—	—	—	—	—
Storage tanks	—	—	—	—	—	—	—	—	—
Off-shore platforms	—	—	—	—	—	—	—	—	—
Piers and docks	—	—	—	—	—	—	—	—	—
Bridges	—	—	—	—	—	—	—	—	—
Ships	—	—	—	—	—	—	—	—	—

14. Approximately how many corrosion protection devices does your firm buy and/or install per year?

_____ units

15. Please indicate how many solar powered corrosion protection devices your company presently uses.

_____ units

16. In what states does your organization use most of its corrosion protection devices?

_____

17. What is your present position with your organization?

_____

18. How many years' experience do you personally have in fields of operation which can utilize corrosion protection devices?

_____

19. Have you had any personal experience in conceptualizing and/or designing ...

solar corrosion protection projects	___ Yes	___ No
any solar cell projects	___ Yes	___ No
solar projects of any kind	___ Yes	___ no

20. Is your organization currently engaged in any solar powered corrosion protection projects?

☐ Yes ☐ No

21. If so, are these projects (Please check all the answers which apply to your organization)

- ☐ only ideas at this time
☐ in advanced R & D
☐ in product development
☐ commercial products being used

22. If you can, please indicate the applications in which you are considering (or using) solar powering for corrosion protection.

---

23. May we have your permission to cite your organization as a participant in this study (that is, your organization's name will appear in a listing of the organization which participated). No remarks or information will be attributed to you or your organization.

☐ Yes ☐ No

Name: _____

Title: _____

Organization: _____

APPENDIX III-D

INDIVIDUAL DEMAND CURVES

INDIVIDUAL DEMAND CURVE EQUATIONS

Battery Charger Application

Subject	B ₀	B ₁	B ₂	B ₃	L
1	3.197	-1907.5	-.179	125.0	80
2	-4.993	1355.7	.447	23.5	0
3	-13.371	5847.0	.602	-4.5	0
4	-11.144	3881.0	.112	8.4	80
5	-.055	986.7	-.079	50.4	0
6	-1.932	1535.4	.016	27.7	0
7	-10.951	9967.3	-.012	18.7	400
8	-18.079	1567.3	.383	87.3	40
9	-7.398	2124.1	.204	34.5	0
10	-6.535	3735.5	.205	-17.6	0
11	-17.398	4628.4	.322	36.7	0
12	1.841	129.6	.186	12.6	0
13	-11.417	17962.8	.025	90.8	400
14	-6.701	1475.3	-.108	89.7	40
15	-10.463	7546.7	.077	-27.5	40
16	-28.412	15795.2	.012	83.4	80
17	-19.419	8048.7	.365	18.1	80
18	-7.660	3460.1	-.035	39.2	0

Lighting Application

Subject	B ₀	B ₁	B ₂	B ₃	B ₄	B ₅	L
1	-4.762	828.9	.050	.15	4.466	-11.051	10
2	-10.952	18742.8	.125	0	5.238	4114.280	400
3	-19.149	12341.0	.127	16.40	.178	402.560	200
4	-5.394	2155.2	.059	.72	.201	476.630	80
5	16.586	4654.6	.011	104.90	16.200	-1783.800	200
6	-23.443	17256.2	.046	18.71	7.029	1496.590	200
7	9.842	19930.4	.009	140.35	-21.150	23307.970	600
8	-0.323	4166.6	-.017	61.38	4.410	-286.020	600
9	-30.714	29257.1	.169	51.43	3.809	1828.570	400
10	-60.333	47840.0	.250	0	-3.238	3245.70	400
11	-2.129	9690.1	.248	13.04	-7.320	3537.40	200
12	2.335	2854.9	.066	.49	-1.200	198.20	40
13	-1.674	6806.5	.038	61.65	-1.177	627.360	200
14	-14.047	7657.1	-.035	132.80	-4.280	5942.85	400
15	-94.631	133084.8	.699	-400.60	14.520	-10269.150	800

Irrigation Application

Subject	B ₀	B ₁	B ₂	B ₃	B ₄	B ₅	L
1	-.694	.79	.002	.047	-.21	15.47	0
2	-317.977	41045.8	.028	.218	.66	0	100
3	3.564	-216.6	-.005	.30	-1.04	75.0	20
4	24.444	-720.6	-.029	.852	-6.25	183.33	0
5	9.861	-284.9	-.014	.405	-1.04	34.52	0
6	-2.500	6.35	.002	.005	.42	9.52	0
7	-15.946	2758.2	.055	5.582	-5.12	658.70	60
8	1.527	-132.5	-.002	.395	3.13	48.81	0
9	-3.194	45.23	.002	0	-.21	13.09	0
10	.748	-22.30	.001	.026	-.67	20.07	1
11	-8.033	125.68	-.007	.983	-1.67	137.29	10
12	-9.627	139.62	.001	.443	1.97	32.22	0
13	50.972	-338.88	.002	.157	-3.54	186.90	0
14	-20.00	504.80	.0175	-.270	2.92	88.10	0
15	-9.30	110.30	.005	.096	-.21	20.24	0
16	4.470	-180.50	-.005	.238	-1.46	51.19	0
17	20.560	-207.94	-.005	.181	-4.17	140.48	0
18	-8.860	131.71	.007	.146	0	26.19	0
19	7.360	199.21	.002	-.110	2.71	46.43	0
20	1.890	-62.86	-.004	.117	-.33	11.43	0

Refrigeration Application

Subject	B ₀	B ₁	B ₂	B ₃	L
1	-5.039	2157.7	.033	54.4	80
2	-6.369	5453.8	.158	57.0	80
3	1.647	-1109.7	-.065	66.1	0
4	-6.473	5165.2	-.002	38.3	40
5	-3.338	4433.5	-.110	182.6	300
6	-2.883	866.3	.038	2.7	0
7	-2.528	1341.3	-.133	155.2	80
8	-19.387	34902.8	-.085	186.1	400
9	-2.518	999.6	-.017	64.4	40
10	-9.358	5327.0	-.018	90.6	80
11	-4.131	605.5	.171	50.9	0
12	4.287	2808.8	-.128	225.7	400
13	-18.714	34540.6	.154	-17.9	200
14	1.570	-245.5	-.115	69.3	0
15	-3.691	5348.9	.110	-3.6	40
16	-12.848	35535.2	-.076	39.2	300
17	7.231	18794.2	0	0	100
18	-10.699	6176.4	.029	83.1	80
19	-12.125	5075.4	-.007	129.0	80
20	-3.880	5140.1	-.040	81.6	400

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APPENDIX III-E

PENETRATION MODEL

APPENDIX III-E
PENETRATION MODEL

The demand functions are used to map a scalar function $M(X, Y)$ where M is market penetration and the ordered pair (X, Y) are states of the world affecting M . For illustration, consider X to be initial cost difference and Y to be operating cost savings.

Forecasting can be accomplished by defining a path through (X, Y) space and calculating the appropriate values of the outcome M at desired time intervals along the path. The path can be described by a table of values giving X_0 and Y_0 plus n values of X and Y corresponding to the states of X and Y at succeeding forecast time intervals. In other words, to forecast n time intervals, $n + 1$ states of X and Y must be defined. One then computes the outcome M at each ordered pair $(X(t), Y(t))$, $t = 1, N$. This yields a time history of M which is determined solely by the path taken through (X, Y) space.

Let R be the position vector of the state of the world in (X, Y) space. Using standard notation that i and j are unit vectors in the X and Y direction respectively then

$$\underset{\sim}{R}(t) = X(t) \underset{\sim}{i} + Y(t) \underset{\sim}{j}$$

We can say that

$$M(t) = M(R(t)) = M(R[X(t), Y(t)])$$

Now we must consider the effect of the introductory period. To do this we introduce a function $I(t)$. The range of I is from 0 to 1 where 1 represents the late growth, early maturity phase in the life cycle and

0 represents the introductory date. Therefore, our function for market penetration becomes

$$M'(t) = I(t) M(t)$$

If we set $t_{(d)}$ as the time until late growth, early maturity is reached, then

$$M'(t) = M(t)$$

for all $t \geq t_{(d)}$

Now we seek values for I in the interval of time from $t = 0$ to $t = t_d$. Consider first the shape of our idealized product life-cycle curve.

$$I(t) = \frac{1 + \sin \left(\left[1.5 + \frac{t}{t_{(d)}} \right] \pi \right)}{2}$$

Therefore,

$$I(t) = \frac{1 + \sin \left(\left[1.5 + \frac{t}{t_d} \right] \pi \right)}{2} \quad ; \quad 0 \leq t \leq t_{(d)}$$

$$1 \quad ; \quad t_{(d)} \leq t$$

One way to proceed is by analogy. That is, by studying the life cycles of other similar products one can get a rough idea of the time to significant sales. Fisher and Pry, for example, studied technological substitution rates for 17 innovations. They found displacement times as short as 8.25 years and as long as 58 years. By making comparisons of products with similar market realities, one can make reasonable judgments about the time period to significant sales, given future estimates concerning the primary factors affecting market acceptance.

To do this one could make a single point estimate of $t_{(d)}$ with which to arrive at $I_{(t)}$. A more defensible approach, however, would be to estimate a reasonable change of values that one would expect to include the true value for $t_{(d)}$, and to let future marketplace realities affect the actual value for $t_{(d)}$. This is desirable because the rate of change of values for the forces acting to change M will also influence the rate of acceptance during the introductory period.

To accomplish this consider the following definition for $t_{(d)}$,

$$t_{(d)} = t_{\min} + (1 - \alpha) (t_{\max} - t_{\min})$$

where α is a function ranging in value from 0 to 1. It is a measure of the rate of acceptance of the innovation. It is reasonable to assume that α is a function of,

- 1) The current states of the world contributing to M .
- 2) How these states are changing.
- 3) How M changes with respect to these state changes.
- 4) How changes in M compare with the maximum change in M available at the current state of development.

Based on the above definitions for $M(t)$, $I_{(t)}$, and $t_{(d)}$ we are now in a position to resolve the model using vector mapping.

If we let t_i be the current state of interest, then the current state is defined by

$$R_i (X_i, Y_i)$$

The states are changing by,

$$d R_i = R_i - R_{i-1} = [X_i - X_{i-1}] j_i + [Y_i - Y_{i-1}] j_i$$

Changes in $M' (X, Y)$ can be computed as

$$\begin{aligned} d M'_i (X_i, Y_i) &= \frac{\alpha M'_i}{\alpha X} \alpha X + \frac{\alpha M'_i}{\alpha Y} \alpha Y \\ &= \left(\frac{\alpha M'_i}{\alpha X}, \frac{\alpha M'_i}{\alpha Y} \right) \cdot (\alpha X, Y \alpha) \\ &= \nabla M'_i \cdot \alpha R_i \end{aligned}$$

From this we can observe that M' changes most rapidly in the direction of $\nabla M'$. An alternative manner of writing $\nabla M' \cdot \alpha R_i$ which clarifies α is as follows,

$$\nabla M'_i \cdot \alpha R_i = \nabla M'_i \cdot \alpha R_i \cos \theta$$

and,

$$\alpha = \cos \theta = \frac{\nabla M'_i \cdot \alpha R_i}{\nabla M'_i \cdot \alpha R_i}$$

Based on a matrix of future estimates of X_i , Y_i , and $t_{\min}$ and $t_{\max}$, we can project $M'_{(t)}$ for any future time point.

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APPENDIX III-F

OPTIMIZATION PROGRAM DESCRIPTION

APPENDIX III-F
OPTIMIZATION PROGRAM DESCRIPTION

Program Name - ITC/Energy System

Description - This program generates solar energy application data for ORIENT = 0 and TILT = 0 and LAT, where

TILT - surface tilt angle of the solar array. (DEGREES)

ORIENT - orientation angle of the solar array. + for east of south and for west of south. (DEGREES)

Description of Program Input and Output Variables

Input:

CITYNA - name of city, state and year that the insolation data pertains to. (36-character literal)

LAT - latitude of CITYNA. (DEGREES)

INSO - vector containing the average daily insolation value for each month of the year. (BTU/SQ FT x DAY) Note: INSO data is from a solar array with zero degrees of tilt and zero degrees of orientation.

LEAP - variable indicating whether or not the year of the INSO data is a leap year. (TRUE OR FALSE)

JULIAN - julian date of the day of the year, around which randomization is done. (5-digit INTEGER) Example: 2 Feb. '72 = 72033

EFFSA - efficiency of the solar array. (%) Note: EFFSA equals 13 percent in this program: ERDA/JPL GOAL.

EFFRG - efficiency of the regulator. (%)

EFFBY - efficiency of the battery. (%)

BATSTO - the battery storage capability. Integral number of days that the system can function with the solar array disconnected. Program limit of 28 days. (DAYS)

EFFCV - efficiency of the converter. (%)

EFFLD - efficiency of the load. (%)

LOAD - the two-dimensional array in which each element contains the load on a specific day of a specific month respectively for 13 consecutive months (WATT x HRS). Each month must have 31 entered values.

Output:

Generated by Subroutine SUNGEO

BETA (I) - solar altitude during a specific month. Angle of sun with respect to the ground on the 15th day of the month. (DEGREES)

PHI (I) - solar azimuthal angle on the 15th day of the month. (DEGREES)

THETA (I) - angle of incidence on the 15th day of the month. Angle of sun with respect to the normal to the surface of the solar array on the 15th day of the month. (DEGREES) Note: subscript I (above) is the on-the-hour time of day from sunrise to sunset.

SUNRIS - time of sunrise on a 24-hour clock on the 15th day of a specific month. (HRS)

SUNSET - time of sunset on a 24-hour clock on the 15th day of a specific month. (HRS)

LD - length of a day during a specific month. (HRS)

HMAX - maximum possible (clear day) solar radiation reaching the ground level at LAT on a day during a specific month. (BTU/SQ FT x DAY)

KTBAR - average daily value, for a specific month, of the fraction for HMAX that reaches the local ground level. ($0 < \text{KTBAR} < 1$)

DAYSUN - total equivalent number of completely clear days in a specific month. The sum of the R(DAY)'s of a specific month. (DAYS)

INSDAT (DAY) - the available insolation for a horizontal surface on a certain day of a specific month. ((WATT x HRS)/SQ M)

INSMTH - the available insolation for a horizontal surface for a specific month. ((WATT x HRS)/SQ M)

Generated by Subroutine ARRAY

DIFFDY (DAY) - the available amount of diffuse radiation for the tilted surface on a certain day of a specific month. ((WATT x HRS)/SQ M)

DIFFMT - the available amount of diffuse radiation for the tilted surface for a specific month. ((WATT x HRS)/SQ M)

BEAMDY (DAY) - the available amount of beam radiation for the tilted surface on a certain day of a specific month. ((WATT x HRS)/SQ M)

BEAMMT - the available amount of beam radiation for the tilted surface for a specific month. ((WATT x HRS)/SQ M)

FLUXDY (DAY) - the available amount of total radiation for the tilted surface on a certain day of a specific month. ((WATT x HRS)/SQ M)

FLUXMT - the available amount of total radiation for the tilted surface for a specific month. ((WATT x HRS)/SQ M)

USFLID (DAY) - the generated electrical energy (the product of FLUXDY (DAY) and EFFSA/100) on a certain day of a specific month. ((WATTx HRS)/SQ M)

USFLIM - the generated electrical energy for a specific month. ((WATTx HRS)/SQ M)

Generated by Subroutine BATTERY

BATCAP (DAY) - the battery capacity on a certain day of a specific month with a BATSTO storage capability. (WATT x HRS)

BATCPM - the largest component of the BATCAP vector for a specific month. (WATT x HRS)

Generated by Subroutine SIZING

AREAYD (DAY) - the area of the solar array on a certain day of a specific month that meets the battery capability and load requirement for that day. (SQ M)

AREAYM - the largest component of the AREAYD vector for a specific month. (SQ M)

Generated by Subroutine ENRGLS

LOSSDY (DAY) - the amount of electrical energy wasted on a certain day of a specific month where the area of the solar array is AREAYM. (WATT x HRS)

LOSSMT - the amount of electrical energy wasted for a specific month where the area of the solar array is AREAYM. (WATT x HRS)

PROGRAM FLOW CHART (OVERALL LOGIC)

APPENDIX III-G

ORGANIZATIONS PARTICIPATING
IN SURVEY

Version 1 - Battery Charger

	<u>Code</u>				
	<u>A</u>	<u>AA</u>	<u>AAA</u>	<u>AAAA</u>	<u>Other</u>
***					
Triple A Specialty Company (IL)				X	
***				X	
Eanco Corporation (PA)	X				
McGraw Edison/Edison Battery Co. (NJ)				X	
***				X	
***				X	
Trilectron Industries, Incorporated (NJ)	X				
Fox Products Company (PA)				X	
***				X	
Teledyne Big Beam (IL)				X	
Carr-Griff (CA)				X	
Marine Electric RPD Incorporated (NJ)			X		
***				X	
Exide Power Systems (PA)				X	
Gordos Corporation (NJ)				X	
Automatic Switch Company (NJ)				X	
Gulton Industries				X	
	<u>2</u>	<u>—</u>	<u>1</u>	<u>14</u>	<u>—</u>

AAAA - \$1,000,000 up

AAA - 500,000 up

AA - 300,000 up

A - 100,000 up

0 - not given

NL - not listed

***Names withheld by request

Version 2 - Outside Lighting

	<u>Code</u>				
	<u>A</u>	<u>AA</u>	<u>AAA</u>	<u>AAAA</u>	<u>Other</u>
Duro-Test Corporation (NJ)					
***				X	
Current Industries Inc., Nassau Co.	X				
Abcofab Industries (NY)			X		
Guardian Light Co. (IL)				X	
***				X	
North American Philips Lighting (NJ)				X	
Keene Lighting/Stoncoline (NJ)	X				
Appleton Electric Co. (IL)				X	
Optical Radiation Co. (CA)				X	
***				X	
Energex Lighting Industries (NJ)			X		
Ingersoll Products (IL)				X	
Cassey Associates (PA)	X				
Unarco Industries, Inc. (IL)				X	
	<u>3</u>	<u>—</u>	<u>2</u>	<u>10</u>	<u>—</u>

***Names withheld by request

Version 3 - Irrigation Pumps

	<u>Code</u>				
	<u>A</u>	<u>AA</u>	<u>AAA</u>	<u>AAAA</u>	<u>Other</u>
Studebaker - Worthington (NY)				X	
Midland Pump, LFE Corp. (CA)				X	
W.W. Grainger Inc. (IL)				X	
Peerless Pumps (CA)				X	
National Council of Farmers Co-ops (DC)					NL
American Marsh Pumps (MD)				X	
Crane (Neming) Pumps (CA)		X			
Irrigation Association (MD)					NL
Jacuzzi Brothers (NJ)				X	
***				X	
***				X	
National Rural Electric Coop. Assoc. (DC)					NL
				X	
Gelber Pump Co. (IL)	X				
Roth Pump Co. (DE)				X	
Flygt Corp. (ITT) (CN)	X				
Irrigation and Industrial Development Corps (NY)					0
Aurora Pump (IL)				X	
Katy Industries (IL)				X	
***				X	
Hale Fire Pump Co. (PA)				X	
Ingersoll & Rand (NJ)				X	
***					
	<u>2</u>	<u>1</u>	<u>X</u> <u>1</u>	<u>15</u>	<u>1 (0)</u> <u>3 (NL's)</u>

***Names withheld by request

Version 4 - Refrigerators

	<u>Code</u>				
	<u>A</u>	<u>AA</u>	<u>AAA</u>	<u>AAAA</u>	<u>Other</u>
Kit Manufacturing Co. (CA)				X	
Cold Star Corporation (IN)					NL
Fogel Commercial Refrigeration Co. (PA)				X	
***					O
Grunert Co. (NJ)					NL
Hill Refrigeration Div., Emhart Inc. (NJ)				X	
North Star Refrigeration Co. (CA)			X		
Glenco Refrigerator Co. (PA)	X				
Domestic Sales Corp. of America (IN)					NL
Geldbach Refrigerator Co. (NJ)				X	
General Thermetics, Inc. (NY)					NL
King Refrigerator Corp. (NY)				X	
Gem Refrigeration Co. (PA)		X			
Wright's Manufacturing Co. (CA)		X			
Six Pac (CA)				X	
Traulsen and Company, Inc. (NY)	X				
Airlfow Co. (MD)				X	
Melcor Materials Electronic Products Corp. (NJ)	X				
Powers Equipment Co., Inc. (PA)	X				
National Commercial Refrigeration Mfg. Corporation (NY)					NL
Elixir Industries (CA)				X	
	<u>4</u>	<u>2</u>	<u>1</u>	<u>8</u>	<u>1 (0)</u>
					5 (NL's)

***Name withheld by request

LIST OF COMPANIES PARTICIPATING IN MAILED SURVEY

(Willing to be Cited)

1. GTE Sylvania, Danvers, Massachusetts
2. Abolite Lighting, Incorporated, West Lafayette, Ohio
3. Tau Electronic Products, Incorporated, Emporium, Pennsylvania
4. Gorman Rupp Company, Mansfield, Ohio
5. Fairbanks Morse Pump Division of Colt Industries, Kansas City, Kansas
6. Morris Pumps, Incorporated, Baldwinsville, New York
7. Thrush Products, Inc., Peru, Indiana
8. Lo Vaca Gathering Company, Houston, Texas
9. Florida Gas Company, Winer Park, Florida
10. Plantation Pipe Line Company, Atlanta, Georgia
11. Northwest Pipeline Corporation, Salt Lake City, Utah
12. Harris Corporation, Melbourne, Florida
13. Parker Hannifin Corporation, Lyons, New York
14. C & D Batteries (Div. of Eltra Corporation), Plymouth Meeting, Pennsylvania
15. Dualite, Inc., Newtown, Connecticut
16. Chloride Electro Newtworks, Caledonia, New York
17. Lawrence Pumps, Incorporated, Lawrence, Massachusetts
18. Baker Manufacturing Company, Evansville, Wisconsin
19. Universal Cooperative, Alliance, Ohio
20. Delmhorst Instrument Co., Boonton, New Jersey
21. Waters Instrument Company, Rochester, Minnesota
22. Modu Flash Co., San Mateo, California
23. Drexel Industries, Incorporated, Horsham, Pennsylvania
24. Auto Lift, Product of Plymouth Locomotive Works, Plymouth, Ohio
25. Mobilabs, Inc. Nashville, Tennessee
26. Whitley Manufacturing Company, South Whitley, Indiana
27. Porta House, Inc., Oakland, California
28. Robertshaw Controls Company, Richmond, Virginia

LIST OF COMPANIES PARTICIPATING IN MAILED SURVEY (CONT'D)

29. U.S. Army Engineers, Baltimore, Maryland
30. Southern Pacific Pipe Lines, Los Angeles, California
31. Gas Department, City of Long Beach, California
32. Four Corners Pipeline Company, Long Beach, California
33. Calnev Pipe Line Company, Bloomington, California
34. Gulf Refining Company, Houston, Texas
35. ITT Space Communications, Ramsey, New Jersey
36. Pulsecom Division of Harvey Hubbell, Inc., Falls Church, Virginia
37. Atlantic Research Corporation, Alexandria, Virginia
38. Varian Associates, Cheverly, Maryland
39. Wescom, Inc., Cheverly, Maryland

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APPENDIX III-H
ADDITIONAL INPUT DATA FOR DEVELOPING MARKET PENETRATION CURVES

APPENDIX III-H
ADDITIONAL INPUT DATA FOR DEVELOPING MARKET PENETRATION CURVES

Projected values for the initial cost differences between photovoltaically powered products (X_i) are tabulated in Table III-H-1 for each of the six constant performance insolation regions described in section V.C.1. The operating cost savings assumed for the applications are denoted Y_i .

Values to bracket the displacement time $t_{(d)}$, or time period to significant sales are tabulated as $t_{\min}$ and $t_{\max}$ for the selected products. Assumptions regarding conventional power source being replaced by photovoltaic power are labelled "application" and are specified for each product in Table III-H-2.

TABLE III-H-1
INITIAL COST DIFFERENCES AND OPERATING COST SAVINGS
FOR PV POWERED SYSTEMS VS. SELECTED ALTERNATIVES
(VALUES OF X_i AND Y_i)

Battery Charger

Application 1: Gasoline generator at \$300 first cost.

Annual Operating Savings: $Y_i = \$250/\text{year}$

Region	Initial Cost Difference (1975 \$)									
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
I	4667	3321	2464	1877	1289	849	506	261	90	16
II	3791	2682	1976	1493	1009	646	364	162	21	-40
III	3353	2363	1733	1301	869	545	293	113	-13	-67
IV	3060	2150	1570	1172	775	477	245	80	-36	-86
V	2768	1937	1407	1044	682	409	198	47	-59	-105
VI	2330	1617	1163	852	541	308	127	-3	-94	-133

TABLE III-H-1 (CONTINUED)

Outside Lighting

Application 1: One thousand feet of underground cable at \$2100

Annual Operating Savings: $Y_i = \$20/\text{year}$

<u>Region</u>	<u>Initial Cost Difference (1975 \$)</u>									
	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>1986</u>
I	7960	5267	3003	2828	653	-228	-913	-1403	-1746	-1343
II	6207	3980	2578	1610	642	-83	-648	-1051	-1331	-1454
III	4780	2800	2090	1226	362	-286	-790	-1150	-1402	-1510
IV	4746	2924	1765	970	175	-421	-885	-1216	-1448	-1547
V	4161	2498	1440	714	-12	-556	-980	-1282	-1494	-1584
VI	3285	1859	952	330	-292	-759	-1122	-1381	-1562	-1640

TABLE III-H-1 (CONTINUED)

Outside Lighting

Application 2: Two hundred feet of underground cable at \$550.

Annual Operating Savings: $Y_i = \$20/\text{year}$

<u>Region</u>	<u>Initial Cost Difference (1975 \$)</u>									
	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>1986</u>
I	9510	6817	5103	3928	2753	1872	1187	697	354	207
II	7757	5539	4128	3160	2192	1467	902	499	217	96
III	6880	4900	3640	2776	1912	1264	760	400	148	40
IV	6296	4474	3315	2520	1725	1129	665	334	102	3
V	5711	4048	2990	2264	1538	994	570	268	56	-34
VI	4835	3409	2502	1880	1258	791	428	169	-12	-90

TABLE III-H-1 (CONTINUED)

Battery Charger

Application 2: Two hundred feet of underground cable plus unit at \$580

Annual Operating Savings: $Y_i = \$25/\text{year}$

<u>Region</u>	<u>Initial Cost Difference (1975 \$)</u>									
	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>1986</u>
I	4387	3041	2184	1597	1009	569	226	-19	-190	-264
II	3511	2402	1696	1213	729	366	64	-118	-259	-320
III	3073	2083	1453	1021	589	265	13	-167	-293	-347
IV	2780	1870	1290	892	495	197	-35	-200	-316	-366
V	2488	1657	1127	764	402	129	-82	-233	-339	-385
VI	2050	1337	883	572	261	28	-153	-283	-374	-413

TABLE III-H-2
VALUES FOR $t_{\min}$ AND $t_{\max}$

I. Battery Chargers

Application 1: Alternative power, gasoline generator at \$300 first cost.

Application 2: Alternative power, 200 feet, underground cable at \$580

<u>Region</u>	<u>Application 1</u>		<u>Application 2</u>	
	<u>$t_{\min}$</u>	<u>$t_{\max}$</u>	<u>$t_{\min}$</u>	<u>$t_{\max}$</u>
1	5.0	7.0	7.0	9.0
2	4.8	5.5	6.5	8.5
3	4.6	5.3	6.0	8.0
4	4.4	5.1	5.5	7.5
5	4.3	5.0	5.5	7.5
6	3.5	4.5	5.0	7.0

II. Outside Lighting

Application 1: Alternative power, 1000 feet, underground cable at \$2100

Application 2: Alternative power, 200 feet, underground cable at \$580

<u>Region</u>	<u>Application 1</u>		<u>Application 2</u>	
	<u>$t_{\min}$</u>	<u>$t_{\max}$</u>	<u>$t_{\min}$</u>	<u>$t_{\max}$</u>
1	5.0	6.0	8.0	10.0
2	5.0	6.5	7.5	10.0
3	4.5	5.5	7.0	10.0
4	4.2	5.2	7.0	10.0
5	4.0	5.5	7.0	10.0
6	3.5	5.0	6.0	9.0

TABLE III-H-2 (CONTINUED)

III. Refrigeration

Alternative power: 1500 feet of underground cable at \$1120

<u>Region</u>	<u>t_{min}</u>	<u>t_{max}</u>
1	5.0	7.0
2	4.5	6.5
3	4.0	6.0
4	4.0	6.0
5	3.5	5.5
6	3.0	5.0

IV. Irrigation

<u>Region</u>	<u>Electricity</u>		<u>Oil</u>		<u>Gas</u>	
	<u>t_{min}</u>	<u>t_{max}</u>	<u>t_{min}</u>	<u>t_{max}</u>	<u>t_{min}</u>	<u>t_{max}</u>
1	7.0	10.0	7.0	10.0	7.0	10.0
2	6.5	9.0	6.5	10.0	6.5	10.0
3	6.0	9.0	6.0	10.0	6.0	10.0
4	6.0	9.0	6.0	10.00	6.0	10.0
5	5.5	8.5	5.5	10.0	5.5	10.0
6	5.0	8.0	5.0	10.0	5.0	10.0

TABLE III-H-3
REGIONAL WEIGHTING FACTORS

<u>APPLICATION</u>	<u>REGION</u> (WEIGHTING FACTOR, %)					
	I	II	III	IV	V	VI
Battery Chargers, App. 1	}					
Battery Chargers, App. 2						
Lighting, App. 1		12.2	33.3	23.5	20.1	9.2
Lighting, App. 2						1.7
Irrigation vs Elec.		0.3	5.4	35.0	16.7	27.5
Irrigation vs Gas.		4.0	12.7	29.5	34.0	15.0
Irrigation vs Oil		1.1	3.7	53.9	17.8	20.2
Refrigeration		27.7	29.3	14.9	11.6	14.0
						2.5