AT03-76CS51101

AEROSPACE REPORT NO.
ATR-76(75-007)-2

MTR F-1101/1 82

MISSION ANALYSIS OF PHOTOVOLTAIC SOLAR ENERGY SYSTEMS

MASTER

QUARTERLY PROGRESS REPORT
1 MARCH 1976 — 31 MAY 1976

1976 AUG 23 AM 11 34

RECEIVED
MAIL & RECORDS

FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

THE AEROSPACE CORPORATION

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SAN/1101-76/1
Aerospace Report No.
ATR-76(7574-07)-2

MISSION ANALYSIS OF PHOTOVOLTAIC SOLAR ENERGY SYSTEMS

Quarterly Progress Report for the Period

1 March 1976 - 31 May 1976

Prepared by

S. L. Leonard, P. K. Munjal, and E. J. Rattin

Energy and Transportation Division

THE AEROSPACE CORPORATION

P. O. Box 92957

Los Angeles, California 90009

Date Published - June 1976

Prepared for

Division of Solar Energy

Energy Research and Development Administration

Under Project Agreement 8, Contract No. E(04-3)-1101

NOTICE

"This report was prepared to document work sponsored by the United States Government. Neither the United States nor its agent the United States Energy Research and Development Administration, nor any federal employees, nor any of their contractors, subcontractors or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represent that its use would not infringe privately owned rights."

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

JHS

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

FOREWORD

This report represents an account of work accomplished during the second quarter of activity under Project Agreement 8, "Mission Analysis of Photovoltaic Solar Energy Systems", on Contract No. E(04-3)-1101 with the United States Energy Research and Development Administration (ERDA).

The study is being conducted by the Energy Programs Group of the Energy and Transportation Division of The Aerospace Corporation. Dr. Leonard Magid is the ERDA Program Manager and Dr. A. B. Greenberg, General Manager of the Energy and Transportation Division, is the Principal Investigator. Dr. M. B. Watson is Associate Director of the Energy Programs Group. Dr. Stanley L. Leonard, Director, Photovoltaic Office, provides the program management.

This report was prepared by Dr. S. L. Leonard, Dr. P. K. Munjal, and Mr. E. J. Rattin. The authors wish to express appreciation for the support of the project by a number of other personnel of The Aerospace Corporation. These include Mr. W. A. Kammer, Mr. J. A. Neiss, Ms. P. L. McGill, Ms. H. Wong, and Mr. H. H. Yoshikawa. The help of Mr. Fred Eggers in overseeing the production of the report and of Ms. Kathy Morris in typing the text is also gratefully acknowledged.

ABSTRACT

The main emphasis of the activity during the second quarter of this project continued to be on Task 1, Analysis of Near-Term Missions, and on Task 2, Analysis of Major Mid-Term Missions. In addition, considerable progress was also made on Task 6, Comparison of the True Societal Costs of Conventional and Photovoltaic Power Production, and starts were made on Task 3, Review and Updating of the ERDA Technology Implementation Plan, and Task 4, Critical External Issues. As was planned, work on Task 5, Impact of Incentives, was deferred to the second half of the program.

During the preceding quarter, the focus of the Task 1 effort was on a quick preliminary study aimed at the early identification of several promising photovoltaic applications that would make attractive demonstration projects. At the beginning of the second quarter, the focus shifted back to the mainline effort to conduct a comprehensive survey of near-term (1976-1985) applications. A large number of such applications were identified and organized into an application "tree" whose principal function is to uncover previously unnoticed applications in one category ("tree branch") that are analogous to already identified applications on another "branch". The more promising applications (on the basis of breakeven array price and potential market size) were subjected to a preliminary technical and economic evaluation, and the results were used in making an initial estimate of the total market for domestic, non-military photovoltaic applications in the near-term period.

As part of Task 2, the investigation of central station missions for photovoltaic power plants using GaAs solar cells and very high concentration (concentration ratio ~ 1000) continued. It was established that the effect on GaAs array output of changes in the insolation spectrum could, in general, be neglected in analyzing system performance. An analysis of the trade-offs associated with array cooling was begun and preliminary results were obtained. Rough computations were also made of the basic capital cost of a high-concentration photovoltaic power plant of the central receiver design. The results indicate that such a plant is unlikely to be competitive with either a solar-thermal plant or with a flat plate photovoltaic plant (if array prices are in the \$100-300/kW_{pk} range) unless the heat rejected into the array-cooling system can be productively utilized.

Also under Task 2, additional computations were made of the effect of relaxation of system reliability criteria on the amount of conventional capacity required to back up photovoltaic on-site or central station systems. As was the case with preliminary computations reported earlier, it was found that relaxing the reliability criterion leads to an increase rather than a decrease in the amount of required backup capacity.

Under Task 6, the emphasis shifted from collection of data to the analysis and comparative evaluation of data, from many different sources, on the various sources of cost to society resulting from coal-fired power generation. At the close of the reporting period, the quantitative assessment of the external (i. e. not reflected in the price of electric power) societal costs of coal-fired generation was essentially complete. On the basis of this assessment it is estimated that the total of such costs amounts to from 3 to 5.5 mills/kWh, depending on plant location.

The initial Task 3 activity was a study of the future photovoltaic market from the point of view of a current or potential array manufacturer, with particular attention to market entry points. This study was not yet complete at the close of the quarter. Under Task 4, the critical external issues to be addressed in the program were tentatively identified and a start was made on a study of one of these, the technical and economic barriers to the feedback of excess solar power from an on-site photovoltaic system to the utility grid.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

CONTENTS

Foreword	iii
Abstract	iv
I. Introduction	1
II. Progress	9
III. Plans	69
IV. References	73

I. INTRODUCTION

This section of the report contains a description of the structure of the study (illustrated by a flow chart that also appeared in the first quarterly report) and an account of planned activities for the report period.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

STUDY FLOW CHART

As is indicated in Chart 1, this study has been divided into six separate but interrelated tasks. The main emphasis of the program is on the first two of these (Tasks 1 and 2), with three of the remaining tasks (Tasks 4, 5, and 6) serving to support the two principal efforts. The results of these primary efforts will then provide needed inputs to the task (Task 3) of reviewing and updating the technology implementation plan that is an integral part of ERDA's 10-year photovoltaic program. During the first quarter of activity on the project (Ref. 1) progress was made in Tasks 1, 2 and 6; in accordance with the schedule, work on the other three tasks was deferred until later quarters. As background information for this second quarterly report, the first quarter results are summarized below:

Under Task 1, an appropriate methodology was developed for conducting the mainline activity of the task - a comprehensive survey of near-term (1976-1985) applications for photovoltaic solar energy conversion - and a start was made on the implementation of the methodology. The main emphasis of the first quarter of effort on the task, however, was placed on a quick, preliminary study aimed at the early identification of several promising near-term applications that would make attractive demonstration projects. Four such applications were identified: a) impressed current corrosion protection of gas well casings, b) impressed current corrosion protection of gas and oil pipelines, c) railroad grade crossing signals, and d) navigation aid buoys. Estimates were made, in each case, of the size of the associated potential market for photovoltaic arrays and of the breakeven array price (the array price at which photovoltaic solar energy conversion would be economically competitive with alternative power sources). The estimated market sizes were as high as 1.1 MW_{pk}/yr (in the case of corrosion protection of deep gas wells) and breakeven costs ranged from \$2/W_{pk} to more than \$50/W_{pk}.

Under Task 2, a start was made on the examination of central station missions for photovoltaic power plants using very high concentration (concentration ratio ~1000). Progress was made on the adaption of computer simulation routines for use in evaluating plant performance and on the computation of the effect of air mass variations on the efficiency of the GaAs cells that are likely to be used in this mission. A preliminary study was also made of the degree to which the need for conventional backup capacity is effected by relaxation of the generation reliability criterion. Initial results indicated that relaxing the reliability requirement leads to an increase, rather than a decrease, in the required amount of conventional backup capacity.

Under Task 6, data on the various elements of social cost resulting from power production were collected from a wide variety of sources. A comprehensive literature search was conducted and supplementary information was obtained through contact with investigators who have studied the various specialized aspects of the overall program.

Study Flow Chart

Chart 1

Chart 2

PLANNED ACTIVITIES - 1 MARCH THROUGH 31 MAY 1976

The activities that were planned for the second quarter of the program are listed in Chart 2, which is reproduced from the first quarterly report (Reference 1). The emphasis under Task 1 was to be on implementing the methodology that had been developed for conducting the main-line Task 1 activity, namely, a comprehensive survey of near-term (1976-1985) applications for photovoltaic solar energy conversion. Under Task 2, both the investigation of the use of high concentration in central power missions and the study of the effect of relaxed reliability criteria on backup capacity requirements were to be completed. It was planned also that a start would be made on an analysis of the effect on on-site mission economics of the productive use of reject heat from the solar arrays. Under Task 3, a brief study was planned of the economic potential of the future solar array market from the point of view of a current or potential array manufacturer. The review of ERDA price/volume scenarios in the light of the results of Tasks 1 and 2 was also to be started. Under Task 4, it was planned that critical external issues identified in Tasks 1 and 2 be reviewed and a tentative selection made of those issues that will be addressed in this program. A start was also to be made at examining one or more of these issues. Finally, the focus of Task 6 was to shift from data collection to data evaluation and to a quantitative assessment of the total societal costs of coal-fired power generation. No activity on Task 5 was planned for this quarter.

As a perusal of the remainder of this report will show, actual activities on this project during the quarter have corresponded fairly well to the plans outlined in Chart 2. The main difference between plans and accomplishments are to be found in the Task 2 effort. Because of delays that were experienced in getting the appropriate personnel assigned to the task, the study of high-concentration central station missions has not yet been completed. Several other studies, not mentioned in Chart 2, were started, however, and the overall effort on the task is not significantly behind schedule. The Task 3 study of the photovoltaic market from the producer point of view is also not yet complete, but again, this delay has not had a significant effect on the program schedule.

Planned Activities - 1 March Thru 31 May 1976

TASK 1: ANALYSIS OF NEAR-TERM MISSIONS

- IMPLEMENT COMPREHENSIVE SURVEY OF POTENTIAL USERS, CONSTRUCT APPLICATION TREES
- GROUP APPLICATIONS INTO A LIMITED NUMBER OF LOAD CLASSES
- SELECT REPRESENTATIVE APPLICATIONS FOR EACH GROUP
- BEGIN TECHNICAL/ECONOMIC ANALYSES OF REPRESENTATIVE APPLICATIONS

TASK 2: ANALYSIS OF MAJOR MID-TERM MISSIONS

- COMPLETE STUDY OF USE OF HIGH CONCENTRATION IN CENTRAL POWER MISSIONS
- CARRY OUT ADDITIONAL MARGIN ANALYSES FOR RELAXED RELIABILITY CRITERIA
- BEGIN ANALYSIS OF ONSITE APPLICATIONS WITH PRODUCTIVE USE OF REJECT HEAT

TASK 3: REVIEW AND UPDATING OF ERDA TECHNOLOGY IMPLEMENTATION PLAN

- CONDUCT STUDY OF MARKET FROM POINT-OF-VIEW OF ARRAY PRODUCER
- BEGIN REVIEW OF VOLUME/PRICE SCENARIOS IN LIGHT OF TASK 1 INTERIM RESULTS

TASK 4: CRITICAL EXTERNAL ISSUES

- BEGIN EXAMINATION OF SELECTED GROUP OF EXTERNAL ISSUES IDENTIFIED IN TASKS 1 AND 2

TASK 6: SOCIETAL COSTS OF CONVENTIONAL AND PHOTOVOLTAIC POWER PRODUCTION

- CONTINUE DATA COLLECTION, CONDUCT ON-GOING COMPARATIVE ANALYSIS OF SOCIETAL COSTS ON CONSISTENT BASIS

Chart 2

II. PROGRESS

This section contains a discussion of the progress that has been made during the reporting period.

Chart 3

ELEMENT OF PHOTOVOLTAIC APPLICATIONS TREE: EXAMPLE 1

Chart 3 and the next several charts show application groups which are considered to represent significant non-military markets for photovoltaic power utilization in the United States. These applications have been selected from a larger set obtained from a comprehensive review of the literature and from contact with solar cell manufacturers, trade associations, original equipment manufacturers, retail outlets, and potential users.

The applications are organized into a morphological tree structure in order to provide overview of related use areas in several of the application domains. Analysis of applications showed that they could be grouped under headings which were repetitive in the several domains of the tree. As a consequence, the groupings of "Sensors", "Communications", and so on, appear in all of the major tree domains. Only those application classes were entered into the tree structure which a preliminary review had indicated to have potential for contributing to a large-scale increase in U. S. demand for photovoltaic power generation systems. The term "large scale" is, of course relative. The screening threshold is consequently adjusted continuously through feedback after preliminary analysis provides quantitative insight into the maximum rates of consumption which can be anticipated for all representative applications. In accordance with original plans, only U.S. applications are being considered in this survey.

Chart 3 overviews the 1st and 2nd levels in the Land/Remote domain of the tree. The following two charts detail 3rd level application groupings for the Sensor and Communication categories. The final category of General Power and Lighting is developed to the 3rd level on Chart 6 which depicts the Land/Rural domain; this listing is identical to that for the same category under Land/Remote. In a number of other instances also, the second and third level groupings are identical for different domains of the tree. In those cases, the details of the grouping are listed only in the chart for one of the domains; in subsequent charts, reference is made to the earlier listing.

Element of Photovoltaic Applications Tree

EXAMPLE 1

Chart 3

Chart 4

ELEMENT OF PHOTOVOLTAIC APPLICATIONS TREE: EXAMPLE 2

The third level of the application tree is displayed in Chart 4 for the Sensors/Data Processing/Transmit grouping of the Land/Remote tree domain. This grouping is essentially the same as the corresponding one in the Land/Rural domain, but differs to some extent from those in the Land/Urban, Airborne, and Marine domains. This application area permits convenient grouping inasmuch as the individual applications have many power characteristics in common. Although there are a large number of installations of these types, probably ranging into the hundreds of thousands in the U. S. alone, each has a relatively small power draw, usually measured in milliwatts of continuous power. Even transmission from remote instruments via satellite can be accomplished with solar arrays rated at less than one watt peak. Although power draw during radio transmission ranges from 10 watts for VHF relay data links to as high as 300 watts for meteor burst transmission, the transmit periods are in the order of micro to milliseconds and occur between 10 and 20 times per day. Standby power draw also is in the range of microwatts to milliwatts. The data processing associated with remote instrumentation generally involves analog to digital transformations. The data transmission systems considered in the sensor market are confined to the base station or data conversion platforms associated with each grouping of instruments. They do not include the repeater stations which may be required but which are instead included under the Communications grouping of applications.

Most sensor data of the types listed on the chart are transmitted over hardwire telephone links. Radio is used for this purpose in from 10 to 20 percent of the applications. When hardwire links are present, photovoltaic power appears to have little or no potential role in the near term. However, a majority of the instruments using radio data links can be considered prime solar cell markets. Approximately 20,000 of such potential installations have been identified for the future weather and hydrology sensor market alone.

Element of Photovoltaic Applications Tree

EXAMPLE 2

Chart 4

Chart 5

ELEMENT OF PHOTOVOLTAIC APPLICATIONS TREE: EXAMPLE 3

The 3rd level tree structure in the Communications grouping of the Land/Remote tree domain is essentially equal in scope to that of the Land/Rural but is considerably more extensive than the same grouping for the other domains. The market depicted by this grouping is quite diverse from the point of view of power requirements and required duty cycles. Power draw ranges from milliwatts in the instances of radio call boxes, road vehicle locators, and most control applications, to several kilowatts for common carrier microwave repeater stations.

In terms of probable future solar cell consumption, the repeater market is the largest of this grouping. Both common carrier and private services operate about 20,000 licensed microwave repeater stations, many of which have more than one transmitter. Safety and Special Radio Services operate about 700,000 additional VHF/UHF stations of which about 20% may be repeaters. Many of these also consist of several transmitters. Although most, if not all, of the currently operating common carrier stations are provided with utility power, the private services have a large proportion of locations served by gasoline or diesel power. These are prime candidates for future conversion to photovoltaic power.

The potential for future application to portable, personal telephone service is also large, depending upon availability of sufficient frequency space. Although currently such service is generally available only in urban areas, remotely located repeaters could be employed to increase the scope of this service.

Radio control is a growing market but operates generally at low continuous power levels. Electronic control of highway signals is a promising market with hundreds of thousands of potential receiver locations associated with repeaters. This photovoltaic market is, of course, somewhat tied to the number of illuminated signs or signals for which photovoltaic power is made economically reasonable by remoteness from power lines. However, even utility-powered signals could be radio-controlled.

Element of Photovoltaic Applications Tree

EXAMPLE 3

Chart 5

Chart 6

ELEMENT OF PHOTOVOLTAIC APPLICATIONS TREE: EXAMPLE 4

Chart 6 details the General Power and Lighting grouping of applications to the third level, while showing the remaining groups of the Land/Rural domain only to the second level. The grouping here presented to the third level is essentially similar to the corresponding one in the Land/Remote domain but differs considerably from those in the other tree domains. Of all the groupings depicted so far, this is the most diverse in power needs, as a result of the great variety of applications which it contains. Power draw ranges from about 10 watts for corrosion protection to several kilowatts in village and in recreational applications. In some cases only DC power is required, while in others inversion to AC is required. A feature distinguishing this grouping from the Sensor, Communications, and Signals groupings is the high duty cycle, ranging up to 100%, required by most of the applications. As a result, the required peak array outputs are large multiples of the actual power draw.

As indicated in the previous quarterly report, there are about 140,000 gas wells and about 450,000 miles of pipeline in the U. S., some portion of which would benefit from photovoltaically powered impressed current corrosion protection systems. In addition, there are about 500,000 concrete decked highway bridges in the U. S., most of which are salted in the winter to prevent icing, and many of which are remote from powerlines. Many of these could also benefit from solar cell powered corrosion protection systems. In addition to these applications which have the largest photovoltaic market potential, others with large potential include trickle (drip) irrigation applications in arid regions, range cattle water pumping, and some of the other highway applications. In the case of the larger electrical loads such as those of recreational and remote village applications, the most likely conventional power sources are gasoline or diesel powered generators, and the breakeven prices at which photovoltaic sources can compete are quite low, less than \$4/W_{pk}. (See also Chart 9.)

Element of Photovoltaic Applications Tree

EXAMPLE 4

Chart 6

Chart 7

ELEMENT OF PHOTOVOLTAIC APPLICATIONS TREE: EXAMPLE 5

As indicated by Chart 7, photovoltaic power generation has a smaller range of near-term applications in urban areas than in the other tree domains, primarily because of the ready availability of utility power. In this market, however, the ability to compete with the powerline depends on the cost of connection to utility power. Applications whose power draw is small, which have a low duty cycle, and which require DC power at low voltage offer the most promising market for solar cell power. This is true because connecting charges often exceed the cost of a solar cell array when transformer, rectifier, and meter charges are considered.

In several such applications it would be economically feasible to actually mount the array and associated load directly on a "live" power pole. Examples of this might be radio call boxes, vehicle locator transponders, pollution sensors, etc.

The urban market thus may well have considerable potential but it has not yet been fully defined.

Element of Photovoltaic Applications Tree

EXAMPLE 5

Chart 7

Chart 8

ELEMENT OF PHOTOVOLTAIC APPLICATIONS TREE: EXAMPLE 6

Considerably fewer civilian applications groupings have so far been defined for further investigation in the Airborne and the Marine domains of the applications tree than for the other domains. The largest markets among those groupings which have been investigated appear to be the lighted and the RF beacon types of navigation aids and a variety of battery trickle chargers for a number of applications. These include, to a possibly important degree, the emergency radios associated with general aviation, the Emergency Locator Transmitters, or ELT's, and the marine Emergency Position Indicating Radio Beacons, or EPIRB's. Hundreds of thousands of ELT's and EPIRB's will be in general use in the future.

Million of small boats have some power needs, presently supplied by batteries, even if only for running lights. Although the number of units sold for such purposes could be quite large, the average array output will be relatively small, thus reducing this total market to the multi-kilowatt range of total installed array capacity rather than the megawatt range.

Balloon mounted radio repeaters using gasoline and diesel generated power have a considerable foreign market; before photovoltaic power can compete for this market, however, array weights will probably have to be reduced.

Off-shore platforms are a relatively small market, only about 2000 such platforms, manned or unmanned, being placed in U. S. waters at this time. In addition, wind power appears to be a strong competitor to photovoltaic technology in this platform market.

The military marine market, not covered by this survey, may offer interesting PV applications in providing power for a variety of surface and submerged sensors as well as for repeaters.

Element of Photovoltaic Applications Tree

EXAMPLE 6

Chart 8

Chart 9

1980 ELECTRIC ENERGY COSTS

If photovoltaic arrays are to find significant markets in any of the applications listed in the preceding charts, the cost of photovoltaic power for the application in question must, in general, be made competitive with the cost of power from the cheapest alternative source. Because of the great differences between the components of the cost of photovoltaic and conventional power, the most appropriate single parameter to use in such comparisons is the overall present-value cost of providing the required electrical service. (This present-value computation must be carried out, of course, for the same total period of service from each source.) The result of the comparison can be expressed in terms of the breakeven array price, the array price at which the total present-value cost of providing photovoltaic power is equal to the present-value cost of the appropriate alternative. If it is then assumed that the successive ERDA array-price goals will be achieved, the year in which photovoltaic solar energy conversion can be expected to become economically competitive can be determined.

An important part of the Task 1 activity, therefore, is the determination of breakeven array prices for the applications under consideration. Chart 9 illustrates some of the elements of such a calculation. Displayed in the chart are 1980 cost figures for electric energy a) from diesel generators (for two different basic fuel prices and two different fuel-cost escalation rates) as a function of power level (assumed constant) and b) from photovoltaic power systems (for four different array prices) as a function of electric storage capacity. The cost figures shown in the chart represent, in every case, the present value cost of 15 years of service divided by the total number of kilowatt-hours of energy produced over the 15 year period. In the present-value calculations, a discount rate of 9% was assumed and the general inflation rate (applied to all costs other than that of fuel) was taken to be 5%.

The calculation of the cost of diesel-generated electricity took into account annual maintenance costs (estimated as being 5% of the installed cost of the generator plus 5% of the fuel cost) and the cost of periodic overhauls (25% of the installed cost of the generator for each overhaul, with overhaul frequency ranging from 3 times per year for very small generators to less than once every two years for very large machines). The figures used for specific fuel consumption ranged from 0.094 gal/kWh for 10 kW generators to 0.074 gal/kWh for 60 kW units. In the calculation of photovoltaic energy cost, the price for battery storage was taken to be \$50/kWh and battery service life was assumed to be five years. The ratio between kW_{pk} and kW was taken to be 6, a value that had been found to be appropriate for the sunnier portions of the U. S. on the basis of an analysis of monthly average insolation on arrays tilted (about an east-west axis) at an angle equal to the local latitude.

1980 Electric Energy Costs

=== DIESEL GENERATORS
- - - - PHOTOVOLTAIC ARRAYS

[Present value cost of 15 yr
of service divided by total
amount of energy produced:
general inflation rate = 5%
discount rate = 9%]

Chart 9

Chart 10

POTENTIALLY LARGE PHOTOVOLTAIC MARKETS MICROWAVE REPEATERS

Chart 10 proves an example of a potentially very large photovoltaic market in which customer acceptance should be good if array prices can be brought into the competitive range. Photovoltaic power has already been used, for several years and at a number of installations, for lower power VHF repeaters, and one manufacturer is already advertising small (4 watt draw) microwave repeater stations powered, if desired, by a photovoltaic array.

The market estimates shown in Chart 10 are based on limited, unofficial FCC licensing data, applicable to the year 1974. These include microwave stations in private service only; the FCC does not license government stations and no data have yet been obtained on common carrier service. On the basis of sampling interviews with personnel from the American Telephone and Telegraph Company, General Telephone and Electronics, and Pacific Telephone Company, it is believed that all existing common carrier repeater stations are served by utility power, with diesel generation backup. The conversion of existing stations to photovoltaic power is therefore unlikely, but new stations may be a good market prospect.

The power draw figure shown in the chart is based on an assumed average of 20 communication channels per repeater station and an average "hop" distance of 25 miles. The presently licensed stations, which are of varying age, utilize a mix of vacuum tube and solid state devices. Future installations will almost certainly be all-solid-state, with a consequent reduction in average station draw to about one-half of the current average.

The market estimates are based on the assumption that 50% of the existing stations are on utility power and are not candidates for conversion to photovoltaic power. It was further assumed that only about 30% of the all-diesel powered stations would convert to solar power. Because of the estimated breakeven costs, it was assumed that appreciable use of solar arrays will not occur until about 1979, and then only in the lower-power-draw segment of the station spectrum. The market estimates are also based on available FCC data which showed that about 10,500 private service microwave stations were licensed to operate by 1974, and that this number was then increasing at about 10% per year, as against a rate of increase over a 20 year period which averaged about 20% per year. This rate of increase will further decrease in future years as a result of saturation of the communications market and the increased use of satellite communication links for the private systems that cover greater distances. Thus, by 1980 the annual rate of increase will not exceed 1000 stations per year, with about 50% utilizing solar power.

The figures in Chart 10 on breakeven array price are calculated as described in connection with Chart 9. It was assumed that the alternative power sources are either diesel generators or utility power; the average power line extension required was assumed to be 1 mile in length, at an average cost of \$15,000. It was further assumed that diesel generator backup was required in all cases (including the photovoltaic alternative) and the delivered price for diesel fuel was taken to be \$1/gallon. The assumed operation and maintenance costs for diesel power generation were based on manufacturers' estimates.

Potentially Large Photovoltaic Markets

MICROWAVE REPEATERS

VHF AND
MICROWAVE

MICROWAVE ONLY
PRIVATE SERVICES ONLY

1. VOICE
2. DIGITAL

PRELIMINARY ESTIMATES

EQUIVALENT CONTINUOUS POWER*, W		350	
ARRAY SIZE, PEAK W		2400	
SIZE OF MARKET**	UNITS	CUM-1980	ANNUAL
		180	500
	kW _{pk}	500	1000
BREAK-EVEN ARRAY PRICE			
vs DIESEL: \$1.0/W _{pk} , vs UTILITY: \$5.6/W _{pk}			
CUSTOMER CLASSES (examples)			
a. PUBLIC SAFETY			
b. INDUSTRIAL			
c. LAND TRANSPORTATION			
DATE OF REALIZATION		1979	

*Typical for Private Line Service

**Excludes Common Carrier and Government Service

Chart 10

Blank Page

Chart 11

POTENTIALLY LARGE PHOTOVOLTAIC MARKETS ILLUMINATED HIGHWAY SIGNS

The market illustrated in Chart 11 is one that is potentially very large indeed but is difficult to assess in quantitative terms. The basic problems lie in determining how many illuminated highway signs are needed and at what price the cognizant agency would be willing to install them. Studies have shown that, at least in the specific cases investigated, accident rates can be reduced through illumination of signs, but the current trend is toward the use of reflectorized signs because of their lower cost. Several concepts now in development may help to reverse this trend and increase the use of illuminated signs. These concepts include internally illuminated signs which reduce power needs, low voltage sign lighting systems which reduce operational costs, and reliable vehicle detection systems which switch lights on only when needed. Other developments involve sensors to activate signs when special hazards are present such as icy roads, fog ahead, etc.

Because of these uncertainties, the size of the market for illuminated highway signs has been estimated for only one type of signal, the hazard warning, and then only in terms of a probable range of market size, from a likely minimum to a conservative maximum. As indicated, officials in one sample highway district estimate that about 10% of its 1500 miles of highway are in areas totally without utility power. An undetermined but high percentage of the remaining road mileage has powerlines more than one-half mile from the roadway. If the 10% value applied on the average to the total surfaced rural roads in the U. S., about 250,000 miles might be the minimum number of highway miles requiring an alternative power source for sign lighting. If the Interstate System, which is 90% rural, could serve as an example of the need for illuminated signs of all types, as many as 2 signs per mile might be required as a maximum.

Photovoltaic-powered illuminated signs on road segments remote from utility power would probably initially be restricted to power-economizing special hazard signs, warning of fog or ice or other hazards which occur only periodically. Such signals could be coupled with sensors which activate these signs only when the need to warn motorists is acute. The assumption that such signs are needed every ten miles on the 10% of the roads totally without utility power provides the minimum market size estimate shown on the chart. Increasing the types of signs to be illuminated with solar power to include informational and action signs, and their number to about one per mile (1/2 of the number now on the Interstate), provides a conservative maximum. A less conservative maximum market would also include illuminated signs on roads where powerlines are excessively distant from the highway. The breakeven array price shown on the chart assumes the power line to be 1 mile away and obviously

indicates that solar power would be competitive at much smaller distances as well. (It should be noted, of course, that highway signs at the locations considered here are not now illuminated, presumably because costs are considered to be too high. If photovoltaic systems are to be used in this application, therefore, the array price will have to be appreciably smaller than the "breakeven" price; it will not be sufficient simply to be economically competitive with a too-costly conventional power source.)

The many uncertainties associated with this market make it unwise to guess a date of realization. Because of the uncertainties associated with customer acceptance of this application, consideration of incentives to promote this market seem appropriate.

Potentially Large Photovoltaic Markets

ILLUMINATED HIGHWAY SIGNS

- HIGHWAY SIGNS
1. FLASHING HAZARD
 2. INFORMATIONAL
 3. ACTION

	<u>MILES</u>
TOTAL U. S. ROADS	3,180,000
TOTAL SURFACED RURAL ROADS	2,450,000
FEDERAL-AID RURAL ROADS	827,000
34,000 mi OF INTERSTATE HAVE 63,000 LIGHTED SIGNS

PRELIMINARY ESTIMATES

EQUIVALENT CONTINUOUS POWER*, W	10	
ARRAY SIZE, PEAK WATTS	70	
SIZE OF MARKET	UNITS	24, 000-240, 000
	kW _{pk}	1, 680-16, 800
BREAK-EVEN ARRAY PRICE: \$216/W _{pk}		
ALTERNATIVE IS POWERLINE AT \$15, 000 per MILE		
CUSTOMER CLASSES (examples)		
a. FEDERAL		
b. STATE		
c. LOCAL GOVERNMENT		
DATE OF REALIZATION		?

SOLID DATA LACKING:

MILES OF ROADS LACKING POWER (sample district in California ~10%)

NEED FOR SIGNING i.e., SOCIAL COST OF LACK OF ILLUMINATED SIGNING

DATA ON NEW LIGHTED SIGN (low power; lighted on demand) CONCEPTS UNDER DEVELOPMENT

*Typical for strobe

Chart 11

Chart 12

POTENTIALLY LARGE PHOTOVOLTAIC MARKETS PRELIMINARY MARKET ESTIMATES

Chart 12 contains a summary of the estimated size of the U. S. markets for photovoltaic arrays in a number of the applications that have been studied. Although several relatively small markets have also been included, the applications listed in the chart are in general those corresponding to the largest potential markets among the more than 35 major application groupings that have been surveyed to date.

The breakeven array price figures listed in the chart are based on an assumed 15 year life cycle and were calculated in the manner described in connection with Chart 9. When utility power is the alternative, the breakeven array price is based on an assumed 1 mile power-line extension at a cost of \$15,000; in some of the applications, diesel backup was also assumed for both photovoltaic array and utility power alternatives. Where primary batteries were the alternative power source, it was assumed that zinc-air cells were used. (In these cases, the average power cost was ~\$13/kWh, in contrast to from \$0.12 to \$0.16/kWh for diesel-generated electricity.) Gasoline or diesel generation was considered a viable alternative when the load was 300 watts or greater.

The cumulative market estimates are based on the assumption that the market first materializes in the target year and builds up gradually. The annual post-1980 markets are averages of the estimated demand over the 1980-1985 period. Customer acceptance factors relating to the highway sign market were discussed in connection with Chart 11. Customer acceptance of bridge decking corrosion prevention by solar-powered impressed-current systems depends upon individual evaluation of concepts which are competitive with impressed current protection (e.g. special coatings on the reinforcing bars). Customer acceptance also depends on individual tradeoffs between the certain current expense of installing the impressed current system (or any other) versus potential future expense in repairing the decking. This trade is strongly, although subjectively, influenced by current budgetary limits.

The totals shown on the chart (8 MW_{pk} by 1980, 15 MW_{pk}/yr thereafter) are estimated values that are intended to include all of the near-term applications that form the applications tree represented by Charts 3 through 8. These estimates are fairly crude at this time but will be refined as the study progresses. As was indicated above, these totals represent U. S. markets only and do not include what may well be significantly larger markets outside the U. S., especially in the underdeveloped nations of the world. In such countries, utility power is often unavailable, and the fuel and operating costs associated with using diesel generators to supply power for a particular application are likely to exceed greatly the corresponding costs for diesel power in the U. S.

Potentially Large Photovoltaic Markets

PRELIMINARY ESTIMATES - DOMESTIC CIVILIAN MARKETS

APPLICATION	AVERAGE POWER, Watts*	BREAKEVEN COST \$/Peak Watt	CUMULATIVE MARKET - 1980, kW _{pK}	ANNUAL MARKET AFTER 1980, kW _{pK}	TARGET YEAR FOR INITIAL USE
HIGHWAY CALL BOXES (radio)	0.5	200.0 (Batteries)	100	50	NOW
ENVIRONMENTAL SENSORS	0.5	200.0 (Batteries)	12	6	NOW
HIGHWAY SIGNALS FLASHING HAZARD, etc.	10	216.0 (Utility)	(1680 to 16,800)		1978**
HIGHWAY BRIDGE DECKING CORROSION PREVENTION	20	100.0 (Utility) 70.0 (Battery)	30	100	1978**
RAILROAD GRADE CROSSING SIGNALS/GATES	55	14.0 (Utility)	600	400	1977
GAS WELL CORROSION PROTECTION	50	7.0 (Utility)	2000	1000	NOW FOR SHALLOW WELLS 1978 FOR DEEP WELLS
PIPELINE CORROSION PROTECTION	300	5.0 (Utility)	50	150	1979
RADIO REPEATERS ***	350	5.6 (Utility) 1.0 (Diesel)	500	1000	1979
OTHERS	--	--	--	--	
TOTALS PROBABLY IN RANGE OF			8 MW _{pK}	15 MW _{pK}	

*Load

**Dependent on customer acceptance factors.

***Private line microwave only.
Other markets not yet sized.

Chart 12

Blank Page

SUGGESTED PROCEDURE FOR IMPROVING CIVILIAN DEMONSTRATION PROGRAM

One of the several purposes of the market survey activity outlined in the preceding charts has been to develop information that can be used in guiding ERDA's "Special and Governmental Applications" (near-term non-military applications) demonstration program. As the study has proceeded it has become increasingly apparent that the breadth and depth of the market survey could be appreciably extended and the demonstration program enhanced if some method could be found to enlist wider and more thoughtful participation in the program by potential users of the photovoltaic technology.

Furthermore, interviews with representatives of the existing photovoltaic industry have revealed that current ERDA demonstration plans, especially of near-term applications, are viewed by some of these companies as threatening to their competitive positions. An ERDA demonstration might well give rise to competition in a market that an array manufacturer had already identified and started to develop. These companies, therefore, foresee relatively little advantage to their businesses from the ERDA demonstrations unless the demonstration program uncovers and helps to develop markets not already recognized by the industry. While it is expected that the current market survey activity will, indeed, identify some previously unrecognized markets, it seems clear that innovative thinking by potential users would substantially increase the number of such novel applications that are discovered (or invented).

One procedure that could enlist the desired user participation in the program is outlined in Chart 13. It is suggested that ERDA issue a Program Opportunity Notice leading to the issuance of a large number (perhaps 50) of small (10 to 20K) planning grants to support short (three month) studies of potential uses for photovoltaic solar energy conversion in a variety of segments of the economy, either private or governmental. The intended recipients of these grants would be the potential photovoltaic power users, themselves, and the products of the studies would be documents providing technical and economic analyses of the application of photovoltaic technology in areas in which the users were experts.

The reports of these studies would then be evaluated largely on the basis of the suitability of the suggested applications as demonstrations. From these would be selected a group (perhaps 10) of the most attractive possibilities, and these would serve as the basis for a series of RFPs for actual demonstrations. The demonstrations would then be carried out by the successful bidders. (These bidders are likely to be contractor teams, perhaps including array manufacturers.)

As is indicated in the chart, this procedure would have a number of advantages. It should be acceptable to current array manufacturers, since it would be unlikely to threaten their individual marketing plans and would, indeed, precondition new classes of potential customers to accept photovoltaic technology. It should lead to a considerable degree of original thinking and is likely to induce the expenditure of a certain amount of the grantee's own funds (and the tapping of reservoirs of information with which outsiders are unfamiliar).

One principal disadvantage would be the obvious one that the grantees would be unlikely to have the necessary degree of knowledge and understanding of photovoltaic technology. This deficiency could be removed by providing a specially-prepared brochure, by convening a tutorial seminar for grantees, or by offering a limited amount of consulting help from within the ERDA Program. Another problem to be dealt with, of course, would be that associated with integrating these demonstrations with the rest of the ERDA program. It might be desirable to keep them separate and to permit the arrays required for these demonstrations to be purchased on the open market.

Suggested Procedure for Improving Civilian Demonstration Program

1. PLANNING GRANTS FOR STUDIES OF USES OF PHOTOVOLTAIC POWER IN A VARIETY OF SEGMENTS OF THE U. S. ECONOMY - TO BE CARRIED OUT BY POTENTIAL USERS
 - MANY (up to 50)
 - SMALL (10-20K)
 - SHORT (3 months)
2. SELECTION OF MOST PROMISING APPLICATIONS FOR DEMONSTRATION
3. SOLICITATION OF PROPOSALS TO CARRY OUT SELECTED DEMONSTRATIONS
4. ERDA FUNDING OF SUCCESSFUL CONTRACTOR-TEAM BIDDERS

ADVANTAGES

- ACCEPTABLE, NON-THREATENING TO CURRENT ARRAY PRODUCERS
- MAXIMUM PARTICIPATION BY POTENTIAL USERS
- FUNDAMENTALLY SIMPLE, QUICKLY IMPLEMENTED
- HIGH PUBLIC APPEAL
- LIKELY TO INDUCE EXPENDITURE OF SOME GRANTEE RESOURCES

DISADVANTAGES

- PRESUMES SOME GRANTEE SOPHISTICATION ABOUT PHOTOVOLTAIC TECHNOLOGY
 - BROCHURE
 - SEMINAR/WORKSHOP FOR GRANTEES
- SHORT IMPLEMENTATION LEAD TIME FOR DEMONSTRATIONS MAY NOT BE COMPATIBLE WITH JPL/LEWIS SCHEDULES
 - OPEN MARKET ARRAY PURCHASES
 - SPECIAL JPL PROCUREMENTS

Chart 14

EFFECT OF RELAXATION OF GENERATION RELIABILITY CRITERION

One of the principal Task 2 objectives has been to determine the economic, institutional, and legal conditions under which the use of photovoltaic arrays would be competitive with alternative energy sources in the major mid-term missions (central station power, on-site residential or commercial power) if array prices are those identified as the ERDA 1985-1990 goals. An earlier study (Reference 2) had indicated that more stringent array-price goals (perhaps as low as \$100-200/kW_{pk}) might have to be met in order for photovoltaic technology to be competitive in such missions. Basic to the economic analysis in this earlier study was the assumption that overall electric service in a utility system containing photovoltaic power sources would be required to maintain the same high degree of reliability that is currently expected. In the search for operating conditions under which photovoltaic solar energy conversion might have a more favorable competitive position, it was therefore decided to investigate the effect on the economic competition of introducing a less restrictive reliability criterion.

The reliability requirement impacts the economic analysis because it leads to the requirement that photovoltaic power sources must be backed up by conventional generation capacity in order that weather-related solar plant outages may not impair service reliability in the utility system. The capital cost of the required conventional backup capacity must then be included in the economic analysis, along with the capital cost of the photovoltaic systems. In the earlier analysis, the assumed reliability criterion was that there should not be more than one day of loss of load (failure of generation capacity to meet overall system demand) in ten years of service (2.4 hours per year). The effect of relaxing this criterion to permit up to one day of loss of load per year (24 hours per year) was determined for a set of representative central station and on-site residential cases. The central station cases include three examples in which a plant in Phoenix, Arizona, was considered to be part of the model Central Arizona utility system and four cases in which a plant at Inyokern, California, was assumed to be part of the model Southern California utility system. Six different residential systems, all located in Phoenix, were studied, but the backup capacity requirements were calculated for both utility models. The results are displayed in Chart 14.

The computations summarized in Chart 14 clearly indicate that relaxation of the generation reliability criterion increases, rather than decreases, the amount of backup capacity required. This result, although surprising at first glance, is not really so anomalous as it sounds. When the reliability criterion is relaxed, the total amount of conventional generation

capacity in the baseline utility system is reduced because the "margin" (excess of total generation capacity above annual peak demand) needed in order to maintain the postulated reliability is reduced. Evidently the replacement of a conventional plant by photovoltaic power sources, with their associated weather-related outages, in a system that is nearer the "ragged edge" produces a somewhat larger destabilizing effect than in the standard case.

Effect of Relaxation of Generation Reliability Criterion

ARRAY AREA (10 ⁶ m ²)	STORAGE CAPACITY (10 ⁶ kWh)	BACKUP CAPACITY REQUIRED FOR 100 MW PHOTOVOLTAIC PLANT			
		CENTRAL ARIZONA UTILITY		SOUTHERN CALIFORNIA UTILITY	
		MAXIMUM LOSS OF LOAD 2.4 hr/yr 24 hr/yr		MAXIMUM LOSS OF LOAD 2.4 hr/yr 24 hr/yr	
CENTRAL STATION POWER PLANTS					
2	0	27.2 MW	36.8 MW	48 MW	61 MW
	0.5	14.3	22.5	20	30
	1.0	14.3	22.5		
3	0			47	60
	0.5			3	5.5
RESIDENTIAL ON-SITE SYSTEMS					
2	0	150	158	80	88
	1.0	140	154	60	66
4	0	95	104	48	59
	1.0	59	67	13	18
6	0	72	83	36	48
	1.0	24	32	9	12

Chart 14

Chart 15

EFFECT OF DIURNAL VARIATIONS IN THE INSOLATION SPECTRUM
ON AlGaAs/GaAs SOLAR CELL OUTPUT

In searching for conditions under which photovoltaic power generation can be economically competitive, another approach that is being taken is to investigate the possibility that heat removed from the arrays (in order to keep array temperatures low and efficiency high) can be put to productive use. The first step in this approach has been to investigate the performance of a power plant configuration that appears likely to lead to the most beneficial combination of photovoltaic power production and thermal energy utilization. This preferred design is one in which large fields of steerable flat mirrors (heliostats) are used to concentrate sunlight upon arrays of $\text{Al}_x\text{Ga}_{1-x}\text{As}/\text{GaAs}$ solar cells attached to a tower-mounted central receiver. Such a design combines the advantages of GaAs cells (high efficiency, unusual tolerance for high temperatures and intense irradiation) with those of the central receiver design (projected collector costs of $\$60\text{-}70/\text{m}^2$ as compared to $\sim \$140/\text{m}^2$ for parabolic trough or dish concentrators). If the concentration ratio is made very large ($X \sim 1000$), furthermore, the impact on overall system cost of the very high projected cost of GaAs arrays ($\sim \$20,000/\text{m}^2$) can be made very small.

An adequate assessment of the suitability of such a system for a given mission can be provided by an hour-by-hour simulation of its performance, using appropriate models to represent the entire system, the insolation input, and the desired power output (mission demand). Central to such simulation computations is a procedure for determining, for each hour, the amount of solar energy that falls on the photovoltaic array. The electric output of the array is then calculated as the product of the collected solar energy and the array conversion efficiency, which is usually assumed to be constant. This procedure is subject to a degree of uncertainty because a) the response of a photovoltaic device depends markedly on the spectrum of the incident light and b) the spectrum of insolation at the earth's surface varies with time of day and with meteorological conditions as a result of atmospheric absorption and scattering. In preparation for future simulation computations, therefore, it was necessary to establish whether or not the error arising from neglecting these facts is likely to introduce significant error into the overall computational results.

The method used to assess the magnitude of the error arising from neglect of variations in the insolation spectrum on GaAs array response was the same as that used in an earlier study (Reference 2) in the case of silicon arrays. Six different models of the atmosphere (tropical, midlatitude winter, and midlatitude summer, each with two different aerosol concentration levels) were used to compute the spectrum of ground-level insolation for a range of solar zenith angles. On the basis of these spectra and a spectral response curve for GaAs, the

electrical output of a typical GaAs cell ("spectral effect included") was calculated for each case. For each case, also, the output of a standard pyranometer (flat spectral response, modified by absorption in the pyrex cover) was calculated. These pyranometer output values were then multiplied by a fixed efficiency to yield "spectral effect neglected" values for cell output. (The fixed efficiency value used was the factor required to make the "spectral effect neglected" value equal to the "spectral effect included" value in one selected case - simulating a calibration.) The difference between the two output values in each case is then a measure of the error introduced by neglecting spectral effects. The results for one of the atmospheric models are shown in Chart 15. It is apparent from these results (and those for the other atmospheres are very similar) that the error can be expected to have only a negligible effect on the outcome of simulation computations.

Effect of Diurnal Variations in the Insolation Spectrum on Al Ga As/Ga As Solar Cell Output

TROPICAL ATMOSPHERE

Chart 16

CAPITAL COST COMPARISON: 100 MW SOLAR POWER PLANTS, INTERMEDIATE LOAD

In order to make a preliminary assessment of the ability of a high-concentration photovoltaic power plant to compete economically with alternative methods of solar power generation, it is useful to compare the capital costs of the competing plants. An example of such a comparison is shown in Chart 16, where basic capital costs (without allowances for spares, contingencies, interest during construction, etc.) are given for four different solar plant designs. The plants represented in the chart are all rated at 100 MW and have essentially equivalent performance characteristics, with plant capacity factors of ~ 0.4 when operated at Inyokern, California. The system and subsystem costs shown in the table are all expressed in terms of dollars per rated kW.

The numbers in the first column of the chart were abstracted from results obtained in The Aerospace Corporation's on-going Solar Thermal Mission Analysis Program. The system costs in this case are dominated by the cost of the heliostat collector field at $\$62/\text{m}^2$.

The cost figures shown for a flat-plate photovoltaic power plant are essentially the same as those obtained in the NSF-Sponsored Photovoltaic Mission Analysis study (Reference 2) that was the forerunner of the current program, except that the assumed cost for array support structure has been increased from $\$15/\text{m}^2$ to $\$25/\text{m}^2$. Two different silicon array prices, $\$100/\text{kW}_{\text{pk}}$ and $\$500/\text{kW}_{\text{pk}}$, were assumed; the values corresponding to the higher array price are shown in parenthesis.

The cost figures shown for the central receiver photovoltaic plants are not based on a detailed system simulation but instead were derived in an approximate manner from the system simulation computations carried out for the other two cases. From the analysis of solar thermal central receiver performance, values were derived for the overall (annual average) efficiency of the central receiver collector system, taking into account reflection losses and shading and blocking of adjacent heliostats. The annual average normal incidence insolation for Inyokern (8.8 kWh/day) was then multiplied by the collector efficiency figure (62%) to yield a value for the average amount of collected radiation (5.4 kWh/day). On the basis of this figure and the corresponding figure for the annual average amount of collected radiation in the flat-plate case (7.2 kWh/day), and taking into account the different conversion efficiencies of silicon and gallium arsenide arrays, a determination was made of the collector area that would lead to the same annual array output in the central receiver photovoltaic plant as in the flat-plate plant. (Array packing factors of 0.9 were assumed for each type of array and the 70°C efficiencies were assumed to be 10% and 17.5% for silicon and gallium arsenide cells respectively. In

the central receiver case, it was assumed that the average array temperature was kept in the neighborhood of 100°C by intensive water cooling). The cost figures for the heliostat field and the receiver towers were taken to be the same as in the solar thermal case; the gallium arsenide array price was assumed to be \$20,000/m², on the basis of manufacturer estimates.

The system-cost totals in Chart 16 indicate that the two alternative solar plant concepts appear to have a moderate economic advantage over the high-concentration photovoltaic concepts, when only the photovoltaic power output is considered. If effective use can be made of the large amount of reject heat from the solar arrays in the latter two cases (either as process heat or in the thermal generation of additional electric power), however, the resultant economic gain might well be great enough to reverse the competitive positions of the alternative concepts. As is indicated in the next chart, these possibilities are currently under investigation.

Capital Cost Comparison

100 MW SOLAR POWER PLANTS - INTERMEDIATE LOAD

	SOLAR THERMAL CENTRAL RECEIVER	PHOTOVOLTAIC		
		FLAT PLATE	CENTRAL RECEIVER	
CELL MATERIAL	--	Si	Al GaAs / GaAs	Al GaAs / GaAs
COLLECTOR AREA (m ²)	1(10 ⁶)	2(10 ⁶)	1.75(10 ⁶)	1.75(10 ⁶)
CONCENTRATION RATIO	600	1	1000	2250
ARRAY AREA (m ²)	--	2(10 ⁶)	1.75(10 ³)	0.78(10 ³)
STORAGE CAPACITY (hr)	6	6	6	6
CAPITAL COSTS		- \$/kW _{rated}		
LAND, STRUCTURES, FACILITIES	92	100	100	100
POWER CONDITIONING, MISC				
COLLECTORS, SUPPORT STRUCTURE	620	500	1085	1085
RECEIVER, TOWER,	121	--	15	15
HEAT EXCHANGER				
PHOTOVOLTAIC ARRAYS	--	225(1125)	350	156
STORAGE	121	120	120	120
TURBINE, GENERATOR, COOLING	102	--	20	20
TOWER				
TOTAL BASIC COST	1056	945(1845)	1690	1496

ASSUMPTIONS:

SILICON ARRAY PRICE: \$100/kW_{pk} (\$500/kW_{pk})

GaAs ARRAY PRICE: \$20,000/m²_{pk}

Chart 16

Chart 17

PHOTOVOLTAIC CENTRAL RECEIVER POWER PLANT

The on-going investigation of photovoltaic power plants using the central receiver configuration (discussed in connection with the preceding chart) has also included an analysis of the cooling requirements for such a plant. The specific configuration studied was one in which GaAs solar arrays were mounted on the exterior surface of a cylindrical central receiver, approximately 9 m tall and 18 m in diameter, mounted on top of a tower. It was assumed that the individual cells were coated on the rear with a layer of tin (to form the rear ohmic contact) and were then attached by a thin layer of adhesive to the aluminum surface of the receiver. Array cooling was provided by a flow of water (inlet temperature, 20°C) in a narrow annular channel on the inner side of the receiver surface. In the calculations, the maximum permissible temperature of any portion of the array was taken to be 200°C, on the basis of manufacturer information indicating that higher array temperatures would reduce cell service life.

The results of the analysis are displayed in Chart 16, where net electrical power output and water exit temperature are plotted against coolant flow rate, for various values of the width of the annular channel. Here net power is defined as the difference between the photovoltaic power generated and the power required for array cooling (pump power).

The curves in Chart 17 indicate that the maximum net power from such a plant is not greatly affected by coolant channel width over the range of widths considered. However, to achieve maximum net power, very large flow rates are required, with the result that outlet water temperatures are relatively low. It may well be more desirable to operate at points just above the dotted portions of the net power curves (i. e. where flow rate and channel width are such as to produce maximum array temperatures just below the 200°C limiting value) in order that more effective use may be made of the heat energy in the cooling water. Since the cooling water, under the conditions of the calculation, absorbs about 300 MW of thermal energy, a very large amount of thermal energy is available, and operation under minimum flow conditions can lead to outlet water temperature in excess of 130°C. Water at such temperatures could be used, for example, to drive a bottoming-cycle generator whose electrical output could then be added to that from the array. This alternative will be investigated during the coming quarter, as will other potential uses for the reject thermal energy, and desirable operational coolant flow rates will be determined.

Photovoltaic Central Receiver Power Plant

Chart 17

Chart 18

CRITICAL EXTERNAL ISSUES

Late in the reporting period, a start was made on Task 4, Critical External Issues. After a review of the issues that had been identified at the outset of the study and those that have come to light as a result of the Task 1 and Task 2 efforts, the questions listed in Chart 18 were tentatively selected for further examination. At the end of the quarter a start had been made on a study of the first of these issues, with the general objective of determining whether or not it is reasonable to consider modes of operation in which excess photovoltaic power is fed back into the utility grid.

As the project proceeds, it is possible that other issues will be found sufficiently important to be included in the study, either as additions to the list in Chart 18 or as replacements for one or more of the issues in the chart.

Critical External Issues

TASK 4

ISSUES TENTATIVELY SELECTED FOR STUDY:

- WHAT ARE THE TECHNICAL AND INSTITUTIONAL OBSTACLES TO FEEDBACK OF EXCESS POWER FROM ON-SITE SYSTEMS TO GRID?
 - SYSTEM PROTECTION, CONTROL, STABILITY, PERSONNEL SAFETY
 - EFFECT OF SIZE, NUMBER OF ON-SITE SYSTEMS
- WHAT WILL BE THE EFFECT OF LARGE-SCALE UTILIZATION OF CAPITAL-INTENSIVE PHOTOVOLTAIC GENERATORS ON NATIONAL CAPITAL SUPPLY, AND VICE VERSA?
- WHAT WILL BE THE ENVIRONMENTAL EFFECTS OF LARGE-SCALE USE OF PHOTOVOLTAIC SYSTEMS?
- WHAT IS THE MOST APPROPRIATE PATTERN OF OWNERSHIP FOR RESIDENTIAL AND COMMERCIAL ON-SITE SYSTEMS?

Chart 18

Chart 19

SOCIETAL COSTS OF COAL-FIRED ELECTRIC POWER GENERATION SYSTEM

During the first quarter of the program, the emphasis under Task 6 (Societal Costs of Conventional and Photovoltaic Power Production) was placed on the collection and sifting of the large volume of existing information (and opinion) on the costs to society of the various methods of electric power generation. In the second quarter, as planned, the focus of this task has shifted from data collection to data evaluation and, in particular, to a quantitative assessment (expressed in mills per kWh of electric power) of the societal costs of coal-fired power generation.

Any assessment of the full non-internalized social costs (i.e. costs to society that are not included in the price of electricity) of coal-fired power generation must take into account the entire production cycle, including fuel production (mining), fuel transportation, and power generation. In Chart 19 are listed the principal sources of societal damage that are associated with each of these three elements of the coal-fired power generation system. Also shown are the main types of damage that occur. Some of the listed damages (e.g. to property values and to health) can, in principle, be quantified in economic terms, (although there is considerable disagreement about the computed magnitudes. Other damages (e.g. to mental health or to climate) are so uncertain, at least at present, that no economic quantification is possible.

In the present study, the very extensive and varied literature on these different types of societal damage was reviewed with the objective of identifying the types of damage that contribute significantly to the total. A critical assessment was then made of the available data about these significant damage elements and their total economic impact (in mills/kWh) was computed on the basis of the data that were judged to be most reliable. In these computations, it was assumed that the generation plants involved were in compliance with current federal law with respect to emissions. The resulting numbers, of course, are subject to appreciable uncertainty, largely because of their dependence a) on long chains of assumptions linking original cause to resulting damage cost and b) on the particular set of social priorities that are reflected in the unit cost assigned to each type of ultimate damage.

In this analysis, no attempt has been made to include the societal benefits (societal economies) that are associated with coal-fired power production. The purpose of this task is to provide a quantitative basis for comparison of the societal diseconomies that are associated with conventional coal and nuclear power plants and give necessary inputs to determine the appropriate size of Federal incentives or subsidies that may be justifiable for photovoltaic power plants.

Societal Costs of Coal-Fired Electric Power Generation System

FUEL PRODUCTION		FUEL TRANSPORTATION		POWER GENERATION	
DAMAGE SOURCE	SOCIETAL DAMAGE TO:	DAMAGE SOURCE	SOCIETAL DAMAGE TO:	DAMAGE SOURCE	SOCIETAL DAMAGE TO:
COAL DUST MINE WASTES COAL DEBRIS LAND DISTURBANCE UNDERGROUND DISTURBANCE EXPOSURE TO POTENTIAL ACCIDENTS	PROPERTY VALUES ROAD AND HIGHWAYS AGRICULTURE: ENVIRONMENT ANIMAL LIFE HUMAN LIFE HEALTH OF MINERS MINE-SITE COMMUNITIES LAND (subsidence) WATER SYSTEMS	ACCIDENT OVERLOADING OF ROAD BEDS	PEOPLE: INJURIES AND DEATHS INCREASED ROADBED MAINTENANCE PROPERTY DAMAGE	EMISSION OF: SO _x (sulfates) NO _x PARTICULATES METALLIC TRACE ELEMENTS CO POLYCYCLIC HC	PHYSICAL HEALTH MATERIALS AESTHETICS MENTAL HEALTH CLIMATE DOMESTIC ANIMALS WILDLIFE, VEGETATION

Chart 19

Chart 20

ESTIMATES OF PHYSICAL HEALTH DAMAGE AND ASSOCIATED SOCIAL COSTS
ATTRIBUTABLE TO INCREASE IN AVERAGE SUSPENDED SULFATES

The single most damaging aspect of the coal-fired electric power generation cycle appears to be SO_x emission, and the associated damage to human health is generally considered to be the most serious element of the total societal cost of this method of power production.

The principal damage resulting from SO_x emission is not produced directly by SO_x , but rather by the suspended particulate sulfates that result when SO_x is oxidized in the atmosphere. This conclusion is based, in part, on epidemiological studies that have indicated an association between ambient sulfate levels and various adverse effects on human health. The CHES (Community Health and Environmental Surveillance System) study (Reference 3) also indicated that health effects seem to be more closely associated with suspended atmospheric sulfate than with exposure to other pollutants. The main types of measurable health damage that are believed to result from increased atmospheric sulfate concentrations are those listed in Chart 20: excess mortality, aggravation of heart-lung disease symptoms, asthmatic attacks, lower respiratory disease in children, and chronic respiratory disease.

Any attempt to compute the total amount of health damage resulting from suspended particulate sulfates, however, is complicated by the fact that there is no general agreement about the relationship between the dose (the quantity of sulfate inhaled or ingested) received by an individual or population and the response in the form of measurable damage to health. In most observational situations, for example, there is uncertainty about the dose received by the exposed population. Different studies have used quite different measures of response. In many cases, other factors that influence the result have been present and it has not been possible to correct for this effect. It has been shown that the dose-response relationship varies significantly with the characteristics (age, race, smoking habits, etc.) of the population involved. And, finally, the basic mechanisms of biological reaction with suspended sulfate particles are not yet fully understood. It is believed that the broncho-constricting potency of particulate sulfates is related both to the physical properties of the particles (e. g. size) as well as to such chemical properties as the pH. The biological reactivity of the sulfate particles also appears to depend on ambient humidity, temperature, and the synergistic effects of the presence of other pollutants.

As a result of these uncertainties, the National Academy of Sciences (Reference 4) has supported the use of a relatively simple dose-response relationship that should be at least approximately correct for a "typical" population. This relation was used in the computation of the damage figures shown in Chart 20. The second column lists the baseline statistics for the

indicated types of health damage in a Northeastern U. S. urban population of 10 million people exposed to an average atmospheric sulfate concentration of $16 \mu\text{g}/\text{m}^3$. The third column gives the annual amount of additional damage that would be expected if the concentration were increased by $1 \mu\text{g}/\text{m}^3$. These incremental damage figures were translated into the cost figures in the fourth column on the basis of unit cost figures that were also suggested by the National Academy of Sciences (Reference 4).

Estimates of Physical Health Damage and Associated Social Costs Attributable to Increase in Average Suspended Sulfates

NORTHEASTERN U.S. METROPOLITAN AREA OF 10 MILLION POPULATION

BASELINE STATISTICS*	TOTAL NUMBER OF CASES*	ADDITIONAL EXPECTED CASES AT AVERAGE CONCENTRATION** INCREASE OF $+1\mu\text{g}/\text{m}^3$	ADDITIONAL SOCIAL HEALTH COSTS AT AVERAGE CONCENTRATION** INCREASE OF $+1\mu\text{g}/\text{m}^3$ (million \$)
MORTALITY RATE (deaths per year)	102.6×10^3	20	0.59
AGGRAVATED HEART-LUNG DISEASE SYMPTOMS (person-days of sickness per year)	21.2×10^6	350×10^3	7.04
ASTHMATIC ATTACKS (cases per year)	2.18×10^6	70×10^3	0.70
LOWER RESPIRATORY DISEASE IN CHILDREN (cases per year)	110×10^3	8.5×10^3	0.64
CHRONIC RESPIRATORY DISEASE (cases per year)	318×10^3	35×10^3	8.83
TOTAL SOCIAL HEALTH COSTS			17.80

*Data from the Statistical Abstracts of the U. S., 1970

**Assumes average annual concentration of $16\mu\text{g}/\text{m}^3$

Chart 20

Chart 21

YEARLY HEALTH DAMAGE RESULTING FROM SO_x EMISSIONS FROM 1000 MW_e URBAN AND RURAL COAL-FIRED POWER PLANTS

In Chart 21 are displayed the results of a calculation of the total annual societal cost associated with health damage resulting from SO_x emissions from two "typical" 1000 MW coal-fired power plants. One of the plants is assumed to be an urban one, located 60 km from a population center like New York City; the other is rural, located 500 km from a region like the northeast corridor of the U. S. Both plants are assumed to be meeting the emission standards set by the New Source Standards of Clean Air Act, which limits hourly emission of SO_x to 12000 pounds. This assumption is equivalent to the adoption of either one of two possible scenarios: a) the plant burns coal with a 0.75% sulfur content and does not use flue gas desulfurization, or b) the plant burns coal with 3% sulfur but uses desulfurization equipment capable of reducing SO_x concentration in the flue gas by 75%.

In order to estimate the total amount of health damage resulting from operation of these two plants, it is necessary first to determine the size of the population at risk and the increase in the ambient concentration of sulfate particles as a result of plant operation. The calculation of these two parameters involves assumptions about a) the dispersion behavior that governs the distribution of the emitted SO_x downwind from the plant, b) the rates at which SO_x is oxidized to sulfate in rural and urban air, and c) deposition rates (wet and dry) for both SO_x and sulfate particles. The resulting numbers are shown in the upper portion of Chart 21. A much larger population is put at risk by the rural plant because the dispersed plume covers a much larger populated area before blowing out to sea, but the ambient sulfate concentration is much smaller. The figures for SO_2 concentration shown in Chart 21 have no direct bearing on health damage but are important in computations of damage to materials.

The figures for annual health damage and the associated costs, in the bottom portion of Chart 21, are based on the results presented in the preceding chart (Chart 20), corrected to account for differences in the size of the exposed population and in the ambient sulfate concentration. (It was assumed that the health damage increases linearly with sulfate concentrations over the narrow range involved in these calculations.) The translation of total cost into a cost per kWh was based on the assumption that the 1000 MW power plant in question operated with an annual capacity factor of 0.8.

Yearly Health Damage Resulting From SO_x Emissions From 1000 MWe Urban and Rural Coal Fired Power Plants

	<u>URBAN PLANT</u>		<u>RURAL PLANT</u>	
POPULATION AT RISK	11.5 MILLION		50 MILLION	
INCREASE IN AVERAGE ANNUAL CONCENTRATION OF SULFATE	0.75 $\mu\text{g}/\text{m}^3$		0.0585 $\mu\text{g}/\text{m}^3$	
INCREASE IN AVERAGE ANNUAL CONCENTRATION OF SO ₂	3.024 $\mu\text{g}/\text{m}^3$		0.141 $\mu\text{g}/\text{m}^3$	
	HEALTH DAMAGE PER YEAR	DAMAGE COST (\$10 ⁶)	HEALTH DAMAGE PER YEAR	DAMAGE COST (\$10 ⁶)
EXCESS PREMATURE DEATHS	17	0.51	6	0.18
AGGRAVATION OF HEART-LUNG DISEASE SYMPTOMS (person- days)	300,000	6.08	100,000	2.06
ASTHMATIC ATTACKS (cases)	60,000	0.63	21,000	0.21
LOWER RESPIRATORY DISEASE IN CHILDREN (cases)	7,300	0.56	2,500	0.19
CHRONIC RESPIRATORY DISEASE (cases)	30,000	7.65	10,000	2.58
TOTAL DAMAGE		15.43		5.22
HEALTH DAMAGE COST PER POUND OF SULFUR EMITTED		\$0.37/lb		\$0.12/lb
HEALTH DAMAGE COST PER kWh		2.2 mills/kWh		0.75 mills/kWh

Chart 21

Chart 22

EXPECTED SOCIETAL COSTS FOR COAL-FIRED POWER PLANTS

Calculations similar in basic philosophy to those illustrated in the preceding two charts were carried out for the other significant types of societal damage produced by coal-fired power generation. The results of these computations are summarized in Chart 22, where they are expressed in mills per kWh of electric energy produced.

In calculating the costs associated with the power generation portion of the cycle, three different approaches were taken. The figures in the first column, the "national average" case, are based on data generated by the Environmental Protection Agency on the total costs to society of various types of air pollution. From the EPA figures for the total national costs resulting yearly from various types of pollution and for the total annual emissions of the pollutants, values were obtained for the social cost per pound of pollutant, for each pollutant type. The next step was to determine the amount of each pollutant emitted, on a per kWh basis, by coal-fired plants that meet the New Source Standards of Clean Air Act. The product, for each pollutant type, of the social cost (in dollars per pound) and the emission rate (in pounds per kWh) is a national average figure for the societal cost (in dollars per kWh) resulting from emission of the pollutant in question by coal-fired power plants meeting current federal standards.

The figures in the second and third columns of the chart, representing "typical" urban and rural power plants, are based on the models that have been described in connection with Chart 21. The same sort of computational procedure was employed, involving estimates of pollutant emission, the population and materials at risk, dispersion behavior, exposure behavior, damage behavior (e.g. dose-response relations), and unit costs for the various types of damage. The costs associated with each type of pollutant include costs resulting from property damage as well as from damage to health. (It is for this reason that the SO_x cost figures in Chart 22 exceed those in Chart 21.)

The societal costs resulting from the coal production and coal transportation elements of the cycle are, of course, the same in all three columns in Chart 22. The figures given for the fuel transportation element are based on a detailed analysis of existing data, but those for fuel production are still preliminary because the analysis had not yet been completed at the end of the reporting period. In this analysis, the assumption is being made that there is a reasonable degree of compliance with the Federal Coal Health and Safety Act.

It should be emphasized that the total societal costs shown in Chart 22 represent merely the "out-of-pocket" costs resulting from damage to health and property. They do not include, for example, the incremental amount a person would be willing to pay to avoid illness, injury, or death, and they do not include costs associated with damage that cannot be quantified in economic terms. Furthermore, it should be recognized that the costs are unevenly distributed over the population; the burden is mainly borne by the three groups identified in the chart.

Finally, as has been mentioned above, the quoted cost figures are based on the assumption that there is (or will be) essentially total compliance with existing federal laws with respect to air pollution and to elimination of health and safety hazards. It is estimated that before these acts were in force the total societal costs of coal-fired power production were from 2 to 3 times greater than the totals shown in Chart 22.

Expected Societal Costs for Coal-Fired Power Plants

NATIONAL AVERAGE, URBAN PLANT, AND RURAL PLANT

POWER GENERATION FUEL CYCLE ELEMENT	SOCIETAL COSTS (mills/kWh)		
	NATIONAL AVERAGE	TYPICAL RURAL PLANT	TYPICAL URBAN PLANT
POWER GENERATION			
SO _x	2.56	1.21	3.17
NO _x	0.36	0.17	0.45
PARTICULATES	<u>0.18</u>	<u>0.09</u>	<u>0.22</u>
SUBTOTAL	3.10	1.47	3.84
FUEL TRANSPORTATION	0.13	0.13	0.13
FUEL PRODUCTION	~1.5	~1.5	~1.5
TOTAL COSTS	4.73	3.10	5.47

- SOCIETAL DAMAGES ARE UNEVENLY DIVIDED. ESPECIALLY AFFECTED ARE:
 - PERSONNEL AND FAMILIES WORKING IN THE POWER PLANT FUEL CYCLE
 - FAMILIES WHO CHOOSE OR ARE OBLIGED TO LIVE IN THE POLLUTION AREA
 - CHILDREN, AND THE ELDERLY AND PHYSICALLY WEAK WHO DO NOT HAVE STRONG RESISTANCE AGAINST DISEASE
- BEFORE COMPLIANCE WITH THE FEDERAL COAL HEALTH AND SAFETY ACT AND NEW SOURCE PERFORMANCE STANDARDS OF CLEAN AIR ACT, SOCIETAL COSTS WERE 2 TO 3 TIMES THE PRESENT AND EXPECTED FUTURE COSTS

Chart 22

Chart 23

SUMMARY OF ACCOMPLISHMENTS

The progress that has been made during the report period is summarized in Chart 23. In most cases these accomplishments have been described in greater detail in the preceding charts, with their accompanying text. No chart was made, however, to illustrate the Task 3 study (not yet complete) of the future photovoltaic market from the point of view of a current or potential array manufacturer. In this study particular attention is being paid to market entry points and to the various obstacles that impede such entry. While no startling new insights have yet resulted, the investigation has given added emphasis to the fairly obvious fact that the main obstacle to a major expansion of array production capacity is that one cannot yet make reliable projections of really substantial future markets, especially for array prices of \$500/kW_{pk} and higher. The study has also served to pinpoint two potential trouble areas in the ERDA technology implementation scenario:

- a) The postulated time interval between pilot-plant demonstration of automated sheet production methods for fabricating silicon arrays and the large-scale commercialization of these methods may be unrealistically short, and
- b) The postulated substantial growth in production volume between the present and the time of introduction of sheet production methods may be difficult to achieve; a producer may well be reluctant to make the necessary large investment if he believes technology breakthroughs are immanent.

Summary of Accomplishments - 1 March 1976 to 31 May 1976

TASK 1: ANALYSIS OF NEAR-TERM MISSIONS

- COMPREHENSIVE SURVEY OF POTENTIAL USERS CONTINUED
- APPLICATION TREES CONSTRUCTED
- PRELIMINARY EVALUATION OF MANY APPLICATIONS COMPLETED

TASK 2: ANALYSIS OF MAJOR MID-TERM MISSIONS

- MARGIN ANALYSIS CARRIED OUT ON BASIS OF RELAXED RELIABILITY CRITERION
- EFFECT OF AIR MASS VARIATIONS ON GaAs CELLS EVALUATED
- STUDY OF USE OF HIGH CONCENTRATION IN CENTRAL STATION MISSIONS CONTINUED

TASK 3: REVIEW AND UPDATING OF ERDA TECHNOLOGY IMPLEMENTATION PLAN

- OBSTACLES TO MARKET ENTRY BY POTENTIAL ARRAY PRODUCER UNDER INVESTIGATION

TASK 4: CRITICAL EXTERNAL ISSUES

- EXTERNAL ISSUES TO BE INVESTIGATED TENTATIVELY IDENTIFIED
- STUDY OF BARRIERS TO FEEDBACK OF EXCESS ON-SITE PHOTOVOLTAIC POWER TO GRID INITIATED

TASK 6: SOCIETAL COSTS OF CONVENTIONAL AND PHOTOVOLTAIC POWER PRODUCTION

- STUDY OF SOCIETAL COSTS OF COAL-FIRED POWER PRODUCTION NEARLY COMPLETED

Chart 23

III. PLANS

This section contains a summary of planned activities during the next quarter.

PLANNED ACTIVITIES - 1 JUNE 1976 TO 31 AUGUST 1976

The activities that are planned for the third quarter of the program are listed in Chart 24. In order to allow adequate time for at least a preliminary assessment of market penetration as a function of time and array price, it will be necessary to bring the Task 1 survey of potential near-term applications to a close by the end of the quarter. During this final phase of the survey, the most promising applications (from the point of view of market size and breakeven array price) will receive the greatest attention. In addition, specific applications that can be considered representative of particular classes of load (electric power demand) will be selected and analyzed; these results will then be extrapolated to form the basis for an estimate of the size and growth rate of the entire near-term photovoltaic market. Toward the end of the quarter, preparations will be made for the questionnaire mailings that will be used in forming estimates of the depth and rate of market penetration by photovoltaic technology.

Under Task 2, the investigation of the use of very high concentration in central station missions will be completed. Three other topics will also be investigated: a) the economics of commercial on-site systems (department stores, shopping centers), with proper allowance for backup capacity, b) the statistics of insolation outage in stand-alone photovoltaic residential systems, and c) the effect of geographic location on central station mission economics. This latter study will be facilitated by the availability of utility system models for five different regions of the United States, models which were developed in the course of The Aerospace Corporation's companion Solar Thermal Mission Analysis program.

Under Task 3, the volume/price scenarios that are a part of the ERDA technology implementation plan will be reviewed in the light of the Task 1 and Task 2 results. In Task 4, an investigation will be made of the potential environmental impacts of widespread use of photovoltaic solar energy conversion, including the environmental effects of those manufacturing processes that are essential to the technology (e.g. silicon production and/or CdS and GaAs production). The study of technical and economic obstacles to the feedback of excess power from on-site photovoltaic systems to the utility grid will continue; this study should be near completion by the end of the quarter. The Task 6 study of societal costs of power generation will continue but the emphasis will shift, early in the quarter, from coal-fired generation to nuclear power. In addition, a start will be made on Task 5, an investigation of the effect of various types of governmental incentives on the economics of photovoltaic power generation.

Planned Activities - 1 June 1976 to 31 August 1976

TASK 1: ANALYSIS OF NEAR-TERM MISSIONS

- COMPLETE SURVEY OF POTENTIAL USERS
- SELECT REPRESENTATIVE APPLICATIONS FOR LOAD-CLASS GROUPS
- CONDUCT TECHNICAL/ECONOMIC ANALYSES OF REPRESENTATIVE APPLICATIONS
- PREPARE FOR MARKET-ANALYSIS STUDY OF PROBABLE PENETRATION OF MOST PROMISING MARKETS

TASK 2: ANALYSIS OF MAJOR MID-TERM MISSIONS

- COMPLETE STUDY OF USE OF HIGH CONCENTRATION IN CENTRAL POWER MISSIONS
- INVESTIGATE BREAK-EVEN ARRAY COSTS FOR STRICTLY SUPPLEMENTAL COMMERCIAL ON-SITE APPLICATIONS
- DETERMINE EFFECT OF GEOGRAPHICAL LOCATION ON CENTRAL STATION POWER PLANT ECONOMICS
 - FIVE LOCATIONS, INSOLATION RECORDS
 - MARGIN ANALYSIS BASED ON REGIONALLY REPRESENTATIVE UTILITY SYSTEM MODELS
- INVESTIGATE OUTAGE STATISTICS FOR STAND-ALONE ON-SITE SYSTEM

TASK 3: REVIEW AND UPDATING OF ERDA TECHNOLOGY IMPLEMENTATION PLAN

- CONTINUE REVIEW OF VOLUME/PRICE SCENARIOS IN LIGHT OF TASK 1 INTERIM RESULTS

TASK 4: CRITICAL EXTERNAL ISSUES

- CONTINUE EXAMINATION OF BARRIERS TO FEEDBACK OF ON-SITE PHOTOVOLTAIC POWER TO GRID
- BEGIN STUDY OF ENVIRONMENTAL IMPACT OF PHOTOVOLTAIC POWER PRODUCTION

TASK 5: IMPACT OF INCENTIVES

- BEGIN STUDY OF IMPACT OF GOVERNMENT INCENTIVES ON PHOTOVOLTAIC ECONOMICS

TASK 6: SOCIETAL COSTS OF CONVENTIONAL AND PHOTOVOLTAIC POWER PRODUCTION

- COMPLETE ASSESSMENT OF SOCIETAL COSTS OF COAL-FIRED POWER PRODUCTION
- BEGIN QUANTIFICATION OF SOCIETAL COSTS OF NUCLEAR POWER

Chart 24

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

IV. REFERENCES

1. Energy and Transportation Division, "Mission Analysis of Photovoltaic Solar Energy Systems, Quarterly Progress Report for the period 1 December 1975 to 29 February 1976", ATR-76 (7574-07)-1, The Aerospace Corporation, 1 March 1976.
2. Energy and Transportation Division, "Final Report: Mission Analysis of Photovoltaic Solar Energy Systems" (3 volumes), ATR-76 (7476-01)-1, The Aerospace Corporation, 1 December 1975.
3. U. S. Environment Protection Agency, "Health Consequences of Sulfur Oxides: A Report from CHESS", EPA-650/1-74-004, Research Triangle Park, North Carolina.
4. National Academy of Sciences, "Air Quality and Stationary Source Emission Control", A Report by the Commission on Natural Resources, prepared for the Senate Committee on Public Works, Committee Print Serial 94-4, March 1975.