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MISSION ANALYSIS OF PHOTOVOLTAIC SOLAR ENERGY SYSTEMS

QUARTERLY PROGRESS REPORT
1 DECEMBER 1975 - 29 FEBRUARY 1976

MASTER

FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

THE AEROSPACE CORPORATION

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MISSION ANALYSIS OF PHOTOVOLTAIC SOLAR ENERGY SYSTEMS

Quarterly Progress Report for the Period

1 December 1975 - 29 February 1976

1 March 1976

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Prepared for

Division of Solar Energy
Energy Research and Development Administration
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Subcontract No.
Report No. <i>ATR-76(7574)</i>
Date of Report <i>29 February 1976</i>
Name & Phone No. of DOE Technical Representative <i>Mike Lopez</i> <i>PROCUREMENT DIVISION</i>

1. Title: *MISSION ANALYSIS OF PHOTOVOLTAIC SOLAR ENERGY SYSTEMS*

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FOREWORD

This report presents an account of work accomplished during the first 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. Morton Prince 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. The author wishes 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, Dr. P. K. Munjal, and Mr. E. J. Rattin. The help of Mr. Fred Eggers in overseeing the production of the report and of Mrs. Kathy Morris in typing the text is also gratefully acknowledged.

ABSTRACT

During the first quarter of activity on this project, the principal focus of the effort has been on Task 1, Analysis of Near-Term Missions. Progress was also made on two other tasks: Task 2, Analysis of Major Mid-Term Missions, and Task 6, Comparison of the True Societal Costs of Conventional and Photovoltaic Power Production. As planned, work on the remaining three assigned tasks was deferred until later in the schedule.

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 break-even 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 break-even 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 adaptation 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 problem.

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I. INTRODUCTION

This section of the report contains a discussion of the objectives of the study, a description of its structure (flow chart), and an account of planned activities for the reporting period.

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Chart 1

PHOTOVOLTAIC MISSION ANALYSIS: OBJECTIVES

The study discussed in this report is designed to provide ongoing support to the Energy Research and Development Administration (ERDA) in its program to develop photovoltaic conversion of solar energy as an alternative method for meeting a significant portion of the nation's energy needs. In Chart 1 are listed the overall objective of the project and the specific objectives that must be met in order to reach the overall goal.

Although this project is, in some respects, a continuation of an earlier study carried out under National Science Foundation (NSF) sponsorship (Ref. 1), the objectives listed in Chart 1 reflect a considerable shift in emphasis, in response to the changing requirements of the national program. The principal thrust of the earlier NSF study was directed toward the technical and economic evaluation of terrestrial photovoltaic missions (applications) that represent very large potential markets for photovoltaic technology in the 1980-2000 period. The general approach that was adopted was a conservative one in which photovoltaic solar energy conversion was treated, without favoritism, as a competitor in an energy market place that is characterized by high standards of service reliability and, in some instances, indirect subsidies for more conventional power generation methods.

The principal focus of the current study, by contrast, is on the identification and technical/economic analysis of applications in which photovoltaic energy conversion will be economically competitive with alternative energy sources in the near term (1976-1985). These analyses are intended to support the implementation of the ERDA strategy to reduce photovoltaic array prices to \$500/kW_{pk} by 1986. The ERDA strategy has two major elements: a) a substantial research and development effort designed to produce significant near-term technological advances with cost-reduction potential, and b) the development of interim markets that, taken together, will constitute a total market whose orderly growth will lead to further price reductions as a result of the usual cost-volume "learning curve." The identification and evaluation of potentially significant near-term applications is therefore required in order that tactics to stimulate the growth of the necessary interim market may be formulated.

The rationale (and justification) for the ERDA strategy also includes the expectation that, when array prices reach (or closely approach) the 1986 goals, photovoltaic energy conversion will become able to compete economically in one or more of the larger markets for electric power (general residential power, central station power, etc.). The materialization of such major markets will require expanded array production capacity and will support the further technical improvements and cost reductions that are characteristic of the learning-curve experience of similar industries. Therefore, another objective of the current study is to identify the major

photovoltaic missions that have the greatest market potential in the mid-term (1985-2000) period and determine under what conditions photovoltaic technology will be competitive in these missions.

Achievement of the remaining two objectives, the analysis of critical external issues and the quantification of the societal costs of power production by conventional and photovoltaic methods, will help to assure continuing proper balance and effective strategic planning in the ERDA program.

Photovoltaic Mission Analysis: Objectives

OVERALL OBJECTIVE:

- TO SUPPORT THE FORMULATION, PLANNING, AND JUSTIFICATION OF THE ERDA NATIONAL PHOTOVOLTAIC PLAN
 - IDENTIFY PROMISING APPLICATIONS, ATTRACTIVE DEMONSTRATIONS, CRITICAL EXTERNAL ISSUES
 - PROVIDE PLANNING SUPPORT TO REFINE THE ERDA TECHNOLOGY IMPLEMENTATION PLAN (program strategy)

SPECIFIC OBJECTIVES:

- SURVEY AND EVALUATE NEAR-TERM (1976-1985) APPLICATIONS; IDENTIFY MOST PROMISING POTENTIAL CONTRIBUTORS TO ORDERLY MARKET GROWTH
 - MILITARY
 - GOVERNMENT
 - PRIVATE
- EVALUATE MOST PROMISING MAJOR MISSIONS FOR MID-TERM (1985-2000) PERIOD; DETERMINE CONDITIONS UNDER WHICH PHOTOVOLTAIC TECHNOLOGY CAN COMPETE AT ARRAY PRICES CONSISTENT WITH ERDA GOALS
- ADDRESS CRITICAL EXTERNAL ISSUES AND IDENTIFY SENSITIVITY OF PHOTOVOLTAIC SYSTEM TECHNICAL REQUIREMENTS TO SUCH FACTORS
- QUANTIFY SOCIETAL COSTS OF ALTERNATIVE ENERGY SOURCES AND IDENTIFY EQUALIZING INCENTIVES

Chart 1

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Chart 2

STUDY FLOW CHART

The approach that has been adopted in the project is illustrated schematically in the flow chart shown in Chart 2. As is indicated there, the study has been divided into six separate but inter-related tasks. The main emphasis of the program is on Task 1, Analysis of Near-Term Missions, and Task 2, Analysis of Major Mid-Term Missions.

The underlying purpose of Task 1 is to make possible an effective strategy for stimulating the growth of the overall market for photovoltaic energy conversion in the 1976-1985 time period. This is to be accomplished by identifying the potential applications that will constitute this market, determining when photovoltaic devices will become economically competitive in each application (as array prices are reduced from the current \$20/W_{pk} to the ERDA 1986 goal of \$.50/W_{pk}), and estimating the subsequent market capture by photovoltaic devices. Accomplishing this task requires the development and utilization of a systematic procedure for surveying all possible photovoltaic applications and then carrying out the technical and economic analyses needed in order to establish the competitive position of photovoltaic technology.

Under Task 2, the two or three major missions that have the greatest market potential in the 1985-2000 "mid-term" period (when array prices are expected to be less than \$.50/W_{pk}) are to be determined. A study will then be made of these preferred missions in order to determine the economic, institutional, and legal conditions that are likely to prove most favorable for the competitive position of photovoltaic energy conversion, so that the large potential market represented by these applications can be realized.

The remainder of the program consists of four supporting tasks. In the first of these (Task 6) a quantitative comparison will be made of the social costs and benefits of photovoltaic power production as contrasted with power production by more conventional fossil or nuclear plants. This task will seek to identify the level of economic support that can be justified for photovoltaic systems based on net public benefits. Task 5 will then identify and evaluate alternative subsidy and incentive mechanisms for distributing the justifiable economic support developed in Task 6. The results of these two tasks will be incorporated into the continuing mission analyses of Tasks 1 and 2. Additionally, a systematic effort will be made to identify external issues or policies that may have major impacts on the large scale terrestrial utilization of photovoltaic systems. The more important of the issues so identified will be analyzed in a separate study effort (Task 4), and the results will also be incorporated into the analyses of Tasks 1 and 2.

Also, the generalized technology implementation plan implicit in ERDA's 10-year photovoltaic program will continually be reviewed, updated as needed, and made more specific (Task 3). It is expected that the near-term applications evaluated in Task 1 will be important elements in the resulting explicit formulation of the plan. A secondary element of Task 3 will be an evaluation of the economic potential of the future photovoltaic market from the point of view of a producer of arrays, with particular attention to market entry points and the effects of possible incentives.

Study Flow Chart

Chart 2

Chart 3

PLANNED ACTIVITIES - 1 DECEMBER 1975 - 29 FEBRUARY 1976

Chart 3 contains a summary of the activities that were planned for the first quarter of effort on the project. As the chart indicates, the principal emphasis was to be on Task 1 while a smaller amount of activity was planned for Tasks 2 and 6. Tasks 3, 4, and 5 were deferred until later in the program.

The plans for Task 1 called for activity in two areas. The first of these was the development of a suitable systematic methodology for the identification and subsequent evaluation of potential near-term missions. A start was then to be made on the implementation of this methodology, the logical first step being the initial assembly of as comprehensive a list as possible of candidate applications and the collection of preliminary data on system requirements and market size.

The second area of planned activity under Task 1 represents a response to the immediate need of the ERDA Photovoltaic Program for the early identification of a small subset of highly visible civilian applications that can be defended as being a) technically feasible, b) economically viable for array prices greater than \$2/W_{pk}, c) representative of substantial near-term markets, and d) suitable for early demonstration. These preliminary results were required in order to provide guidance in the selection and justification of forthcoming demonstration projects.

Under Task 2, the principal planned activity was to begin an investigation of the use of photovoltaic systems employing very high concentration ($X \sim 1000$) in central station power plants. In addition, as a start on the task of identifying favorable operational conditions for photovoltaic energy conversion, an assessment was to be made of the effect of relaxing the overall reliability standard for electric power generation on the amount of back-up capacity that would be required for a photovoltaic power plant. It had been postulated that the rigid but widely-used reliability standard (no more than one day of loss-of-load in 10 years of operation) unduly penalized solar power plants by increasing the backup capacity requirement.

Because of the very nature of the task, the main activities under Task 6 must be a) a comprehensive and far-reaching program to collect data on power production impacts from a wide variety of sources, and b) a systematic effort to reduce these data, which are necessarily of highly variable quality, to a consistent quantitative basis. Accordingly, the planned effort on Task 6 during the first quarter was to be devoted to the data collection activity, with initial emphasis on conventional coal-fired power generation.

Planned Activities - 1 December 1975 Thru 29 February 1976

TASK 1: ANALYSIS OF NEAR-TERM MISSIONS

- DEVELOP METHODOLOGY FOR SURVEY AND EVALUATION OF CANDIDATE MISSIONS, BEGIN IMPLEMENTATION
- IDENTIFY CANDIDATE APPLICATIONS, COLLECT TECHNICAL/MARKET DATA
 - LITERATURE SEARCH
 - TELEPHONE AND IN-PERSON INTERVIEWS
- CARRY OUT QUICK PRELIMINARY EVALUATION OF SMALL SUBSET OF PROMISING APPLICATIONS
 - TECHNICAL/ECONOMIC FEASIBILITY
 - SUITABILITY FOR DEMONSTRATION PROJECT

TASK 2: ANALYSIS OF MAJOR MID-TERM MISSIONS

- BEGIN ANALYSIS OF CENTRAL STATION POWER PRODUCTION USING VERY HIGH CONCENTRATION
- INVESTIGATE EFFECT OF RELAXING REQUIREMENTS FOR GENERATION RELIABILITY

TASK 6: SOCIETAL COSTS OF CONVENTIONAL AND PHOTOVOLTAIC POWER PRODUCTION

- COLLECT DATA ON POWER PRODUCTION IMPACTS
 - LITERATURE SEARCH
 - PREVIOUS SURVEYS
 - AD HOC STUDIES
 - INTERVIEWS
- INITIAL EMPHASIS ON COAL-FIRED GENERATION

Chart 3

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II. PROGRESS

This section contains a discussion of the progress that has been made during the first quarter. As was planned, most of the effort during this period was devoted to Task 1, and, in particular, to the quick preliminary study that was requested in order to provide guidance to the ERDA demonstration program. The results of that study are reported here, along with an account of progress in the mainline element of Task 1 and in Tasks 2 and 6.

Chart 4

TASK 1: ANALYSIS OF NEAR-TERM MISSIONS: APPROACH

As was planned, the principal efforts on Task 1 during the reporting period were devoted to two somewhat different subtasks. The first of these was the development and initial implementation of a suitable methodology for conducting a comprehensive survey and evaluation of potential near-term applications for photovoltaic solar energy conversion. The second subtask was to carry out a quick preliminary study designed to provide early identification of several promising applications that could be highlighted in attractive demonstration projects.

The method that was selected for conducting the comprehensive survey task is illustrated in flow-diagram form in Chart 4. The first step is an extensive literature search aimed at identifying as many as possible previously considered applications. The initial list generated in this way is then supplemented by applications identified in the course of an organized program of interviews with photovoltaic array manufacturers, users of stand-alone power sources, current users of photovoltaic arrays, and other likely sources of information. The augmented list is then used in the construction of application trees (see Charts 5 and 6) whose main function is to uncover previously unnoticed applications in one category ("tree branch") that are analogous to already identified applications on another "branch".

When as complete a list of potential applications as possible has been prepared by the above procedure, it is then divided into a limited number of groups that are so categorized as to permit a single application within the group to represent it for purposes of preliminary system design and costing. Approximate break-even array cost analyses are carried out for these single representative applications within each group. The various application groups are then ranked on the basis of a) break-even array cost and b) (estimated) potential market. More complete analyses are then made of applications in the top-ranking groups. These analyses should include more penetrating investigations of both the total size of the potential market and the probable degree of actual market penetration, as a function of time.

This approach is designed to ensure that the total field of applications receives at least some analysis, with the more promising application areas receiving more detailed attention.

During this first quarter of activity on the project, the effort to implement this methodology was concentrated on the first step in the procedure. The literature survey was completed and substantial progress was made on the planned program of interviews.

Task 1: Analysis of Near-Term Missions

APPROACH

Chart 4

Chart 5

POTENTIAL PHOTOVOLTAIC MARKETS
EXAMPLE OF APPLICATION TREE - FIRST LEVEL

An example of what is meant by an application tree is displayed in Chart 5. Since the actual construction of such trees for use in this study has not begun, this example is intended to serve merely as an illustration of the concept. The comparison of the different branches of such a tree facilitates the recognition of previously unnoticed applications in a given branch that are similar to already identified applications in a parallel branch.

Potential Photovoltaic Markets

EXAMPLE OF APPLICATION TREE - FIRST LEVEL

Chart 5

Chart 6

POTENTIAL PHOTOVOLTAIC MARKETS EXAMPLE OF APPLICATION TREE BRANCH - SECOND LEVEL

Chart 6 contains an example of the second level of an application tree; again, this example is intended to be illustrative only, since actual construction of such a tree has not yet been carried out in this study. It is obvious that the tree shown in Charts 5 and 6 is by no means complete, either in terms of horizontal branching or in the number of levels that it would be feasible and useful to construct. Furthermore, even when the actual application tree has been constructed to the maximum useful level of ramification, new branches or sub-branches may well be added as the study proceeds.

Potential Photovoltaic Markets

EXAMPLE OF APPLICATION TREE BRANCH - SECOND LEVEL

Chart 6

PRELIMINARY STUDY OF NEAR-TERM APPLICATIONS

As has been indicated earlier in this report, the mainline activity under Task 1 is to carry out comprehensive a survey as possible of the potential near-term photovoltaic applications. The methodology, accordingly, must be systematically wide-ranging, converging to detailed evaluations of specific applications only relatively late in the study. It became apparent in the first weeks of the project, however, that early identification and evaluation of at least a few promising applications was needed in order to provide guidance in the selection of attractive demonstration projects. Accordingly it was decided to conduct, in parallel, a quick preliminary study of a limited subset of applications that appeared to be strong candidates on the basis of already available information.

The objective of this preliminary study is spelled out in Chart 7, along with a listing of the basic elements of the approach that has been taken. A fairly substantial list of candidate applications was already available as a result of the literature search and the program of interviews. The first step in this study therefore was to adopt, and apply, a set of criteria for ranking the candidates on this list. In the absence of hard data about most of the candidates, it was necessary to apply these criteria very largely on the basis of the judgement and experience of the personnel involved. From the top-ranking application on the resulting ordered list, a small number of candidates were selected and subjected to a preliminary technical and economic evaluation, including an estimate of the associated market for photovoltaic arrays.

Preliminary Study of Promising Near-Term Applications

OBJECTIVE

- IDENTIFY A SMALL NUMBER OF HIGHLY VISIBLE CIVILIAN APPLICATIONS THAT WOULD MAKE ATTRACTIVE DEMONSTRATION PROJECTS AND THAT ARE:
 - TECHNICALLY FEASIBLE NOW
 - ECONOMICALLY COMPETITIVE AT ARRAY PRICES GREATER THAN \$2/W_{pk}
 - REPRESENTATIVE OF SUBSTANTIAL MARKETS

APPROACH

- RANK CANDIDATES FROM AVAILABLE APPLICATIONS LIST ON BASIS OF JUDGEMENTALLY - APPLIED CRITERIA
- FROM TOP-RANKING APPLICATIONS, SELECT THREE OR FOUR FOR FURTHER INVESTIGATION
- CARRY OUT PRELIMINARY TECHNICAL/ECONOMIC EVALUATION
- REFINE MARKET ESTIMATE

Chart 7

Chart 8

PRELIMINARY STUDY OF NEAR-TERM APPLICATIONS
SELECTION CRITERIA

The selection criteria that were used in ranking the existing list of candidate applications are shown in Chart 8. As was mentioned earlier, it was necessary to apply these criteria very largely on a judgemental basis since hard data, in general, were lacking.

While the rationale for the use of each of these criteria is, in general, straightforward, some additional comments might be offered about three of them:

- a. The requirement that the application be able to absorb array costs greater than $\$2/W_{pk}$ (i. e. having a breakeven array cost greater than $\$2/W_{pk}$) simply ensures that photovoltaic conversion will be economically competitive in the application before about 1982 (when ERDA expects to have established a $\$2/W_{pk}$ array price).
- b. Institutional customers are preferred to individuals because in institutions the authority to buy is relatively centralized, thereby simplifying the development of information on market needs and market size. The buy decision is also likely to be based on a sound economic rationale and is therefore predictable.
- c. Preference for applications in which photovoltaic devices have not yet been extensively tested or sold commercially is based on the desire to concentrate demonstration activities in application areas where they are most needed and to minimize the amount of apparent (or real) competition with private enterprise.

Preliminary Study of Near-Term Applications

SELECTION CRITERIA	
AS APPLICATION	AS DEMONSTRATION
<ul style="list-style-type: none"> ● ABILITY TO ABSORB ARRAY COSTS GREATER THAN \$2/W_{pk} ● LARGE, NEAR-TERM MARKET POTENTIAL ● SUITABLE CUSTOMER (institutional customer preferred) ● INSENSITIVITY TO GEOGRAPHIC LOCATION 	<ul style="list-style-type: none"> ● ABSENCE OF EXTENSIVE TESTING OR COMMERCIAL EXPLOITATION ● PUBLIC/INDUSTRIAL APPEAL ● ABILITY TO BE DEMONSTRATED WITH CURRENT STATE-OF-THE-ART EQUIPMENT ● ABILITY TO BE DEMONSTRATED IN EXISTING OPERATING ENVIRONMENT

Chart 8

Chart 9

PRELIMINARY SURVEY TOP-RANKING APPLICATIONS

Each of the applications on the available list of candidates was assigned a numerical rating with respect to each of the criteria listed on the preceding chart. The ratings for each application were then summed to produce a total score and scores assigned by different evaluators were averaged. The candidates were then ranked on the basis of the average score. The top-ranking applications identified by this process are listed in Chart 9; the differences in the scores assigned to the applications on this list were judged to be small in comparison with the inherent uncertainties in the ranking process.

From this list of high-ranking candidates, the four indicated applications were selected for further study, largely on the basis that these four appear to represent larger markets than the others. In some cases (notably that of highway signals) candidates were not selected because it would have been difficult to get additional information about them within the time allotted for the preliminary study. The decision not to select the perimeter control application was made after preliminary contacts with the Immigration and Naturalization Service indicated that the possible use of photovoltaic devices in policing the entire Mexican-U.S. border would probably be limited to powering roughly 60 VHF radio repeaters whose power requirements appear to average less than one watt. (The actual sensors, of course, must be exceedingly inconspicuous and are therefore not candidates for photovoltaic power.)

The results of the preliminary evaluations of the four preferred applications are described in the next eight charts (Charts 10-17).

Preliminary Survey

TOP-RANKING APPLICATIONS

- CATHODIC PROTECTION
 - NATURAL GAS WELLS
 - OIL/GAS PIPELINES
 - OFFSHORE PUMPING PLATFORMS
 - BUOYS
- SIGNALS AND CONTROLS
 - RAILROAD CROSSINGS
 - HIGHWAYS
 - OIL/GAS WELLS
 - PIPELINES
 - BUOYS
- COMMUNICATIONS
 - MICROWAVE REPEATERS
 - TELEMETRY
 - OIL/GAS WELL, PIPELINE MONITORING
 - REMOTE ENVIRONMENTAL INSTRUMENTATION
 - BUOY INSTRUMENTATION
- SECURITY
 - PERIMETER CONTROL
 - PHOTOVOLTAIC EQUIPMENT SELF-PROTECTION

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Chart 10

APPLICATION/DEMONSTRATION CANDIDATE IMPRESSED CURRENT CORROSION PROTECTION - GAS WELL CASINGS

Chart 10 summarizes the market-related information that has been collected with respect to the first of the preferred applications identified in the preceding chart, impressed current protection (ICP) of gas well casings.

The estimated values shown in the table for the potential U.S. market for photovoltaic devices in this application are based on the fundamental assumption that the number of producing gas wells drilled each year will remain roughly constant at about the present figure and that the ratio of shallow to deep wells will also remain the same. Specifically, it was assumed that there will be approximately 150,000 producing gas wells at the end of 1976 (60,000 shallow and 90,000 deep) and that more wells will be drilled at the rate of 8000/year (3200/year shallow and 4800/year deep). Additional assumptions made in the separate calculations of the markets associated with shallow and deep wells are listed below:

1. Shallow Wells

- a. The ICP system, on the average, requires 8 watts of continuous DC power per well. This power can be supplied by a 60 W_{pk} flat-plate photovoltaic array tilted at an angle equal to the local latitude if it is located in an average Southwestern site.
- b. By 1980, 15% of the currently-existing (1976) shallow wells will be protected by photovoltaic ICP systems and 30% of the new wells added between 1976 and 1980 will be so protected.
- c. After 1980, 50% of the new wells will be protected by photovoltaic ICP.

2. Deep Wells

- a. The ICP system requires an average of roughly 100 W of continuous DC power per well, so that the array size requirement in the Southwest is about 760 W_{pk}.

- b. By 1980, 5% of the existing (1976) deep wells and 15% of those added between 1976 and 1980 will be served by photovoltaic ICP systems.
- c. After 1980, 30% of the new deep wells added each year will be protected by photovoltaic ICP.

Application/Demonstration Candidate

IMPRESSED CURRENT CORROSION PROTECTION - GAS WELL CASINGS

MARKET ENVIRONMENT

- FORCING FUNCTION
 - EXPENSE OF REPLACING OLD AND DAMAGED WELL CASINGS IS HIGH AND INCREASING
 - PRESERVATION OF EXISTING CASINGS
 - INCREASES LIFE OF FIELD-WELLS
 - INCREASES UTILIZATION OF RESOURCE
- STATISTICS - 1974
 - No. OF PRODUCING GAS WELLS IN U.S. = 127,000
 - No. OF PRODUCING GAS WELLS DRILLED (in 1974) = 7,240
 - SHALLOW WELLS (up to ~3700 ft deep) ABOUT 40% OF TOTAL
 - No. OF ACTIVE GAS WELLS IN UNDERGROUND STORAGE FIELDS = 16,000
- POTENTIAL U. S. MARKET (estimate):
 - SHALLOW WELLS: 13,000 AT 60W_{pk} EACH → 780 kW_{pk}
PLUS 96 kW_{pk}/yr AFTER 1980
 - DEEP WELLS: 7400 AT 760W_{pk} EACH → 5600 kW_{pk}
PLUS 1100 kW_{pk}/yr AFTER 1980

Chart 10

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APPLICATION CHARACTERISTICS IMPRESSED CURRENT CORROSION PROTECTION - GAS WELL CASINGS (DEEP WELLS)

Any attempt to determine the break-even array cost associated with the use of photovoltaic arrays to power ICP systems for gas wells is subject to considerable uncertainty. For one thing, the power requirement is highly variable, depending as it does on such parameters as the depth of the well and on local soil conditions. (The current density that must be impressed is determined by the "corrosion potential," which is strongly dependent on soil salinity and local pipe "corrosion cells." The voltage required to drive the current is, in turn, dependent on resistivity). At the power levels involved, the principal competitive source for electric power for ICP systems is the conventional utility power line. The cost of providing this type of power, of course, depends both on the distance between the well and the nearest existing power line and on the type of terrain over which a connecting line would have to be built. (For some soil conditions, notably where soil resistivity is low, galvanic protection - the use of sacrificial anodes - is practical for shallow wells and would, in general, be the method of choice, and ICP, whatever the power source, would probably not be competitive.)

As a result of these uncertainties, the calculation of break-even array cost that is displayed in Chart 11 must be considered to be, at best, a rough approximation. The calculation is carried out only for the deep well case because there are strong indications that the use of photovoltaic ICP for shallow wells is already economically competitive (at array prices of \$20/W_{pk} or greater) and that this market is already being penetrated by private enterprise. There would, therefore, appear to be little justification for a demonstration of photovoltaic ICP on a shallow well.

In the chart, the present-value cost (taking into account both inflation and the cost of capital) of providing the required ICP power by photovoltaic means is compared to the cost of providing this power from an existing power line that is relatively near (0.5 - 1.0 miles) the well. The array cost is initially considered to be unknown and is set at \$ X/W_{pk}; the break-even value of X is then determined by solving the equation that is obtained when the present-value costs of power from the two sources are set equal to each other. The assumed duration of the requirement for ICP in this case was somewhat arbitrarily set at 15 years. The service life of the photovoltaic array was assumed to be at least that long.

The cost figures used in these calculations are approximate but are believed to be roughly representative of costs that can be expected in typical locations during the next 5 years. The \$6000/mile cost for a connecting power line, for example, represents costs for overhead lines constructed over fairly gentle terrain. The computation does not include the cost of several necessary system components, e.g. current/voltage control circuits for both systems and a rectifier for the conventional power source. These costs should be small and roughly comparable in the two cases; their omission should not affect the break-even cost determination to a significant extent.

The present value coefficients used in Chart 11 were calculated by the standard procedure. In the case of the batteries, which must be replaced every five years, the coefficient is obtained from the relation

$$1 + \left(\frac{1+g}{1+r}\right)^5 + \left(\frac{1+g}{1+r}\right)^{10}$$

where g is the escalation rate (inflation) and r is the discount rate (cost of capital). The energy charge is an annual one, incurred at the end of each year, and the present value coefficient is therefore

$$\sum_{i=1}^{15} \left(\frac{1+g}{1+r}\right)^i = \left(\frac{1+g}{r-g}\right) \left[1 - \left(\frac{1+g}{1+r}\right)^{15}\right]$$

Application Characteristics

IMPRESSED CURRENT CORROSION PROTECTION - GAS WELL CASINGS (deep wells)

LOAD: 100W (continuous DC)

ARRAY SIZE: 760 W_{pk}

STORAGE: 7.2 kWh (3 days)

	PHOTOVOLTAIC	ALTERNATIVE
SYSTEM COST ELEMENTS	ARRAY \$760X (at \$X/W _{pk}) BATTERIES 360/EVERY 5 yr (at \$50/kWh, 5-yr service life)	POWER LINE \$6000 D (D mi at \$6000/mi) ENERGY CHARGE 50/yr (at \$0.05/kWh)
PRESENT VALUE COST OF SERVICE* (15 yr)	$760X + 360(2.52)$ $= 760X + 900$	$6000 D + 50(11.27)$ $= 6000 D + 560$

BREAKEVEN

D = 1.0 mi

X = \$7.50/W_{pk}

ARRAY COST

D = 0.5 mi

X = \$3.50/W_{pk}

*Escalation rate = 5%, discount rate = 9%

Chart 11

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Chart 12

APPLICATION/DEMONSTRATION CANDIDATE IMPRESSED CURRENT CORROSION PROTECTION - PIPELINES

Market information relative to photovoltaic ICP for pipelines is summarized in Chart 12. As is indicated there, the market potential for photovoltaic devices in this application is considerably enhanced by the recent imposition by the Department of Transportation of a requirement that all new pipelines (and hazardous old ones) carrying dangerous materials be cathodically protected. As was the case with gas wells, the use of galvanic (sacrificial anode) techniques would be feasible and preferable in some cases, especially where soil resistivity is low, but in many cases the use of ICP will be necessary and photovoltaic solar energy conversion would be a candidate source for the necessary electric power.

The market figures shown in Chart 12 reflect the conservative assumption that it is transmission pipelines that are the main candidates for photovoltaic ICP, since they are more likely than gathering or distribution lines to be remote from conventional power sources. In addition to the general assumption that construction of oil and gas transmission lines will continue into the future at about the present rate, a number of specific assumptions have been made in estimating the potential market:

1. Gas Pipelines

- a. By 1980, roughly 5% of the existing (1974) pipelines and 10% of those added between now and 1980 will be protected by photovoltaic ICP.
- b. After 1980, 30% of new pipelines will be served by photovoltaic ICP.
- c. The power requirement for ICP for new 30" diameter pipes will be about 17 W/mile (corresponding to an array rating of $\sim 100 W_{pk}/\text{mile}$), while old pipes will require roughly twice the power.

2. Oil Pipelines

- a. By 1980, 5% of all existing pipelines (1976) and 5% of all those added between now and 1980 will be served by photovoltaic ICP.

b. After 1980, 5% of all new pipelines will be protected in this way.

The principal reason for assuming a lower penetration percentage for oil pipelines than for gas pipelines is that oil lines require more closely spaced pumping stations, with associated utility power that could be used for ICP without construction of new power lines.

Application/Demonstration Candidate

IMPRESSED CURRENT CORROSION PROTECTION — PIPELINES

MARKET ENVIRONMENT

- FORCING FUNCTION

- DOT REGULATIONS (1973) REQUIRE CATHODIC PROTECTION OF ALL NEW AND HAZARDOUS OLD PIPELINES CARRYING DANGEROUS MATERIALS
- EXPENSE OF REPLACING OLD AND CORRODED PIPELINES IS HIGH AND IS INCREASING

- STATISTICS - 1974

- TOTAL GAS TRANSMISSION PIPELINES IN U. S. = 260,000 mi
- NEWLY ADDED (1974) = 2,430 mi
- TOTAL OIL TRANSMISSION PIPELINES IN U. S. = 150,000 mi
- NEWLY ADDED (1974) = 10,000 mi

- POTENTIAL U. S. MARKET (estimate):

- GAS PIPELINES: 14,000 mi BY 1980 → 2700 kW_{pk}
PLUS ~80 kW_{pk}/yr AFTER 1980
- OIL PIPELINES: 9500 mi BY 1980 → 1700 kW_{pk}
PLUS ~50 kW_{pk}/yr AFTER 1980

Chart 12

Chart 13

APPLICATION CHARACTERISTICS IMPRESSED CURRENT CORROSION PROTECTION - PIPELINES

Chart 13 displays the elements of an approximate calculation of the break-even cost of photovoltaic arrays for use in ICP for oil or gas pipelines. All of the uncertainties that were discussed in connection with gas well ICP (Chart 11) are equally applicable in the pipeline case, and these computations were carried out in essentially the same way.

The indicated power requirement, 300 W of continuous D. C., is considered to be roughly representative. It would provide cathodic protection to some miles or tens of miles of pipe, depending on soil conditions, the condition of the coating on the pipe, and the pipe diameter. (At the 17W/mile loading assumed in Chart 12, it would protect approximately 18 miles of 30" pipe.) The ICP systems for pipeline protection would, therefore, tend to be more widely separated than those used for protecting wells in a gas field. For this reason the break-even array cost calculations in Chart 13 employed somewhat larger values of D, the length of the auxiliary power lines employed in the competitive conventional power system.

As in the previous case, the present value cost calculations were based on a presumed service period of 15 years. (Since the calculation essentially balances the capital cost of the photovoltaic array against the capital cost of a power line, the result is independent of the service period used in the computation, provided that the effective service life of the array and the power line are considered to be roughly the same).

Application Characteristics

IMPRESSED CURRENT CORROSION PROTECTION - PIPELINES

LOAD: 300W (continuous DC)

ARRAY SIZE: 2280 W_{pk}

STORAGE: 21.6 kWh (3 days)

	PHOTOVOLTAIC	ALTERNATIVES
SYSTEM COST ELEMENTS	ARRAY \$2280 (at \$X/W _{pk}) BATTERIES 1080/EVERY 5 yr (at \$50/kWh, 5-yr service life)	POWER LINE \$6000 D (D mi at \$6000/mi) ENERGY CHARGE 150/yr (at \$0.05/kWh)
PRESENT VALUE COST OF SERVICE* (15 yr)	$2280X + 1080(2.52)$ $= 2280X + 2700$	$6000D + 150(11.27)$ $= 6000D + 1690$

BREAKEVEN

D = 2.0 mi

X = \$4.80/W_{pk}

ARRAY COST

D = 1.0 mi

X = \$2.20/W_{pk}

*Escalation rate = 5%, discount rate = 9%

Chart 14

APPLICATION/DEMONSTRATION CANDIDATE RAILROAD GRADE CROSSING SIGNALS

Chart 14 contains market information relative to photovoltaic - powered railroad grade crossing signals. It reflects the fact that, although the railroad industry in the U.S. is certainly not expanding, there is still a very substantial and continuing need for providing protection at grade crossings. The increasing national concern with safety should ensure that pressure will continue to be exerted on the railroads to drive them toward adding to the 23% of crossings that are currently protected. Since many of the currently unprotected crossings are rural and therefore likely to be distant from existing power lines, the use of photovoltaic power should be economically justifiable at the array costs that are expected in the 1976-1985 period.

The market potential estimates in Chart 14 are based on the assumption that roughly 22,000 new grade crossing-protection systems will be installed between now and 1980 and that the installation rate will stabilize at 5000/year thereafter. It was further assumed that photovoltaic power would be provided for 10% of the installations made before 1980 and for 20% of those in succeeding years.

The indicated array size per installation ($420 W_{pk}$) is based on an estimated power requirement that is equivalent to about 55 W of continuous power. The total load is composed of a continuous 50W power drain in the motion detector system and an intermittent load of 150W associated with the lights and gate. If the system is activated for about 2 minutes in every hour, on the average, this intermittent load is equivalent to an additional 5W of continuous load.

Application/Demonstration Candidate

RAILROAD GRADE CROSSING SIGNALS

MARKET ENVIRONMENT

- FORCING FUNCTION
 - HIGHER PROPORTION OF UNPROTECTED CROSSINGS REMOTE FROM UTILITY POWER
 - RAILROADS PREFER INDEPENDENCE FROM COMMERCIAL POWER
 - FEDERAL HIGHWAY ACT OF 1976 PROVIDES 125 MILLION FOR ~8000 CROSSING SIGNALS/yr ON PUBLIC ROADS
- STATISTICS - 1976
 - ABOUT 220,000 PUBLIC RAILROAD CROSSINGS
 - ABOUT 170,000 CURRENTLY UNPROTECTED
 - ANTICIPATED MANUFACTURING CAPABILITY BY 1978; ~5000/yr
- POTENTIAL U. S. MARKET (estimate):
 - BY 1980, 2200 NEW CROSSINGS AT $420 W_{pk} \rightarrow 920 kW_{pk}$
1000/yr AT $420 W_{pk} \rightarrow 420 kW_{pk}$ /yr AFTER 1980

Chart 14

Chart 15

APPLICATION CHARACTERISTICS RAILROAD GRADE CROSSING SIGNALS

Break-even array cost calculations for the railroad grade crossing application are displayed in Chart 15. These results also are subject to a number of uncertainties. As was true with the cathodic protection computations, the cost of bringing in a connecting power line (the logical competing power source) is a major consideration, since the length of such a line will depend on the exact location of the railroad crossing, and the cost per mile of its installation will depend sharply on the nature of the intervening terrain. The magnitude of the load is also somewhat uncertain, since it depends on the density of rail traffic at the location in question.

The system costs for the conventionally-powered system, as shown in Chart 15, include an allocation for 2 kWh of battery storage. Apparently this sort of storage is provided in connection with existing crossing protection systems in order to ensure operation in the event of a power failure. The figures in Chart 15 do not, however, include the cost of the rectifier that would be required in order to charge these batteries. It is assumed that this rectifier cost is roughly balanced by the cost of the power control circuitry that would be needed in the photovoltaic power source. A 15-year service period (or, alternatively, roughly equal service lives for array and power line) has again been assumed in the computation of present value costs.

Application Characteristics

RAILROAD GRADE CROSSING SIGNALS

LOAD: ~55W (equivalent continuous DC)

ARRAY SIZE: 420 W_{pk}

STORAGE: 4 kWh

	PHOTOVOLTAIC	ALTERNATIVE
SYSTEM COST ELEMENTS	ARRAY \$420X (at \$X/W _{pk}) BATTERIES (4 kWh 200/EVERY at \$50/kWh, 5 yr 5-yr service life)	POWER LINE \$6000 D (D mi at \$6000/mi) BATTERIES (2 kWh 100/EVERY at \$50/kWh, 5-yr life) 5 yr ENERGY CHARGE 25/yr (at \$0.05/kWh)
PRESENT VALUE COST OF SERVICE* (15 yr)	$420X + 200(2.52)$ $= 420X + 500$	$6000D + 100(2.52) + 25(11.27)$ $= 6000D + 535$

BREAKEVEN

D = 1.0 mi

X = \$14.40/W_{pk}

ARRAY COST

D = 0.5 mi

X = \$ 7.20/W_{pk}

*Escalation rate = 5%, discount rate = 9%

Chart 15

Chart 16

APPLICATION/DEMONSTRATION CANDIDATE LIGHTED NAVIGATION AIDS: BUOYS, SHORE AIDS, OFFSHORE PLATFORMS

Market-related information on the last of the four preferred candidates is summarized in Chart 16. As is indicated there, the search for solid information on this class of applications has had only limited success to date. It seems clear that buoys and other navigation aids that are powered by primary batteries are fine candidates for conversion to photovoltaic power. Where the power requirements are large, however, so that the use of diesel generation can be justified (as, for example, on off-shore platforms where substantial power is needed for other purposes, e. g. oil drilling) photovoltaic power for the on-board navigation aids is unlikely to be competitive. While it is known that the U. S. Navy has deployed many navigation aid systems and that roughly 2000 off-shore platforms are being operated in U. S. waters, it has not yet been possible to get any information about the distribution either in load size or geographical location.

Application/Demonstration Candidate

LIGHTED NAVIGATION AIDS: BUOYS, SHORE AIDS, OFFSHORE PLATFORMS

MARKET ENVIRONMENT

- FORCING FUNCTION
 - COST OF BATTERIES IS HIGH AND INCREASING
 - COST OF BATTERY DISPOSAL IS INCREASING
- STATISTICS - 1976
 - 14,000 COAST GUARD LIGHTED AIDS CONSIDERED SUITABLE FOR CONVERSION
 - NAVY AIDS (several thousands)
 - OFFSHORE PLATFORMS (~2000)
- POTENTIAL U.S. MARKET BY 1980 (conservative)
 - COAST GUARD: 1000 AT $30 W_{pk} = 30 kW_{pk}$; REPLACEMENT OR ADDITIONS?
 - OTHERS?

Chart 16

Chart 17

APPLICATION CHARACTERISTICS LIGHTED NAVIGATION AIDS: BUOYS, SHORE AIDS, OFFSHORE PLATFORMS

The break-even array cost computations for a representative U. S. Coast Guard navigation aid buoy is shown in Chart 17. In this calculation, it has been assumed that the life of the photovoltaic array, because of the relatively hostile environment involved, is only five years. Because reliability is a major concern, furthermore, it has been assumed that the photovoltaic powered version contains a full set of primary batteries (with 5-year shelf life) as back-up. (Both the weight and volume of the secondary batteries required to store photovoltaic energy are negligible in comparison with the weight and size of the back-up primary batteries. Thus the alternative power sources should be reasonably interchangeable with respect to their effect on the seaworthiness of the buoy.)

In calculating the present value cost of the successive sets of primary batteries in the conventional system, the recurring battery costs have been treated as if they occur annually, at the beginning of the year. The present-value factor is thus computed in accordance with the equation

$$\sum_{i=0}^4 \left(\frac{1+g}{1+r} \right)^i = \left(\frac{1+r}{r-g} \right) \left[1 - \left(\frac{1+g}{1+r} \right)^5 \right]$$

where, as before, g is the escalation rate (inflation) and r is the discount rate (cost of capital).

The calculation summarized in Chart 17 indicates that the use of photovoltaic arrays to provide power for such buoys should be economically competitive even at current array prices, provided only that the array purchased at these prices is able to withstand the effects of the ocean-surface environment for the postulated 5 years. If the array life were reduced to 2 years, the break-even cost would drop to \$13.50/W_{pk}.

Application Characteristics

LIGHTED NAVIGATION AIDS: BUOYS, SHORE AIDS, OFFSHORE PLATFORMS

LOAD: 4W (equivalent continuous DC)

ARRAY SIZE: 32 W_{pk}

STORAGE: 0.3 kWh

	PHOTOVOLTAIC	ALTERNATIVE
SYSTEM COST ELEMENTS	ARRAY 32X (at \$X/W _{pk}) SECONDARY BATTERIES 15 (at \$50/kWh 5-yr service life) PRIMARY BATTERIES 465 FOR BACKUP (at \$465, 5-yr shelf life)	PRIMARY BATTERIES \$465/yr (14 zinc-air batteries at \$33.27 each)
PRESENT VALUE COST OF SERVICE* (5 yr)	32X + 480	465(4.65) = 2160

BREAKEVEN
ARRAY COST

$$X = \$50/W_{pk}$$

*Escalation rate = 5%, discount rate = 9%

Chart 17

Chart 18

SUMMARY - POTENTIAL MARKETS

Chart 18 contains a summary of the results of the rough calculations that have been presented in the preceding eight charts. Also included are the break-even array cost figures for photovoltaic ICP protection of shallow wells for the case where the nearest power line is 0.5 to 1.0 miles away and the power line construction costs are \$6000/mile. The market estimates summarized in the chart indicate that these four applications might give rise to a cumulative market for nearly 12 MW_{pk} of arrays by 1980 and an annual market for perhaps 1.8 MW_{pk}/year thereafter.

Summary - Potential Markets

APPLICATION	ESTIMATED MARKET 1980			SUBSEQUENT MARKET	BREAKEVEN ARRAY COST \$/W _{pk}
	MARKET BASE	POWER / UNIT (W _{pk})	TOTAL (kW _{pk})	kW _{pk} /yr	
GAS WELL CORROSION PROTECTION	13,000 SHALLOW WELLS	60	780	96	50-100
	7400 DEEP WELLS	760	5600	1100	3.5-7.5
OIL/GAS PIPELINE CORROSION PROTECTION	14,000 mi GAS PIPELINES	200/mi	2700	80	} 2-5
	9500 mi OIL PIPELINES	180/mi	1700	50	
RAILROAD GRADE CROSSING SIGNALS	2200	420	920	420	7-14
LIGHTED NAVIGATION AIDS	1000	30	30	?	50

Chart 18

ATTRACTIVE DEMONSTRATIONS

The preliminary analyses whose results have been reported in the preceding charts lead to the conclusion that, of the four preferred applications that were studied, at least three (the two ICP applications and railroad grade crossing systems) represent significant near-term markets. All four would make attractive demonstration projects. The appeal and value of such demonstrations could be considerably enhanced, however, if the use of the photovoltaic power is not confined to serving the principal load but is, in addition, used to serve smaller auxiliary loads that are logically associated with the primary one. In effect, several related demonstrations can be mounted at a cost that is little greater than that associated with the primary one. Chart 19 summarizes some recommended examples of such combined demonstrations.

In connection with the cathodic protection demonstrations, it would be logical also to provide photovoltaic power for instruments that monitor well or pipeline status (pressure, flow rate, etc.). Telemetry links would permit centralized monitoring of the status of many wells in a gas field or many locations along a stretch of pipeline. It should also be possible, through such telemetry links, to operate various types of controls (e.g., valves). Some sort of security monitoring (intrusion detection) or even intrusion repulsion (electrified fences) might also be desirable. The accumulation of water in gas wells, furthermore, is a fairly frequent occurrence, leading to reduced gas flow and sometimes forcing abandonment of a well before the gas being pumped is actually exhausted. If power requirements can be met, the addition of water pumps on such wells could prolong the life of the well and increase the amount of gas that is eventually recovered.

Similar types of auxiliary uses for photovoltaic power would be logical elements of the other demonstrations.

The principal function of each of these demonstrations would be to provide experimental evidence of the effective performance and acceptable service life of photovoltaic arrays in the various applications. In the case of the railroad crossing signals and navigation aids, conversations with potential users of the photovoltaic-powered systems have made clear that the problems of vandalism and theft are important user concerns. (One railroad had an experimental windmill generator that functioned well for several months and then was stolen, in toto). For these particular applications, therefore, it is important that the demonstrations build confidence that the systems are, or can be made, reasonably safe from theft and vandalism.

Attractive Demonstrations

DEMONSTRATION	PRINCIPAL LOAD	SUBSIDIARY LOADS	USER CONCERN/RESERVATION TO BE ADDRESSED
NATURAL GAS WELLHEAD INSTRUMENTATION	CATHODIC PROTECTION	STATUS MONITOR CONTROL TELEMETRY SECURITY (WATER PUMP)	PERFORMANCE SERVICE LIFE
OIL/GAS PIPELINE INSTRUMENTATION	CATHODIC PROTECTION	STATUS MONITOR CONTROL TELEMETRY SECURITY	PERFORMANCE SERVICE LIFE
RAILROAD GRADE CROSSING SIGNALS	WARNING LIGHTS BARRIER MOTION SENSOR	TELEMETRY SECURITY	PERFORMANCE SERVICE LIFE SAFETY FROM THEFT, VANDALISM
NAVIGATION AID BUOYS	LIGHT BEACON	RF BEACON ENVIRONMENTAL MONITORING INSTRUMENTS STATUS MONITOR TELEMETRY SECURITY	RELIABILITY SERVICE LIFE UNDER ADVERSE CONDITIONS SAFETY FROM THEFT, VANDALISM

Chart 20

RECOMMENDATIONS

Chart 20 contains a brief list of recommendations that are made on the basis of the preliminary study discussed in the preceding charts. In summary, it is recommended that the appropriate initial steps be taken that will lead to the mounting of demonstration projects based on the preferred applications discussed in this report. It is also recommended that the market survey and analysis be continued, extended, and deepened.

The first of these recommended activities would appear to be a logical part of the ERDA Test and Demonstration Project now being carried out by the NASA Lewis Research Center. The second activity is, of course, the mainline activity originally planned for Task 1 in the current study.

Recommendations

- DEVELOP SPECIFIC NEAR-TERM DEMONSTRATION PLANS FOR IDENTIFIED APPLICATIONS
 - IDENTIFY AND CONTACT COOPERATING ORGANIZATIONS
 - DEFINE SPECIFIC ENGINEERING REQUIREMENTS AND CONCEPTS
 - DEVELOP ENGINEERING DESIGNS
 - DEFINE SPECIFIC DEMONSTRATION PLAN
- CONTINUE MARKET SURVEY AND ANALYSIS
 - SYSTEMATICALLY EXPAND MARKET SURVEY
 - EXTEND DATA COLLECTION AND APPLICATION ANALYSIS TO GREATER DEPTHS

Chart 20

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Chart 21

PROGRESS IN OTHER TASKS

Although the emphasis during the first quarter of this study has been on Task 1, progress has also been made on Tasks 2 and 6, as shown in Chart 21. Activity on the other three tasks was not scheduled to begin until after the end of the quarter.

Under Task 2 a start was made on the examination of central station missions for photovoltaic power plants utilizing very high concentration. Subroutines representing types of concentrators that are capable of achieving concentration ratios of the order of 1000 have been adapted for insertion into the simulation model that was developed in the earlier NSF-sponsored mission analysis project. These subroutines will permit the determination of the actual amount of solar energy that can be collected by such concentrators at representative locations and therefore of the extent to which the higher efficiency of GaAs concentrator-type solar cells is offset by optical losses in the concentrator. Subroutines for simulating the operation of a forced (probably pumped water) cooling system are also being constructed in order that the effect of cell temperature on electric output may be determined. In addition, calculations are being made of the effect of air-mass variations on the efficiency of GaAs solar cells. In the earlier study (Ref. 1) it was established that these effects would have a relatively unimportant effect on simulation calculations of the performance of silicon cells.

In the earlier study, also, analyses were made of the amount of conventional generation capacity needed to backup photovoltaic conversion systems. In these calculations the assumed standard of overall generation reliability was that there should not be more than one day of loss-of-load in ten years of service. In the current study, the effect of using a less rigid reliability standard is being investigated. A beginning was made on this task during the reporting period. Margin analysis calculations were made for three sample cases in which a 100 MW photovoltaic power plant was inserted in the Central Arizona 1990 utility system model in place of a 100 MW conventional plant. The required amount of backup capacity was computed for two different reliability criteria: a) no more than one day of loss-of-load in 10 years of operation (2.4 hrs/yr) and b) no more than one day of loss-of-load per year (24 hrs/yr). The results were:

Case	Array Area	Storage Capacity	Backup Capacity Required	
			2.4 hrs/yr	24 hrs/yr
1	$0.2(10^6) \text{ m}^2$	0	27.2 MW	36.8 MW
2	"	$0.5(10^6) \text{ kWh}$	14.3	22.5
3	"	1.0	14.3	22.5

Although these three cases are too few to permit positive conclusions to be drawn, they suggest that relaxation of the reliability requirement increases rather than decreases the backup capacity needed. This result is not really so anomalous as it sounds. When the reliability requirement is relaxed, one effect is that the baseline utility system model is modified; the capacity margin is decreased. It is not too surprising, then, that the insertion of a solar plant, with its associated insolation outages, into a system that is nearer to the "ragged edge" produces a somewhat larger destabilizing effect than in the standard case.

The activity in Task 6 during the first quarter was necessarily largely devoted to the collection of data from a wide variety of sources. The main literature-search effort was completed, although updating will undoubtedly continue throughout the program.

Progress in Other Tasks

TASK 2: ANALYSIS OF MAJOR MID-TERM MISSIONS

- CENTRAL STATION POWER PRODUCTION USING HIGH CONCENTRATION ($X \sim 1000$)
 - CONCENTRATOR SUBROUTINE ADAPTED, READY FOR INSERTION INTO SIMULATION MODEL
 - CENTRAL RECEIVER, HELIOSTAT FIELD
 - PARABOLIC DISH
 - EFFECT OF AIR MASS VARIATIONS ON GaAs EFFICIENCY UNDER STUDY
 - FORCED COOLING SUBROUTINES UNDER DEVELOPMENT
- EFFECT OF RELAXED GENERATION RELIABILITY STANDARDS
 - THREE CASES EXAMINED TO DATE:
RESULTS INCONCLUSIVE
 - ADDITIONAL ANALYSES PLANNED

TASK 6: SOCIETAL COSTS OF CONVENTIONAL AND PHOTOVOLTAIC POWER PRODUCTION

- LITERATURE SEARCH
 - FIRST STAGE COMPLETED
 - UPDATING CONTINUES
- OTHER DATA COLLECTION EFFORTS
 - INTERVIEWS WITH PRINCIPAL INVESTIGATORS IN RELEVANT STUDIES
 - EMPHASIS ON COAL-FIRED GENERATION

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III. PLANS

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

Chart 22

PLANNED ACTIVITIES - 1 MARCH THROUGH 31 MAY 1976

The activities that are planned for the second quarter of the program are listed in Chart 22. Under Task 1, the emphasis will be on implementing the methodology illustrated in Chart 4. Under Task 2, the investigation of the use of high concentration in central power missions will be completed, as will the study of the effect of relaxed reliability criteria on backup capacity requirements. A start will then be made on an analysis of the effect on on-site mission economics of the productive use of the heat that must be removed from the solar arrays. The focus of Task 6 will shift from data collection to an attempt to find a consistent basis for the assessment of the disparate sources of cost to society that result from power production. The emphasis during most of the quarter will continue to be on coal-fired generation.

Starts will also be made on two additional tasks. Under Task 3, a brief study will be made of the economic potential of the future photovoltaic market from the point of view of a current or potential manufacturer of arrays. The focus will be on considerations affecting the decision to enter the market. The impact of the results of the preliminary study made under Task 1 on the ERDA price/volume scenario for photovoltaic arrays will also be examined. Late in the quarter a beginning will also be made on the examination of critical external issues identified in the course of Tasks 1 and 2.

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 22

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REFERENCES

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