General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

5103-36, VOLUME II

DOE/JPL-1060-9
Distribution Category UC-62

Thermal Power Systems
Small Power Systems Applications Project

ANNUAL TECHNICAL REPORT

Volume II: Detailed Report
Fiscal Year 1978

(NASA-CR-162104) THERMAL POWER SYSTEMS SMALL POWER SYSTEMS APPLICATIONS PROJECT. VOLUME 2: DETAILED REPORT Annual Technical Report, Fiscal Year 1978 (Jet Propulsion Lab.) 212 p HC A10/MF A01 CSCL 10E G3/44 N79-30718 Unclas 31789

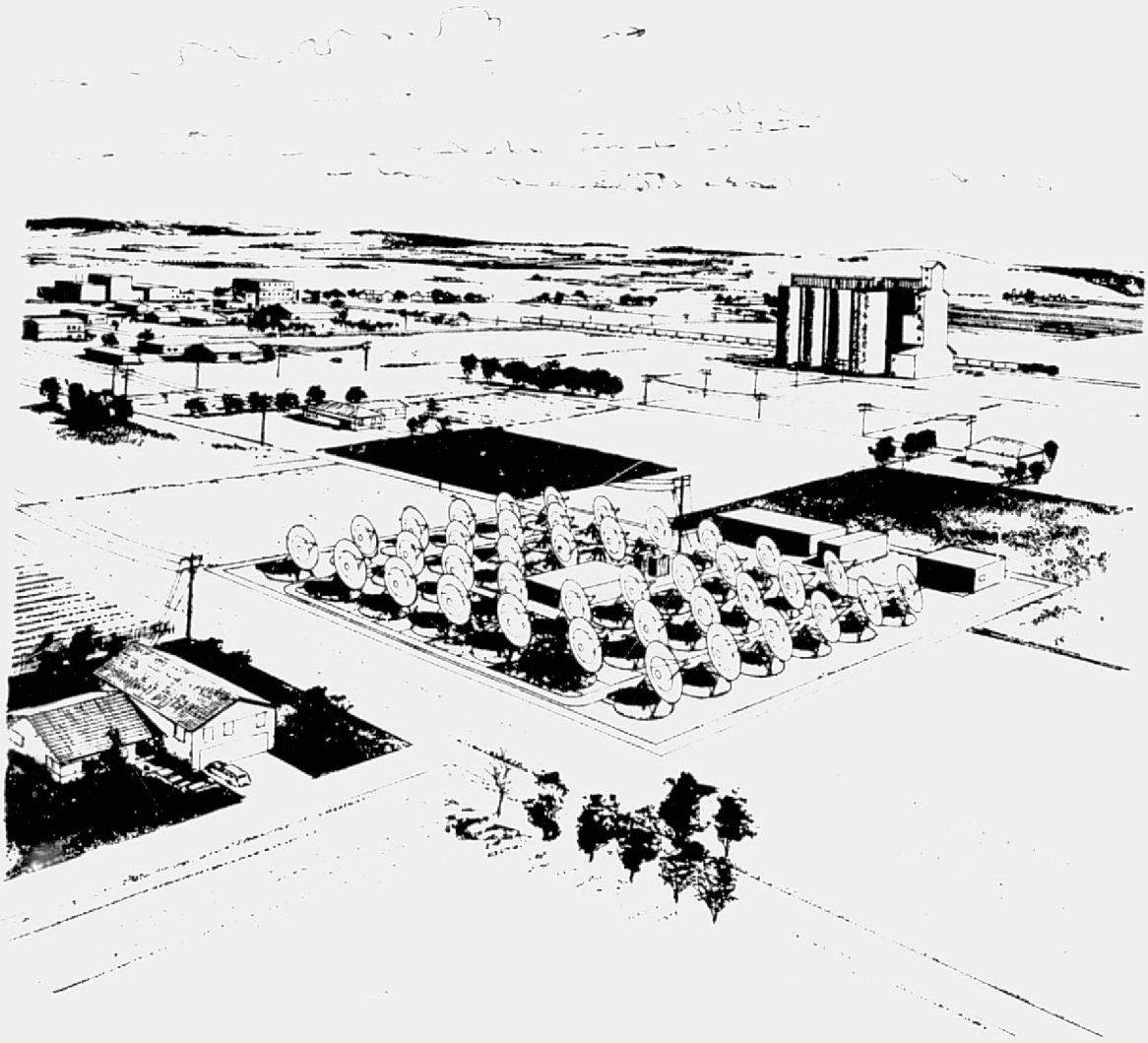
January 15, 1979

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

(JPL PUBLICATION 79-43, VOLUME II)

SEP 1979
RECEIVED
NASA STI FACILITY
ACCESS DEPT.



5103-36, VOLUME II

DOE/JPL-1060-9
Distribution Category UC-62

Thermal Power Systems
Small Power Systems Applications Project

ANNUAL TECHNICAL REPORT

Volume II: Detailed Report
Fiscal Year 1978

January 15, 1979

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

(JPL PUBLICATION 79-43, VOLUME II)

Prepared by the Jet Propulsion Laboratory, California Institute of Technology, for the U.S. Department of Energy through an agreement with the National Aeronautics and Space Administration.

The JPL Solar Thermal Power Systems Project is sponsored by the U.S. Department of Energy and forms a part of the Solar Thermal Program to develop low-cost solar thermal electric generating plants.

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or 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.

ABSTRACT

This report, Volume II, is the Annual Technical Report of the SPSA Project. It covers Small Power Systems Applications activities for FY 1978. Studies were conducted to address current small power system technology as applied to power plants up to 10 MWe in size. Markets for small power systems were characterized and cost goals were established for the project.

Candidate power plant system design concepts were selected for evaluation and preliminary performance and cost assessments were made. Economic studies were conducted at JPL and under contract to Burns & McDonnell. Breakeven capital costs were determined for leading contenders among the candidate systems.

An applications study was made of the potential use of small power systems in providing part of the demand for pumping power by the extensive aqueduct system of California, estimated to be 1000 MWe by 1985.

Criteria and methodologies were developed for application to the ranking of candidate power plant system design concepts.

Experimental power plants concepts of 1 MWe rating were studied by three contractors as a Phase I effort leading toward the definition of a power plant configuration for subsequent detail design, construction, testing and evaluation as Engineering Experiment No. 1 (EE No. 1). Site selection criteria and ground rules for the solicitation of EE No. 1 site participation proposals by DOE were developed.

FOREWORD

This report documents the Small Power Systems Applications (SPSA) Project activities and accomplishments which occurred during fiscal year 1978. The project was formally initiated in August 1977 and thus, these results represent the first year's endeavors.

The SPSA Project supports the U.S. Department of Energy Small Thermal Power Systems Section of the Thermal Power Systems Branch. The JPL work is performed under a NASA/DOE Interagency Agreement.

Subsequent to completion of this report, the SPSA Project title was changed to Point Focusing Thermal and Electric Applications Project (PFTEA).

CONTENTS

I. INTRODUCTION 1-1

A. General 1-1

1. Purpose 1-1
2. Scope 1-1

B. The SPSA Project 1-1

1. Project Description 1-1
2. Goals and Objectives 1-2
3. Project Organization 1-2
4. Project Schedule 1-5

C. Technical Approach 1-5

1. Strategy 1-5
2. Implementation 1-7

II. SUMMARY 2-1

A. Introduction 2-1

B. Project Management 2-1

C. Requirements Definition 2-1

D. Systems Definition 2-3

E. Project Analysis and Integration 2-4

F. Field Test Integration 2-5

III. PROJECT MANAGEMENT 3-1

A. Introduction 3-1

B. Task Area Organization 3-1

C. Activities 3-1

IV. REQUIREMENTS DEFINITION 4-1

A. Introduction 4-1

B. Task Area Organization 4-1

C. Technical Approach 4-1

CONTENTS (Continued)

1. Applications Requirements 4-1
2. User Integration 4-3
3. Market Potential 4-3
4. Plant Requirements Analysis 4-3
5. Goals Analysis 4-4

D. Technical Activities in FY 1978 4-4

1. Applications Requirements 4-4
2. User Integration 4-20
3. Market Potential 4-23
4. Plant Requirements 4-24
5. Cost Goals Analysis 4-26
6. Contract Review Activities 4-39
References 4-41

V. SYSTEMS DEFINITION 5-1

A. Introduction 5-1

B. Task Area Organization 5-1

C. Technical Approach 5-1

1. Technology Comparisons 5-1
2. Engineering Experiments 5-3

D. Technical Activities for FY 78 5-3

1. Technology Ranking Methodology 5-3
2. Systems Analysis 5-19
3. Engineering Experiment No. 1 5-58
References 5-77

VI. PROJECT ANALYSIS AND INTEGRATION

A. Introduction 6-1

B. Task Area Organization 6-1

C. Technical Approach 6-3

CONTENTS (Continued)

D. Technical Activities in FY 1978 6-4

1. Barriers and Incentives Study 6-4
2. Industrialization Studies 6-14
3. Market Development Studies 6-17
4. Decision Analysis 6-21
5. Other Activities 6-29
References 6-31

VII. FIELD TEST INTEGRATION 7-1

A. Introduction 7-1

B. Task Area Organization 7-1

1. Site Selection 7-1
2. Site Integration 7-1
3. Experiment Implementation 7-1
4. Test and Evaluation 7-3

C. Technical Approach 7-3

1. Development of Siting Plan 7-3
2. Siting Issues Study 7-3
3. Site Evaluation 7-3
4. Site Integration 7-4
5. Experiment Implementation 7-4

D. 1978 Technical Activities 7-4

1. Development of Siting Approach for EE#1 7-4
2. Siting Issues Study 7-10
3. EE#1 Site Evaluation 7-22

Figures

1-1. Thermal Power Systems Projects Organizational Structure 1-3

1-2. Small Power Systems Applications Project Organizational Structure 1-4

1-3. SPSA Project Schedule 1-6

1-4. SPSA Project Approach 1-10

3-1. Project Management Work Breakdown Structure 3-2

4-1. Requirements Definition Task Area Organization 4-2

4-2. Range of Small Power Systems Expansion Plan Cost, 1980-2000 200 MW Generation and Transmission Cooperative 4-15

4-3. Solar Plant Versus Utility Applicable Costs 4-18

4-4. Small Power Systems Energy Cost Targets for Levelized Busbar Energy Costs for First Year Operation of Plants Constructed Between 1985 and 2000. 4-31

4-5. Energy Costs for Baseload Systems, 1986 Year of Commercial Operation 4-31

4-6. Energy Costs, Intermediate Load Systems 1986 Year of Commercial Operation 4-32

4-7. Fuel Price Forecast Extremes 4-32

4-8. California Aqueduct Elevation Profile 4-37

4-9. State Water Project Estimated Loads 4-38

5-1. Systems Definition Work Breakdown Structure 5-2

5-2. Point Focus Distributed Receiver Concept. 5-5

5-3. Point Focus Central Receiver Concept 5-6

5-4. Line Focus Distributed Receiver Concept Using Parabolic Troughs 5-7

Figures (Continued)

5-5. Line Focus Distributed Receiver Concept Using Moveable Segmented Mirrors 5-9

5-6. Line Focus Central Receiver Concept (Adapted from Ref. 5-12) 5-10

5-7. Fixed Mirror Distributed Focus Concept 5-11

5-8. Line Focus Distributed Receiver Concept Using Fixed Mirrors and Moveable Receivers 5-11

5-9. Low Concentration Non-Tracking Concept (CPC) 5-12

5-10. Flowchart Depicting the Operation of the SES Computer Program 5-14

5-11. Energy Costs Versus Capacity Factor for a Solar Thermal Power Plant 5-16

5-12. Simplified CPC Solar Power Plant Design 5-23

5-13. Thermal Efficiency of CPC Collector Versus $(T-T_a)/I$ 5-25

5-14. Pipe Cost Breakdown 5-29

5-15. CPC Power Plant Field Layout 5-31

5-16. Thermal Energy Transport System (Piping Grid Only) Adjusted Energy Cost (in $/kWth) Versus Insulation Thickness 5-34

5-17. Effect of Collector Field Size and Plant Capacity Factor on Busbar Energy Cost for a CPC System 5-38

5-18. Busbar Energy Costs Versus Collector Costs for a 5 MW CPC Plant 5-38

5-19. Heliostat Concept (from Ref. 5-12) 5-39

5-20. Line Central Receiver (from Ref. 5-12) 5-40

5-21. Collector Field Optical Efficiency 5-43

5-22. Receiver Thermal Efficiency 5-43

5-23. Power Flow (Adapted from Ref. 5-12) for Line Focus Central Receiver 5-44

Figures (Continued)

5-24. $\overline{BBEC}$ versus Collector Cost 5-48

5-25. Parabolic Dish-Steam (Rankine) System 5-50

5-26. Parabolic Dish-Electric (Brayton or Stirling) System 5-50

5-27. Cavity Receiver (Brayton) 5-51

5-28. Power Flow for Point Focus Distributed Receiver . . . 5-53

5-29. $\overline{BBEC}$ versus Collector/Receiver Costs, $\$/m^2$ 5-57

5-30. Engineering Experiment No. 1 Schedule 5-59

5-31. System Schematic Identifying Four Principal Subsystems of McDonnell Douglas Concept 5-63

5-32. Artist's Concept of McDonnell Douglas Power Plant Layout 5-64

5-33. Heliostat Assembly with Rectangular Mirrors 5-65

5-34. Artist's Concept of GE Plant Layout 5-66

5-35. GE Plant Concentrator Layout 5-67

5-36. General Electric Proposed Collector, Receiver/ Boiler Assembly Construction 5-68

5-37. Vacuum Piping Concept Applied to Pedestals, Headers, Laterals, and Expansion Joints 5-69

5-38. General Electric's Complete Power Conversion Submodule for the 1 MW Plant 5-69

5-39. Artist's Concept of Ford Plant Layout 5-71

5-40. System Schematic of Ford Design 5-72

5-41. Artist's Concept of Ford Solar Thermal Power Module 5-73

5-42. 1 MWe Solar Power Facility, Plan View 5-75

5-43. Receiver Power Conversion Unit 5-76

Figures (Continued)

6-1. Project Analysis and Integration Work Breakdown Structure 6-2

6-2. Key Decision Support Matrix 6-5

6-3. Summary of SPSA Barriers and Incentives 6-7

6-4. Implementation Process for Ranking Methodology 6-23

6-5. Criteria and Attributes for Ranking Solar Thermal Electric Power Systems Technology Alternatives 6-26

7-1. Field Test Integration Work Breakdown Structure . . . 7-2

7-2. Schematics of Solar Thermal Electric Systems 7-13

7-3. Representative Total Insolation — Goldstone 7-15

Tables

4-1. Estimates of Market Potential for Small Solar Thermal Hybrid Systems 4-7

4-2. Economic Viability Sensitivity: Simple All-Solar Plant 4-8

4-3. Economic Viability Sensitivity: All-Solar Plant with Storage 4-8

4-4. Economic Viability Sensitivity: Hybrid Plant 4-9

4-5a. Small Power Systems Types and Characteristics 4-11

4-5b. Small Power Systems Subsystem Characteristics 4-11

4-6. Characteristics of Seven Reference Utilities 4-12

4-7. Economically Attractive Applications 4-16

4-8. Breakeven Capital Cost for 10% Solar MIX (1975 $/kW) 4-19

4-9. Plant Cost Assumptions 4-31

4-10. Seven Capital Cost Forecasts 4-34

Tables (Continued)

4-11. Present Generation Mix and Planned Additions by 1986 - Selected Southwest Utilities. 4-35

5-1. CPC Cost Breakdown 5-18

5-2. Subsystems Definitions and Engineering Information Summary 5-20

5-3. Ground Rules for the Technology Comparison Studies 5-21

5-4. Physical Properties of CPC 5X Design 5-24

5-5. CPC Collector Field Size Calculations for a 5 MWe Plant 5-28

5-6. Collector Module Pressure Drop/Pumping Power for Two Modules in Series 5-32

5-7. Organic Rankine Energy Conversion Efficiency as a Function of Size 5-35

5-8. Energy Transport Subsystem Performance Summary for Various Ratings and Field Sizes 5-36

5-9. Five Megawatt Plant at 0.55 Capacity Factor 5-37

5-10. Optics Program 5-41

5-11. Thermal Program 5-42

5-12. Study Design Parameters 5-54

5-13. Phase I Contractors 5-60

5-14. Assumed Program Event Times 5-60

5-15. Design Specifications for Phase I Study 5-62

6-1. SPSA Technology Alternatives Criteria and Attributes with Tentative Scales 6-27

7-1. Site Integration Issues for Experimental Solar Thermal Power Systems 7-5

7-2. Items to be Furnished by Site/User Organization . . . 7-6

7-3. Siting Issue Summary 7-11

SECTION I

INTRODUCTION

A. GENERAL

1. Purpose

The Small Power Systems Applications (SPSA) Project is an ongoing activity with the long term goal of demonstrating the commercial readiness of small solar thermal power systems. In the course of any year, technical tasks are initiated, some completed, and those not, continued into the subsequent year. It is important that the essential results and conclusions of these activities be made available to project participants, the Department of Energy, other government organizations and institutions, and industry. Thus, the purpose of this Annual Report is to convey this information. It also provides an insight to work in progress and plans for the near future.

2. Scope

This report covers the period from project initiation (formally 7-30-77) to the end of FY 1978. Since this is the first year of the project, much of this period was spent planning and initiating contracts and studies. Therefore, the overall impression may be that this is primarily a progress or status report. While this is essentially the case, significant conclusions were reached in various areas and these are described. The emphasis, even in those studies not completed, is on results acquired to date.

Activities discussed in this report include project management, the technical task areas and ad hoc tasks initiated at the request of the DOE during the year. In the two latter cases, the discussion of results or progress are within the task areas.

B. THE SPSA PROJECT

1. Project Description

The Thermal Power Systems Branch of the Department of Energy (DOE) Division of Solar Energy is responsible for developing the technology for low-cost, long-life, reliable thermal power systems suitable for a wide range of applications. To accomplish this goal, programs have been established in three primary areas: advanced technology, large power and small power applications. Responsibilities of the Small Thermal Power Systems Section include technology development and the investigation of applications suitable for dispersed power with the objective of accelerating the adoption of solar thermal power for selected applications. One program within the Small Thermal Power Systems Section

considering both applications and technologies is the Small Power Systems Program. Two projects were formed at JPL in support of this program: the Point Focusing Distributed Receiver (PFDR) Project and the Small Power Systems Applications (SPSA) Project. The Small Power Systems Applications Project was established in July of 1977 as a result of an interagency agreement between NASA and DOE in which JPL was named as the technical manager of the project.

2. Goals and Objectives

The overall goal of the SPSA Project is to establish technical, operational, and economic readiness of small solar thermal power systems for a variety of applications that require less than ten megawatts of power. The project will develop systems to the point at which subsequent commercialization activities can proceed and lead to successful market penetration. Applications which currently derive power from high cost energy sources seem to be the first feasible markets. Initial commercial adoption for higher cost energy markets is targeted for the mid-1980's with widespread adoption to occur in the post-1990 time frame.

To ensure achievement of these goals and to monitor progress, a number of interim objectives and system cost targets were developed as follows:

(1) Bring on-line a number of experimental power plants that demonstrate the feasibility of the small power systems approach. The first power plant is to be operational in 1982.

(2) Achieve by 1985 as a first interim target, the initial penetration of small power systems in various early markets. To reach this goal, it is anticipated that capital costs in the range 1500 to 2000 $/kWe (1978 dollars) and an energy cost between 75 and 100 mills per kilowatt hour (e) will be required.

(3) Demonstrate by the late 1980's the practicality of building power plants with a potential mass-produced cost in the range of $600 to $1000/kWe (1978 dollars) and a resulting life-cycle busbar energy cost of 50 to 60 mills/kW-hr.

These targets are under continual assessment and, as new information becomes available, will be updated as needed.

3. Project Organization

The SPSA Project is one of three in the Thermal Power Systems (TPS) Organization at JPL. TPS is part of the Office of Energy and Technology Applications, the organization structure of which is shown in Figure 1-1.

The SPSA Project is organized in accordance with a project management activity, with four functional task areas, and an ad hoc task area. Figure 1-2 illustrates the first level of organization of the project. Each of the technical task areas is described in their respective subsections in this report.

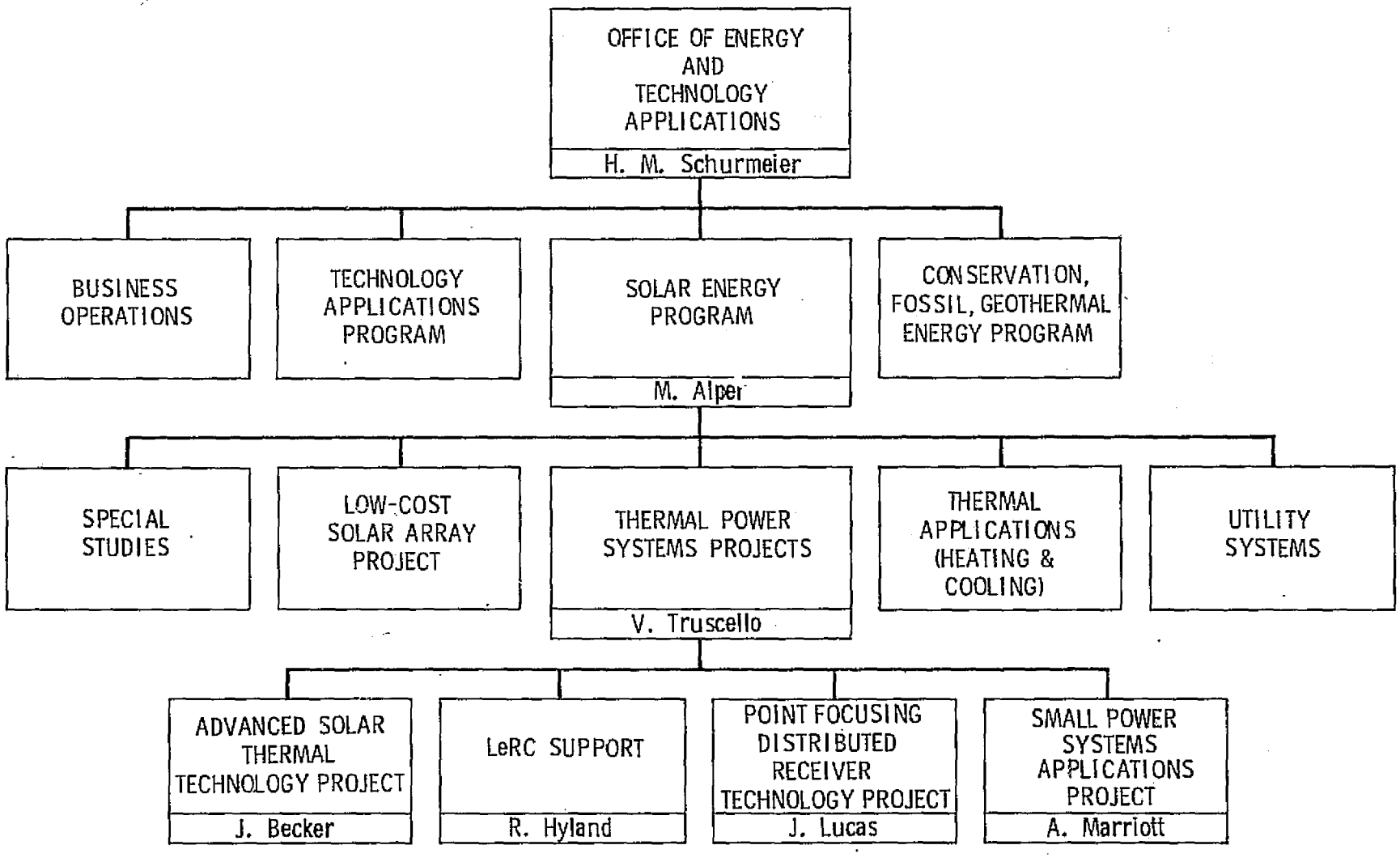


Figure 1-1. Thermal Power Systems Projects Organizational Structure

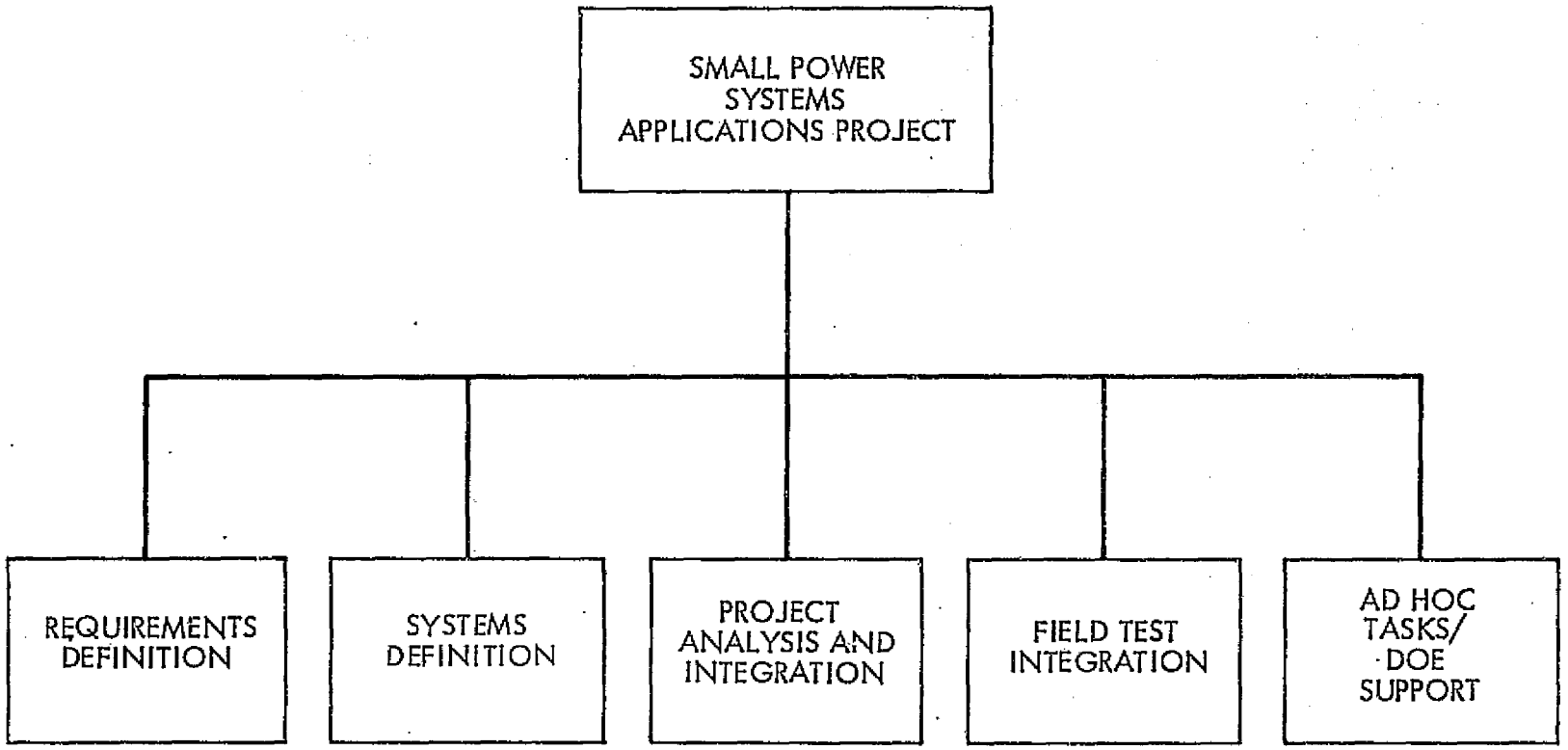


Figure 1-2. Small Power Systems Applications Project Organizational Structure

4. Project Schedule

Major activities of the SPSA Project are shown in Figure 1-3 and a schedule for each is shown through FY 1986. The project is centered around the three series of experiments designated Engineering Experiments (EE) 1 through 3. The first experimental power plant for a small community application is scheduled for completion by the latter part of 1982. Initial market penetration is anticipated by the mid-1980's and several small power system experiments will be on-line by 1985.

C. TECHNICAL APPROACH

1. Strategy

The three successive milestones required in the development of a new technology to the point of commercial readiness are: 1) demonstrating technical feasibility, 2) verifying readiness of the technology, and 3) meeting cost goals required for commercial readiness. The three phases in the evolution of a new technology can be described as creation, manufacturing, and marketing. Participation by both government and the private sector may be necessary, with increasing activity by the latter as the commercial readiness phase is approached. Potential users are to be involved early, and to the maximum extent possible. Limited incentives on the part of government may be required.

SPSA project direction is predicated on an established set of specific objectives and cost targets. These parameters must be developed early in the project and continually updated as new information becomes available.

The potential users will be identified and their needs characterized. Both the potentially limited near-term and major far-term markets must be developed. Applications and system analyses will be conducted in order to identify the candidate system configurations and to develop viable applications. The objectives will be to provide the best match of configurations and applications in order to maximize the potential for successful penetration of the energy market.

The selected system concepts will be developed by means of contracts let to private industry. Questions of user acceptance and technical and economic feasibility will be addressed by constructing a series of experimental power plants in various locations.

Analyses will be conducted in order to understand the commercialization process, to provide information for program decisions, and to form the basis for a determination of a commercialization strategy that will provide the maximum probability of commercial adoption of the small power systems concept. This strategy will then be implemented.

A key element of the project strategy is the determination and penetration of near-term markets which will provide a stimulus for the establishment of a manufacturing industry. This, in turn, will lead to cost reductions as a result of improved manufacturing methods coupled with an increasing volume of

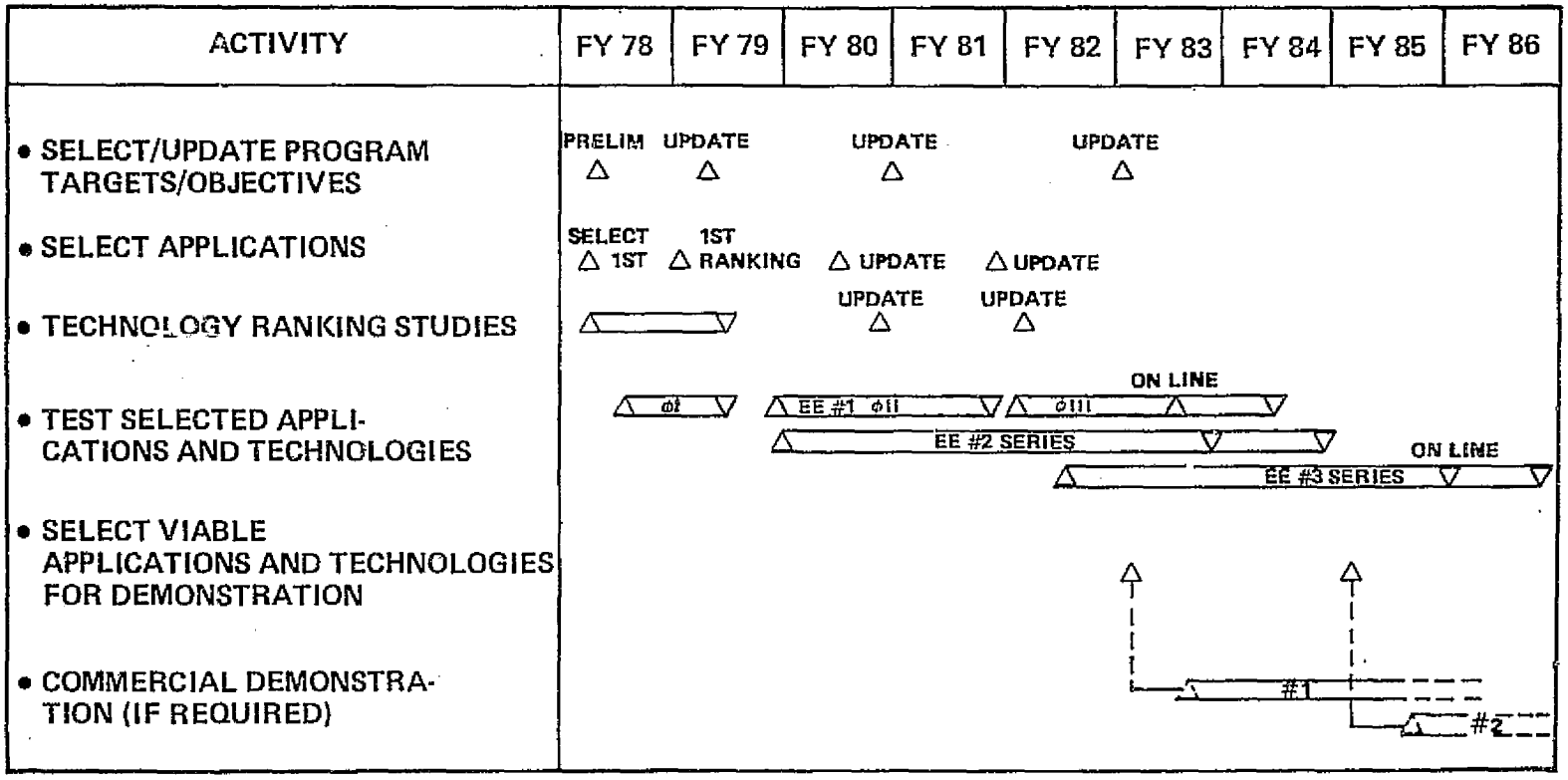


Figure 1-3. SPSA Project Schedule

production as lower cost markets are penetrated. The importance of this element of the program lies in the belief that design improvements alone will not result in a sufficiently low price to penetrate the utility market. However, a combination of mature technologies and mass production offers the potential for economically competitive power systems having a significant environmental advantage.

2. Implementation

The project approach is structured to implement the strategy previously outlined. The Department of Energy, in conjunction with NASA, has designated the Jet Propulsion Laboratory (JPL) as the Project Technical Manager. JPL will work with other DOE agencies, industry, universities and other institutions to accomplish the goals of the project.

Analyses will be conducted to identify, characterize and rank the potential small power system applications. Both near-term and long-term markets will be defined and developed. A maximum interchange of information will be promoted between the project and potential users through workshops, seminars, direct contact, and studies conducted by appropriate A&E and industrial firms. From the data obtained, a determination of end-use requirements influencing system design will be developed.

In order to provide the power plant system designers with specific cost objectives, a continuing assessment of appropriate cost goals and targets will be conducted. Analyses will be conducted to determine the market potential in terms of both time to achieve a significant penetration (predicated on the cost goals) and the production volume indicated by the market penetration.

Comparative system studies will be performed to identify the most appropriate small power system technologies for the selected experimental applications, and for eventual commercial use. Seven generic classes of systems are being considered for small power system applications; these are as follows:

(1) Point-focusing distributed receiver systems using thermal, chemical or electrical (when heat engine is at focus) energy transport with power conversion by Rankine, Brayton or Stirling engines.

(2) Point-focusing central receiver systems using a field of two-axis tracking heliostats with chemical or thermal transports to large Rankine, Brayton or Stirling engines

(3) Line-focusing single-axis tracking collector (troughs or facets) distributed receiver systems with suitable energy transport and power conversion subsystems

(4) Line-focusing single-axis tracking collector central receiver systems with suitable energy transport and power conversion subsystems

(5) Fixed mirror distributed focus, spherical collector with articulating receivers

(6) Fixed mirror, line focusing

(7) Low concentrator non-tracking systems such as the Compound Parabolic Concentrator or Vee-Trough with suitable energy transport and power conversion subsystems

After determination of the most promising types of applications and the most appropriate matching technologies for the experimental power plants, studies will be performed and procurements conducted to identify sites for these plants. In cooperation with industry, a series of experimental power plants will be designed and built.

The experimental program has been structured to take place in three stages. The first stage will be conducted using near-term technology or systems requiring very little development. The first engineering experiment (EE#1), targeted for small community application, is part of this stage. Others may be added if deemed necessary. Problems relating to systems integration, performance, reliability, operations and maintenance will be addressed during the conduct of these experiments. The second stage will consist of a series of small experiments (of the order of 100 kWe) which will focus primarily on the early market sectors and will employ first generation technologies being developed within the JPL Point-Focusing Distributed Receiver Program. The technologies for this second stage are expected to be available for the EE#2 series of experiments that will be operational starting in 1983. The third stage will employ second generation (or commercially mature) technologies in a series of experiments (EE#3) whose primary purpose is to demonstrate commercial systems in viable applications as determined by the results of the proceeding experiments, adjunct analyses, and the market situation at the time. In all, these experiments will be conducted over a period of approximately eight years, providing the basis for assessing the technical merit and the economic and industrial feasibility of the selected approach in various application environments.

Many of the applications may require systems with storage capability. It is the intent of this program that storage technology developed by the DOE Division of Storage Systems be employed to the greatest possible extent thus minimizing the effort within the SPSA experimental program.

A significant part of the program will involve identifying factors which could impede commercialization. This effort will provide input to the experimental plants and will be part of the development of potential markets. Its main thrust will be to characterize the socioeconomic, institutional and environmental aspects of dispersed power systems that could influence the design, development and commercialization of small power systems.

The marketing strategy ultimately developed will be based on this effort, plus the following:

(1) An analysis of the effect of mass production and industrialization on cost and performance

(2) Operational data and technological assessment of the experimental power plants

The industrialization analysis will compare estimated equipment production costs with the program cost targets, thereby providing a basis for management decisions.

As part of the overall effort to develop the most viable strategy, it will be determined whether government-funded commercial plant demonstrations are needed.

The project approach is graphically illustrated in Figure 1-4. Each of the principal activities and elements previously discussed is shown.

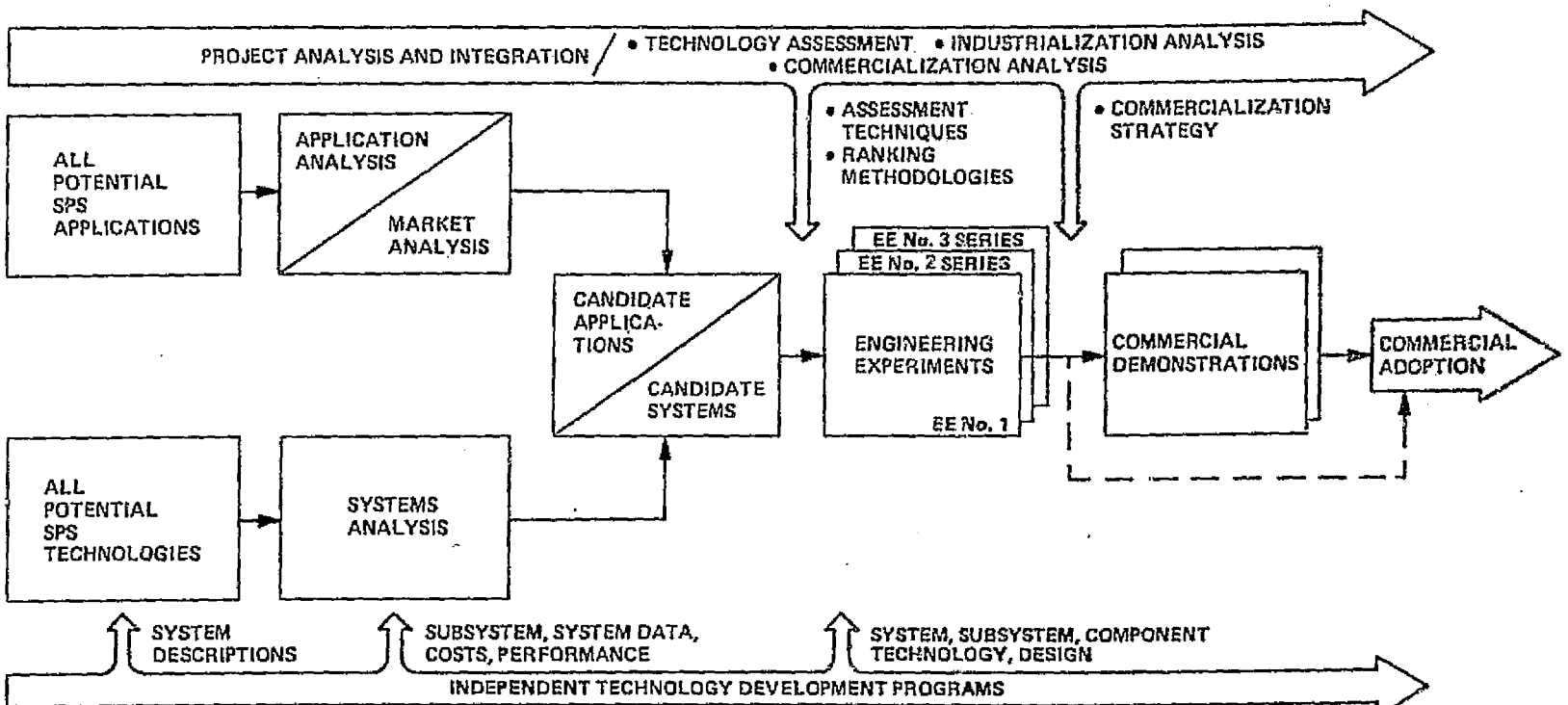


Figure 1-4. SPSA Project Approach

SECTION II

SUMMARY

A. INTRODUCTION

This section briefly summarizes the major activities and accomplishments of the Small Power Systems Applications Project (SPSA) in FY 1978. The project management task and each of the functional task areas are summarized.

B. PROJECT MANAGEMENT

FY 1978 was the first full year for which JPL was funded to support DOE in the management of the SPSA Project. Thus, the first significant project management effort was the planning and staffing of technical activities. In addition, a project control system was established. Staffing was completed in FY 1978, and with the help of several interactive meetings with DOE, a preliminary program plan was completed and published in August. It provides a framework for annual planning of the SPSA Project and gives DOE a basis for assessing the project's direction and overall strategy.

C. REQUIREMENTS DEFINITION

The Requirements Definition Task may be considered the "front end" activity of the SPSA project. This task examines various potential users of small power systems. It identifies and characterizes the generation needs and power plant requirements which could be met by solar thermal electric technologies. The participants in this activity seek an understanding of various users' needs. Concurrently, they provide potential users with solar technology and SPSA program information. The principal Requirement Definition outputs are solar thermal electric plant requirements for the Systems Definition task and hardware design teams.

Specific objectives are to: (1) identify, characterize, and quantify the electrical power needs and plant requirements for small power system users; (2) understand the user community and develop effective communication between users and the SPSA Project; and (3) establish functional, economic, performance, environmental, and operational requirements for system design.

The Requirements Definition Task is organized in five topical areas: Application Requirements, User Integration, Market Potential, Plant Requirements, and Goals Analysis. Major activities in FY 1978 are described below.

A seven-month study contract was awarded in January 1978, to the architect and engineering firm of Burns & McDonnell to assess the potential utilization of small solar thermal power systems by small utilities.

The results of this study will be used to determine the kinds of small utilities, geographical regions, and plant configurations that should be selected for detailed analysis. This analysis, the Solar Thermal Plant Analysis and Requirements Definition Study, will begin in October, 1978. Data from the Burns & McDonnell study will be supplied to contractors on Phase I of the first in a series of engineering experiments. These are described below under Systems Definition.

An important accomplishment in User Integration was the establishment of communications with the utility industry and the electric power community. A Solar Electric Workshop, held in October, 1977, aroused industry interest and opened channels for program, application, and technology exchanges between JPL and electric utility personnel. In addition, ties were established with recognized utility organizations: the American Public Power Association, the National Rural Electric Cooperative Association, and the Electric Power Research Institute. Many presentations and exchange meetings occurred with groups representing various user categories. Also, six technical papers were presented at technical symposia.

Market potential activities largely were based on exchange of information with the Aerospace Corporation. While Aerospace's detailed market potential studies are expected to produce results late in FY 1978, data will not be available in time for current project needs. To help fill this gap, Aerospace and JPL collaborated throughout the year on specific items, such as detailed review of the Burns & McDonnell work plan. Some Goals Analysis work was oriented to development of market potential information as exemplified by the California Aqueduct Study discussed later in this report. Military market potential and foreign market potential studies also were initiated this year and are continuing into FY 1979. An outgrowth of the initial military market potential work was a joint program with the U.S. Navy Civil Engineering Laboratory to design and build an experimental 100 kWe hybrid-fired gas turbine (Brayton) plant (EE#2a).

A comprehensive package was prepared by Plant Requirements subtask personnel, for the combined procurement of the studies: Electric Utility Expansion and Solar Plant Impact Study and Plant Requirements Definition Study. The combination, called Solar Thermal Plant Impact Analysis and Requirements Definition Study, is a major twenty-six month effort. It will emphasize near-term applications involving both non-utility loads and utility systems loads. Inputs to this study will flow from the Burns & McDonnell study mentioned earlier and from an in-house study of hybrid solar thermal plants. The latter study, initiated in mid-FY 1978, will aid in establishing hybrid plant configurations for detailed analyses.

During FY 1978, a Cost Goals Analysis was initiated to determine power generation costs in the 1985-2000 time period with conventional power generation mixes, transmission and distribution systems, and expansion plans of representative electric utilities and other power users in the southwest U.S. This analysis provides a basis for estimating the levelized busbar energy costs of conventional power systems.

Those systems will be competing with solar thermal power systems in the targeted period. A brief study of California Aqueduct pumping using solar thermal power also was completed, and a summary is included as a part of this report. Goals and market potential analyses are underway on several military and developing countries applications.

D. SYSTEMS DEFINITION

The Systems Definition Task is responsible for determining technologies and system designs that meet the needs of selected applications in the less-than-10 MWe power range. Developing solar thermal power plants that can compete with fossil fuel power plants required two major system definition activities: technology comparisons and studies of actually built and operating experimental plants (engineering experiments).

The relative merits of various solar thermal power plant concepts are being evaluated via technology comparison studies. Performance and cost data were collected for each subsystem necessary for the concepts identified as potentially attractive. The studies are concentrating primarily on the collector subsystem, since it normally amounts to over 50% of a solar plant cost. Solar thermal power plants are synthesized based on the performance characteristics of each concept. The plant performance characteristics and cost estimates are integrated in a computer program. The program interfaces a yearly insolation data type with the plant performance characteristics and, using the plant subsystem, operation, and maintenance cost estimates, calculates total plant costs and the levelized busbar energy cost for the plant's estimated lifetime. The computer program output and the intrinsic characteristics of each concept will be subjected to a methodology for ranking the various concepts relative to one another. To date, two line focusing and one point focusing solar thermal plants have been analyzed. The results, based on the cost assumptions used for power conversion, operation, and maintenance, indicate that non-tracking and single-axis-tracking line focusing systems will be unable to achieve levelized busbar energy costs of 100 mills/kWe-hr.

To achieve a more in-depth understanding of technologies for solar thermal plants operating in the 1.0 to 10 MWe range, a series of engineering experiments were initiated. Engineering Experiment No. 1 (EE#1) is designed to meet the needs of a small community. Near-term technologies will be emphasized for the first experiment, although advanced technologies compatible with the proposed system concepts also will be identified. The primary purposes of EE#1 are to demonstrate the feasibility of small power system technologies in a user environment; to determine the economic, performance, operational, and institutional characteristics of a solar plant; to advance the acceptance of small power systems; and to stimulate the creation of an industrial base for small power systems.

Currently, three companies are funded for a Phase I System Definition Study to develop detailed design characteristics of their proposed solar plant concept. The three types of plants under study are: point focus central receiver with central power conversion, point focus distributed receivers with distributed power conversion, and point focus distributed receiver with central power generation. Figures in Section V show the three concepts. All three are being considered for EE#1 in this first phase.

E. PROJECT ANALYSIS AND INTEGRATION

The Project Analysis and Integration (PA&I) Task supplements the other tasks with activities designed to facilitate successful commercialization of SPSA technology. These activities include economic, financial, and policy analysis; strategic planning; information dissemination; and project integration. Objectives are:

(1) To provide analyses of the economic, financial, social, and institutional factors that could impede the commercialization of SPSA technology.

(2) To provide integrated program plans designed to enhance the probability of success of the SPSA Project.

(3) To promote productive interfaces among the SPSA Project, governments, the private sector (i.e., suppliers and users) and the public at large.

(4) To promote productive interfaces between the SPSA Project and other Thermal Power Systems projects and programs.

(5) To promote internal consistency and optimal interfaces among the tasks within the SPSA Project.

In FY 1978 PA&I developed criteria and methods for ranking small solar thermal power systems options; completed a preliminary survey of the current technology and industry base for small solar thermal power systems; partially completed a study of barriers and incentives to the development of small solar thermal power systems (this study will be completed in October 1978); processed an RFP for a study of the industrialization and mass production of small solar thermal power systems (a contract will be signed in November 1978); processed an RFP for a study of the effects of systems factors on the economics of and demand for small solar thermal power systems (a contract will be signed in November 1978); and partially completed a study of the effects of financial and ownership alternatives on the life cycle costs of small solar thermal power systems (the study will be completed by June 1979).

In addition, PA&I completed design and preparation of public information materials. The first leaflet will be distributed in October 1978. Identification and preliminary analysis of possible program initiatives to accelerate the commercialization of small solar thermal power systems

was done. A joint program (AMPS - Advanced Military Power Systems) with DOD was initiated and planned for developing small solar thermal power systems for military applications. PA&I contributed significant input to the President's Domestic Policy Review of Solar Energy. Finally, a draft comprehensive report entitled "Small Solar Thermal Electric Power Systems: An Assessment of the Development and Commercialization of a Modular Energy System" was completed.

PA&I FY 1978 analytical activities yielded the following principal results. The private sector's view of solar thermal electric technology is very pessimistic. Market growth is expected to be slow. Hence, industry feels that a significant investment of private capital is not warranted at this time. As yet, a detailed market penetration analysis, pertaining to small solar thermal electric power systems, has not been done. PA&I has an RFP in process to remedy this situation. Industry feels that government should set R&D goals and then leave the innovation to the private sector. Industry would prefer more flexible Program Research and Development Announcements (PRDA's) to the current prescriptive RFP's. PA&I will evaluate the PRDA route in FY 1979. Modularity may have significant economic benefits to the user due to savings arising from less interest during construction, automated installation procedures, better demand tracking, more even maintenance schedules and other factors. Preliminary results indicate that reduced interest during construction alone could reduce the overall power cost by 7%. Other factors may be more significant. In FY 1979 PA&I will continue quantifying the economic impact of modularity. A statistical analysis of current estimates of the future contribution of solar thermal technology to the U.S. energy supply indicates that little is expected by 1985 and that the contribution in the year 2000 will be in the range of .21 to 1.25 quads (primary energy displaced). These studies, however, have numerous shortcomings. A preliminary study of energy requirements in 1985 indicates that small solar thermal power systems could be used in applications requiring an aggregate capacity of 29 gigawatts. Further analysis in FY 1979 will determine the rate at which SPSA technology could penetrate this potential market.

Clearly, PA&I accomplishments and results in FY 1978 were more process oriented than analytic due to the effort required to launch the analytic program itself. In FY 1979 the emphasis will shift to the analytic side.

F. FIELD TEST INTEGRATION

The first of the engineering experiments (EE#1) is scheduled to begin experimental operation in late 1982. The primary responsibility of the Field Test Integration Task is construction and integration of these experimental power plants, after requirements and systems definition activities have laid the proper groundwork.

The technical approach includes: site selection and management; integration of site activities with the power plant construction; technical management of system contracts for power plant fabrication and installation; and coordination of test, operation, and evaluation activities.

A successful experiment requires a suitable application environment as well as an experimental power plant system. Initial work was completed on definition of the siting approach for each application, studies of the pertinent siting issues, preparation of proposal requests, and development of proposal evaluation factors and procedures. DOE retains formal responsibility for site evaluation and selection and negotiation of site participation agreements. Field Test Integration will provide technical management of site participation agreements for DOE. Also, integration of site activities with power plant system contract efforts will be done. Site participation will vary with the application but typically will include: site and permit acquisition; participation in site preparation and layout; provision of access and services; connection to a utility grid; and maintenance and operation participation.

The task emphasis in FY 1978 was on siting EE#1. Inputs from the utility industry were obtained at the Small Power Systems Solar Electric Workshop, held in October 1977. A review of the workshop results, defined the following issues for further consideration in the development of EE#1 siting plans:

(a) Delay of site selection until the power system technology approach is defined;

(b) Geographic site restrictions based on minimum insolation requirements;

(c) Proposal restrictions based on utility capability for experimental operation and/or type of system load application;

(d) Specific definition of items and services to be furnished by the successful utility/site proposer and definition of government support;

(e) Mitigation of potentially high site proposal costs.

Following discussion and review at JPL, the key issues were reviewed with DOE. It was agreed that site restrictions should be minimized except for those which define the small community application. Rather, siting factors should be accounted for in an evaluation with a strong technical basis. Also, it was decided that the application must be in a definitive, small community with a load demand less than 100 MWe. The community character may be primarily residential, agricultural, or commercial served by a utility or cooperative. A two-stage site selection process was preferred to minimize proposal costs for a large number of potential participants. Simple preliminary proposals will be screened, and more definitive proposals will be requested from remaining candidates.

A siting issues study was completed and a final report was published. This study described the programmatic and system technology background for the first experimental system and defined siting issues together with a discussion of their significance. This study was done

to support preparation of the siting PRDA and associated evaluation factors and to provide background for potential site participation. A more detailed siting factors study will be conducted to develop the evaluation approach for each factor. Siting issues were grouped into categories. Relationships between solar thermal electric power plants and their sites may be categorized as effects of site on plant and effects of plant on site. Effects of the site on the plant were discussed by identifying resources required for plant operation, physical site characteristics, and social-institutional characteristics desirable for construction, operation, and maintenance of a solar thermal electric power plant. Impacts plants may have on their sites were identified, and how these site impacts may result in construction delays and even development termination was discussed. The study report describes these various relationships and delineates information that should be assembled during site selection in order to make wise siting decisions.

A PRDA for site participation in the first experimental system having application in a small community was prepared for DOE review and release. Announcements were prepared for publication in the Commerce Business Daily and appropriate utility and municipal trade journals. Suggested factors, weightings, and methodology were developed for evaluation and screening of proposals to be submitted in response to this PRDA. Potential interactions between site and the experimental system were considered together with siting factors, all of which will provide a base for a successful experiment.

SECTION III

PROJECT MANAGEMENT

A. INTRODUCTION

The objective of the SPSA Project Management task is to accomplish the activities as described by the Annual Operating Plan in accordance with the funding made available by the Department of Energy.

Management of the project is the responsibility of the SPSA Technical Manager who reports to the Thermal Power Systems Projects Manager (see Figure 3-1).

B. TASK AREA ORGANIZATION

Figure 3-1 shows the organizational structure of the Project Management task area. The three main elements are Technical Management, Planning and Assessment, and Supporting Functions, which includes administration and control.

C. ACTIVITIES

The primary FY 1978 activities in the project management area were the organization and staffing of the project, planning of technical activities within each of the functional task areas and the establishment of a cost control system.

Management reporting was conducted through both internal JPL reviews and DOE reviews. In addition, monthly project management reports were written and sent to DOE.

Three major project documents, in addition to several topical reports, were published during the year. The Annual Operating Plan for FY 1979 was completed in July 1978. This document describes in detail the planned activities for the next fiscal year, the resources required to accomplish these tasks and a plan for implementation. It is submitted to NASA and subsequently by NASA to DOE. Approval and signature by all parties constitutes an agreement to carry out the work described therein. Funds are transferred to JPL via NASA by an Interagency Agreement Amendment.

A preliminary SPSA Program Plan was published in August, 1978. This plan provides DOE with the project goals and objectives, the rationale and strategy of the project, and a comprehensive multi-year plan for accomplishing the goals of the project.

The third major document of the year is this Annual Technical Report. Its purpose and scope are described in Section I.

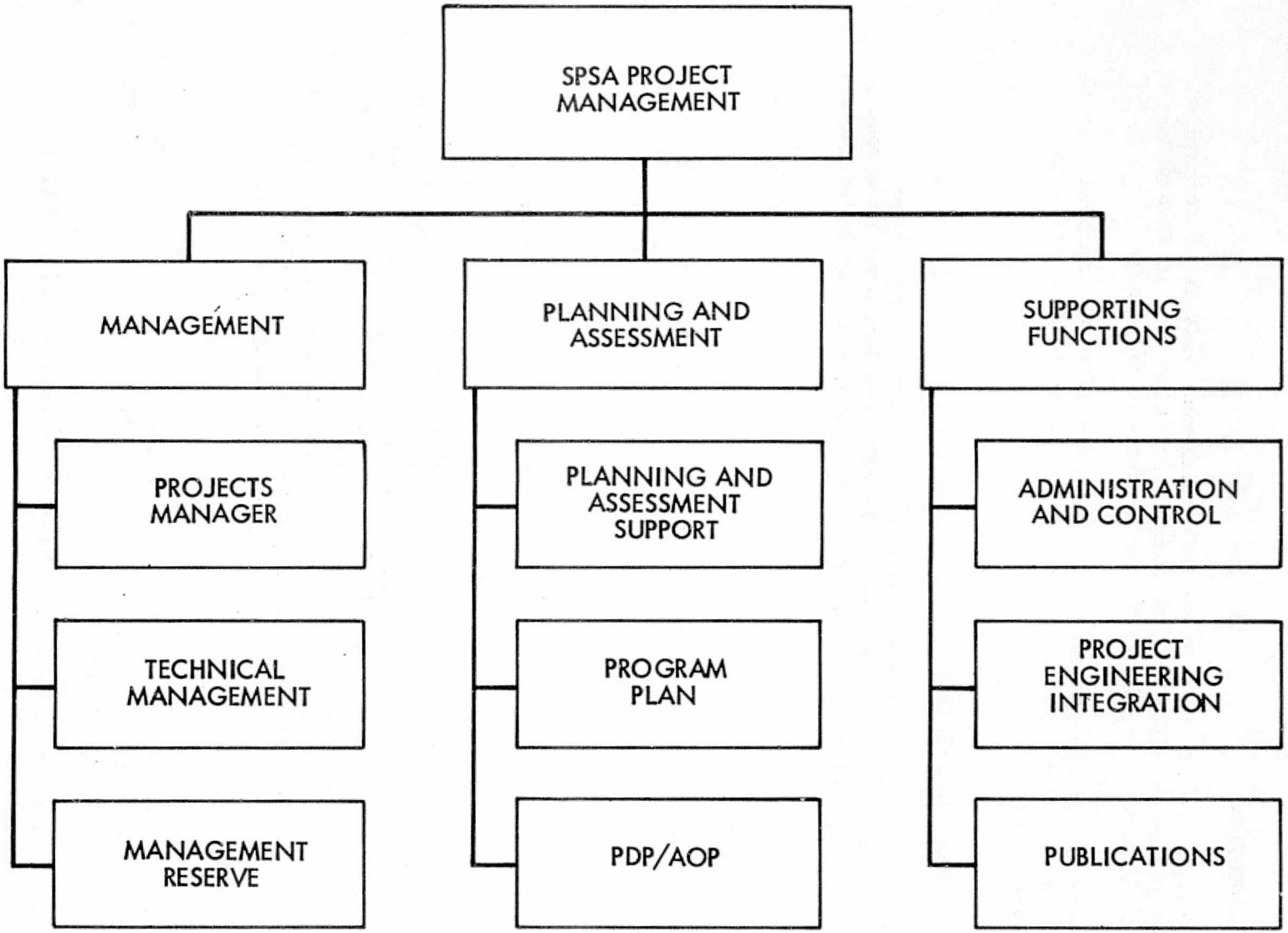


Figure 3-1. Project Management Work Breakdown Structure

SECTION IV

REQUIREMENTS DEFINITION

A. INTRODUCTION

The Requirements Definition task may be considered the "front end" activity of the SPSA project. This task examines various potential users of small power systems and characterizes their power plant requirements, which could be met by solar-thermal electric technologies. The participants in this activity strive to understand users' needs and provide solar technology and program information. The principal Requirements Definition outputs will be solar thermal electric plant design requirements for the Systems Definition task and design teams, and a determination and characterization of the potential markets for small power systems.

Requirements Definition objectives are to: (1) identify, characterize, and quantify the electrical power needs and plant requirements of small power system users; (2) understand the user community and develop effective communication between users and the SPSA Project; and (3) establish functional, economic, performance, environmental, and operational requirements to be used in system design.

B. TASK AREA ORGANIZATION

Requirements Definition activities are organized in five topical areas as shown in the task work breakdown structure, Figure 4-1. The five areas are: Application Requirements, User Integration, Market Potential, Plant Requirements, and Goals Analysis. These areas are further delineated by subtask blocks in Figure 4-1. Subtask activities that were active in FY 1978 are shown with a shaded edge.

C. TECHNICAL APPROACH

The Requirements Definition task approach is delineated in five functional activities. These activities are described in the following paragraphs.

1. Applications Requirements

A breakeven economic analysis is performed for each major market segment. Market penetration goals are set for (1) penetration as a function of time, and (2) power plant cost as a function of time. Then, using cost projections for specific technologies, the applications with the greatest potential are determined and recommended for development.

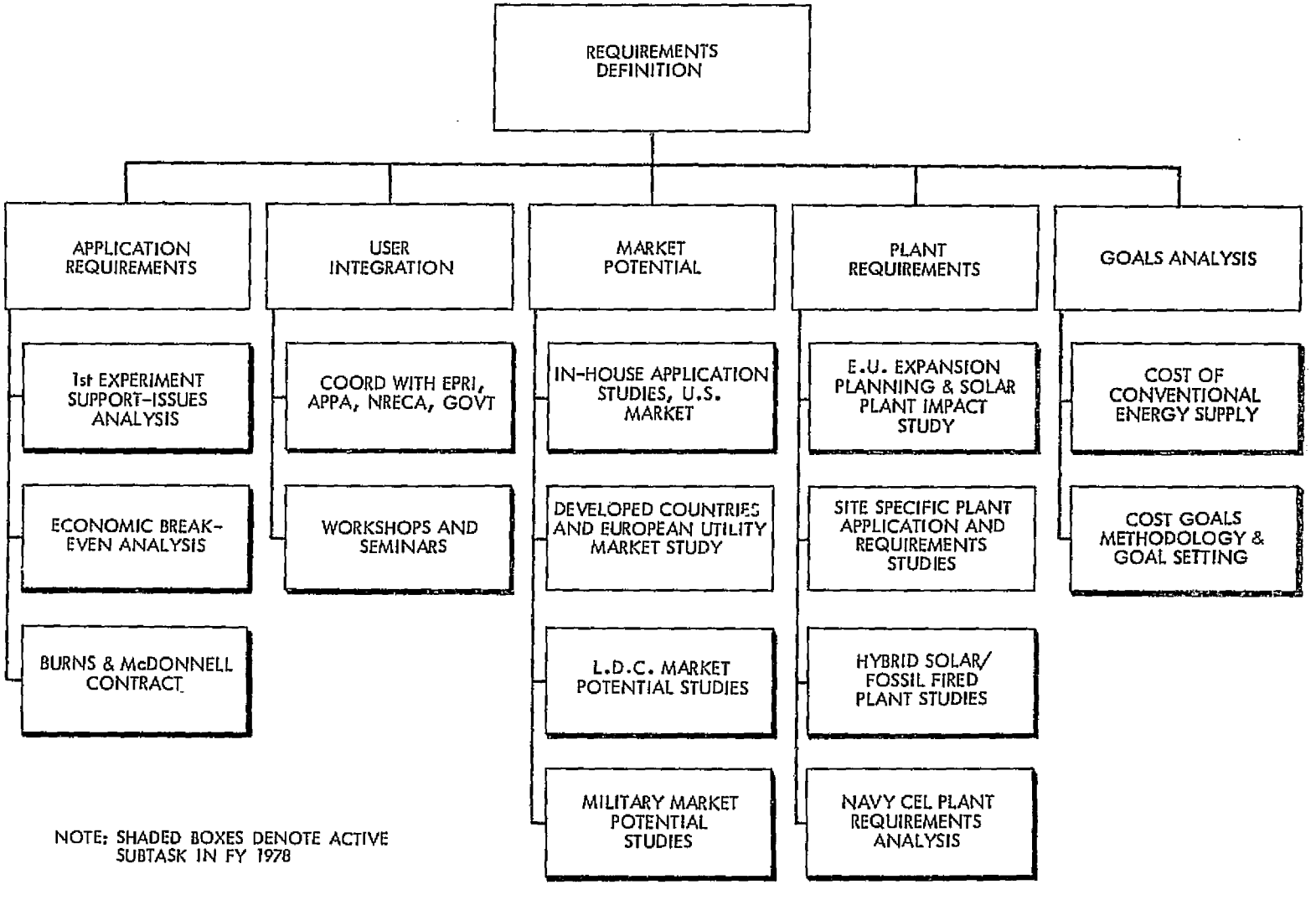


Figure 4-1. Requirements Definition Task Area Organization

2. User Integration

An important aspect of developing markets for small power systems is the establishment of early rapport with users in each market. Several possible methods for developing user contacts exist. The three being used extensively by the SPSA Project are (1) workshops, such as the small utility applications workshop held October 1978 in Aspen, Colorado, (2) seminars and technical meetings, and (3) personal visits to users. All three of these techniques were employed in FY 1978.

3. Market Potential

For small power systems to be commercialized, there must be significant market segments available in the 1985 to 2000 time period. Energy prices of competitive systems must be at or above the cost of small power systems at that time. For example, the energy cost of the best small power system technologies in 1985 may be $1800 per kWe with busbar energy cost of 160 mills per kWhr. The U.S. electric utility industry will be producing power in that period for 20-100 mills per kWhr, so it is obvious that these utilities will not figure prominently in the 1985 market potential. Many less developed countries, on the other hand, are producing power at costs of 200 mills per kWhr or greater, and busbar costs will likely be at least 50% higher in 1985. These countries obviously represent potentially viable early (1985) markets for small power system technologies. Some special U.S. markets have been identified for potential initial penetration in the 1985-1990 period. They include remote power for islands and several military applications.

These market areas and others identified as appropriate for small power system utilization will be explored in order to provide the data base for market development and other project activities.

4. Plant Requirements Analysis

An applications-related plant requirements study is being performed to help form an in-depth understanding of special plant requirements of small power systems users. Since there is great diversity in small power systems user sizes, types, load structures, and geographic location, this work requires extensive analysis of electric utilities and knowledge of specific non-utility applications. A close working relationship with utilities typical of the several types and size ranges must be developed to understand specific plant-related needs. Much of the work in this area will be accomplished via a major study subcontract to industry. This study will examine electric utility operations constraints which may apply to solar thermal power plants. Non-utility loads identified as important for early small power systems application will receive equal consideration with electric utility plant requirements.

5. Goals Analysis

A methodology was formulated in FY 1978 to set SPSA cost goals which could be applied to each market segment. The method enables identification of penetration goals into specific market segments at specific future times. In turn, segments best for early commercialization are identified, and competitive cost and potential for small power system penetration are quantified.

D. TECHNICAL ACTIVITIES IN FY 1978

The 1978 technical activities are described here under activity sub-headings which are in accordance with the task area organization shown previously in Figure 4-1.

1. Applications Requirements

Applications requirements work for FY 1978 includes contributions to first experiment issue analysis, economic breakeven analysis, and potential utilization by small utilities.

a. First Experiment Issue Analysis. The SPSA Project was initiated to identify systems offering potential for relatively near term use. In support of this objective, EE#1, a 1 MWe solar thermal power system, was designed to identify suitable technological approaches for small power systems applications. EE#1 includes design, fabrication, deployment, testing, and evaluation of a solar power facility based on an optimum use of near-term technologies. Investigation of the performance, functional, operational and institutional aspects of such a facility in a field test environment are additional objectives. The issues germane to site selection will strongly influence the experiment, and a full understanding of these issues is essential to the success of EE#1.

Three site selection issues were studied to determine their effects on the fielding of the first experiment. These were (1) the type of utility proposed, (2) the type and size of load supplied by that utility, and (3) effects of regional economics on competing power technologies. The Arizona utility system was used as an example in helping to rate the importance of favorable and restrictive factors.

The analysis indicated that a utility with a small generating capacity might best be served by the addition of solar power. It was assumed that the greatest improvement in load factor would result in a system having a high summer load which peaks about midday with a smooth morning buildup and afternoon falloff.

An EPRI study that categorized utilities into six groupings was used to determine which type of fuel mix and what length of transmission line was best associated with the load curve. A review of the National

Electric Reliability Council, a group sponsored by the utilities, predicted when each geographical region was expected to have deficiencies in its generating capacity. A study that identified regions with rising or falling economies was used with this prediction to see where solar energy could be applied best and to identify the competing power technologies in those regions. The best area for deployment was seen to be the southwest sun belt. Future power generation competing in this region will be primarily coal and nuclear with some oil used in intermediate generation.

b. Economic Breakeven Analysis. The objective of this study was to examine the potential economic viability of solar thermal small power systems in dispersed siting applications in small utilities of the Southwest. This was accomplished by determining the value of the solar thermal plant to the user and comparing the value with the estimated plant capital cost. Potential market size then was estimated for those cases with cost-value ratios (C/V) less than one. The sensitivity of solar thermal plant economic viability to changes in plant parameters then was determined.

The methodology was based on the Simplified Generation Expansion Method commonly used in the utility industry. Costs are in 1978 dollars. Inflation was assumed to be zero. Three plant types were studied:

(1) Simple (no storage) solar thermal plant with diesel back-up capacity. (This plant is referred to as Plant A.)

(2) Solar thermal plant with dedicated storage and diesel back-up capacity. (This plant is Plant B.) The number of hours at storage plant rated capacity is indicated in parentheses, e.g., B(2).

(3) Hybrid oil-fired solar thermal plant. (This plant is referred to as Plant C.) The capacity factor is indicated in parentheses, e.g., C(.600).

Plant rated capacity was 10 MWe.

The study concentrated on areas with 2800 hours/year of useable sunshine and average annual mean daily direct insolation of 6.5 $kWhr/m^2$, which typifies the Southwest. A preliminary study showed that the Southeast and Northern regions of the U.S. are unfavorable and the Southcentral region is marginal for solar plant penetration.

Stanford Research Institute (SRI) international projections of the price of petroleum to electric utilities were used to provide two data points for the study period: $3.19/MBtu (1985) and $4.12/MBtu (2000).

The user was a small municipal or cooperative utility operating a diesel plant to meet intermediate loads. The diesel was assumed to have a heat rate of 9950 Btu/kWehr, a capital cost of $420/kWe, fixed operations and maintenance (O&M) costs of $3.70/kWe-yr, and variable O&M costs

of 3 mills/kWehr (not including fuel costs). It was assumed that the diesel unit would be installed at an existing plant site. Solar thermal subsystems costs and performance were based primarily on the Point Focusing Distributed Receiver Technology Project targets for 1985 and on information in the 1978 Technical Assessment Guide published by the Electric Power Research Institute (Reference 4-1). Two levels of technology were employed: level 1, corresponding to maximum efficiency and minimum collector cost, and level 2, corresponding to moderate efficiency and moderate collector cost.

The results of the study show hybrid plants to be the most competitive solar thermal configuration. Furthermore, hybrid plants were found to compete successfully with diesel generators throughout the range of fuel price and at both levels of technological development. Simple all-solar thermal plants were economically viable at the lower technology level once fuel price exceeded $3.53/MBtu, and at the higher technology level throughout the range of fuel price. Plants with storage were not generally economically viable at the lower technology level for the fuel prices studied. The only exception was the two-hour storage case at the high fuel price. At the higher technology level, plants with up to six hours storage were found to be competitive practically throughout the fuel price range. Plants with minimum storage (two hours at plant rated capacity) were consistently more competitive than plants with six hours storage. The optimum amount of storage was 2 hours in all cases except the high technology/high fuel price case in which 3.5 hours were justified.

As fuel price increased $0.93/MBtu, or 29 percent, the economic breakeven cost of solar thermal plants increased 22 to 25 percent, depending on plant type. As solar technology improved from level 2 to level 1, the economic breakeven cost of solar thermal plants increased 23 to 28 percent, depending on plant type. The impact of improving the solar technology consistently was slightly more significant than the impact of a 29 percent increase in fuel price.

Since hybrid plants consistently were more economical than other solar thermal plant types, the market potential study was limited to hybrid plants.

Market estimates, shown in Table 4-1, were based on the Burns and McDonnell small utility data base, assumed penetration rates (10 to 50 percent), and assumed intermediate capacity additions (20 to 60 percent of total capacity additions). The estimates range from about 100 to 1500 MWe by the year 2000. The baseline case assumed that solar thermal would penetrate 30 percent of the new intermediate capacity and that intermediate capacity would account for 40 percent of all new capacity.

If the penetration rate is 100 percent, and intermediate generating technologies captured 60 percent of new capacity additions, then the ultimate U.S. small utility market size would be about 3000 MWe by the year 2000.

Table 4-1. Estimates of Market Potential For Small Solar Thermal Hybrid Systems

Period	Small Utility Market Penetration (MWe)		
	Low	Baseline	High
1985-89	20	118	294
1990-94	34	202	504
1995-99	45	269	672
1985-99	99	589	1470

The sensitivity of solar thermal plant economic viability to changes in plant parameters is shown in Tables 4-2, 4-3, and 4-4. In the tables, VOM refers to variable operations and maintenance costs, excluding fuel. FOM is fixed operations and maintenance cost. MCC is miscellaneous capital cost, which includes site preparation, land, contingencies, legal fees, engineering fees, taxes, and spare parts. Overall plant efficiency refers to the average annual efficiency of the solar subsystems: collector, transport, conversion, and storage, as applicable. As can be seen from the tables, the characteristic of greatest impact is hybrid fossil fuel heat rate. Unit collector cost is next in importance, followed by solar subsystem overall efficiency. These results are based on level 2 technology and a fuel price of $3.19/MBtu.

From the study results, it can be concluded that for Southwest small utility dispersed siting applications:

(1) Hybrid solar thermal/fossil fuel systems potentially may be more competitive than simple all-solar plants and all-solar plants with storage;

(2) Hybrid systems potentially may be competitive with diesel plants;

(3) Hybrid systems may provide up to 1500 MWe of new small electric utility capacity by the year 2000.

c. Potential Utilization by Small Utilities. The Burns & McDonnell study of potential utilization of Small solar thermal Power Systems (SPS) by small utilities was more detailed than the overview in-house study. It was especially valuable in determining the kinds of small utilities, geographical regions, and all-solar plant configurations that should be selected for detailed analysis in the Solar Thermal Plant Impact Analysis and Requirements Definition Study.

Table 4-2. Economic Viability Sensitivity: Simple All-Solar Plant

Southwest Small Utility 1985 Fuel Price of $3.19/MBtu Dispersed Siting Application Capacity Factor = 0.320		
Ten Percent Change in Plant Characteristic		Sensitivity of Plant Capital Cost
VOM	0.08 mills/kWe-hr (10%)	$ 2.4/kWe (0.2%)
FOM	$ 0.9/kWe-yr (10%)	$ 9/kWe (0.7%)
MCC	$ 33/kWe (10%)	$ 33/kWe (2.4%)
Solar systems overall	2.74 percentage points (10%)	$ 55/kWe (4.0%)
Collector cost	$ 10/m^2 (10%)	$ 70/kWe (5.1%)

Table 4-3. Economic Viability Sensitivity: All-Solar Plant With Storage

Southwest Small Utility 1985 Fuel Price of $3.19/MBtu Dispersed Site Application Capacity Factor = 0.365 Two Hours Storage		
Ten Percent Change in Plant Characteristic		Sensitivity of Plant Capital Cost
VOM	0.16 mills/kWe-hr (10%)	$ 5.10/kWe (0.3%)
FOM	$ 1.48/kWe-yr (10%)	$ 14.80/kWe (0.9%)
MCC	$ 33/kW (10%)	$ 33/kWe (2.1%)
Overall plant efficiency	2.65 percentage points (10%)	$ 69/kWe (4.4%)
Collector cost	$ 10/m^2 (10%)	$ 90/kWe (5.7%)

Table 4-4. Economic Viability Sensitivity: Hybrid Plant

Southwest Small Utility
1985 Fuel Price of $3.19/MBtu
Dispersed Site Application
Capacity Factor = 0.600
Level 2 Technology

Ten Percent Change in Plant Characteristic		Sensitivity of Plant Capital Cost
VOM	0.1 mill/kWe-hr (10%)	$ 5.20/kWe (0.4%)
FOM	$ 1.06/kWe-yr (10%)	$ 10.60/kWe (0.9%)
MCC	$ 33/kWe (10%)	$ 33/kWe (2.7%)
Solar subsystems overall efficiency	2.74 percentage points (10%)	$ 55/kWe (4.4%)
Collector	$ 10/m^2 (10%)	$ 70/kWe (5.6%)
Hybrid/fossil fuel heat rate	960 BTU/kWe-hr (10%)	$ 75/kWe (6.0%)

The Burns & McDonnell study included development of a seventh synthetic utility; this allowed very small utilities (2 MWe) to be included in the study. (Six synthetic small utilities previously were developed by Burns & McDonnell for the Electric Power Research Institute to model utilities in the 2 to 500 MWe range.)

The study also included modification of the Burns & McDonnell power supply program to (1) develop solar thermal plant models, which approximate optimum designs; (2) dispatch the solar plants against hourly loads, and analyze plant output; and (3) to determine solar plant capacity credit. A comparison of optimum conventional and solar thermal expansion plans determined the net improvement, if any, in utility revenue requirements which could result from the addition of solar plants.

Four different small power system (SPS) configurations were considered in the study representing three different solar thermal technologies:

(1) 2-MWe and 10-MWe power plants using parabolic dish concentrators with a 15-kW heat engine mounted at the focal point of each dish (Types I and II). These systems used advanced battery energy storage.

(2) A 10-MWe system with variable slat concentrators and central steam Rankine energy conversion (Type III). This system used thermal energy storage.

(3) A 50-MWe system consisting of a field of heliostats concentrating energy on a tower-mounted receiver and a central steam Rankine conversion system (Type IV). This system also used sensible thermal storage.

The characteristics assumed in the study for each small power system type are summarized in Tables 4-5a and 4-5b. The characteristics shown assume a plant location in the Southwestern United States.

The subsystem characteristics were provided by JPL, with one exception: the high estimates of "other" capital costs, primarily site development and related construction items, were developed by Burns and McDonnell. Small Power System characteristics were provided by JPL with the exception of capital costs, which were developed by Burns and McDonnell. These costs were based on subsystem cost and performance and an hourly analysis, which led to optimized plant configurations.

The comparison of economics of power supply expansion plans was for seven hypothetical small utilities through the year 2000 both with and without the small power systems. Key characteristics of the reference utilities are summarized in Table 4-6. Small power systems expansion plans were developed by replacing new conventional intermediate and peaking capacity with capacity from the applicable small power system types for each reference utility. Small power system penetrations of 5, 10, and 20 percent were analyzed for each system type. In addition, these expansion plans were analyzed considering a range of potential capital costs for each system type. The results for each reference utility are discussed below. Costs are presented in 1975 dollars.

1) 1.3-MW Municipal. The 1.3-MW municipal reference utility was expanded initially with small power system type I, a 2-MWe power plant using parabolic dish concentrator system. It was found that the smallest penetration (solar mix) attainable with this unit, due to size of the unit relative to the utility's peak, was 20 percent of the utility's capacity requirement. At this level of penetration, the present worth of all future revenue requirements (PWAFRR) of the solar expansion plan ranged from less than 1 percent less expensive to 26 percent more expensive than the PWAFRR of the optimum conventional expansion plan. (The PWAFRR is the present value of revenues needed by a utility to exactly offset annually incurred costs for the series of years under study.)

In order to investigate the economics of the parabolic dish concentrator system at lower levels of penetration, characteristics were developed for a 1-MWe parabolic dish small power system. The results of the analyses are that PWAFRR of the solar expansion is less than the PWAFRR of the optimum conventional expansion only for the low end of the range.

Table 4-5a. Small Power Systems Types and Characteristics

Characteristic	SPS Type I	II	III	IV
Plant Size (Rated Capacity, MWe)	2	10	10	50
Commercial Availability	1985	1985	1985	1985
Cost Characteristics (1975 $)				
Capital Cost ($/kW)[1,2]	578-2,312	508-1,848	1,506-3,806	1,103-2,759
Operation & Maintenance				
Fixed ($/kW-yr)	2-14	2-14	2-14	2-14
Variable (mills/kWhr)	1-4	1-4	1-4	1-4
Other Characteristics				
Average Plant Efficiency	0.28	0.28	0.14	0.22
Equipment Forced Outage Rate	0.01	0.01	0.07	0.07
Annual Maintenance (wks/yr)[3]	0.1	0.1	1.0	1.0
Storage				
Capacity Rating (MWe)	2	10	7	35
Energy Rating (MWhr)[2]	4	20	14	70
Collector				
Area (km^2)[2]	0.008	0.040	0.112	0.422
Intensity Rating (kW/m^2)[2]	0.9	0.9	0.9	0.8
Land Area (km^2)[2]	0.026	0.133	0.373	1.407
Solar Multiple[2]	1.0	1.0	1.5	1.5
Lifetime (years)	30	30	30	30

[1] Does not include interest during construction.
[2] Assumes allocation in the Southwest United States.
[3] Assumes most routine maintenance will be done at night.

Table 4-5b. Small Power Systems Subsystems Characteristics

	SPS Type I	II	III	IV
Capital Cost (1975 $)				
Collector ($/$m^2$)	62-192	62-192	85-171	65-145
Transport ($/kW)	18-50	18-50	75-150	150-300
Conversion ($/kW)	53-200	53-200	175-350	175-350
Storage ($/kWh)	45	45	60	60
Other ($/kW)[1]	170-1,206	100-744	185-1,274	109-764
Efficiency				
Concentrator/Collector	0.864	0.864		
Receiver	0.804	0.804	0.54	0.65
Transport	0.95	0.95	0.92	0.95
Conversion	0.42	0.42	0.30	0.36
Storage (Round Trip)	0.75	0.75	0.75	0.75
Lifetime (years)				
Collector	30	30	30	30
Transport	30	30	30	30
Conversion	15	15	30	30
Storage	15	15	30	30

[1] Includes costs of land, site development, water supply, buildings, electrical connections, and overhead. Does not include interest during construction.
[2] Types III & IV: Concentrator and receiver efficiencies are combined in a collector efficiency.

Table 4-6. Characteristics of Seven Reference Utilities

1974 Peak Demand (MW)	System Type	Peak Season	Load Factor (%)	Total Generation Capacity	1974 Power Resources (Number of Units @ Given Size)				
					Coal Steam	Oil Steam	Combustion Turbine	Diesel	Hydro
1.3	Municipal	Summer	49	1.2 MW	-	-	-	2@.2 MW 1@.3 MW 1@.5 MW	
10	Municipal	Summer	49	12 MW	-	-	-	2@1 MW 3@2 MW 1@4 MW	-
10	Municipal	Summer	49	None	-	-	-	-	-
35	Municipal	Summer	45	40 MW	2@5 MW 1@20 MW	-	1@10 MW	-	-
35	Municipal	Winter	55	24 MW	-	1@5 MW 1@10 MW	-	3@3 MW -	-
35	Distribution Cooperative	Summer	49	10 MW	-	-	-	3@1 MW 2@2 MW 1@3 MW	-
200	Generation & Transmission Cooperative	Summer	57	180 MW	2@10 MW 1@60 MW	1@30 MW	1@20 MW	-	50MW*

*Assumes 20 MW of firm and 30 MW of firm peaking capacity from a U.S. government agency

2) 10-MW Municipals. The two 10-MW municipal reference utilities also were expanded with small power system type I with solar mixes of 5, 10, and 20 percent. For the 10-MW municipal with generation, the solar expansion plans are competitive with the conventional expansion plans only for low small power system costs. For the 10-MW municipal without generation, however, the solar expansion plans are competitive with conventional expansion plans for both low and intermediate small power system costs at solar mixes up to 10 percent. For a solar mix of 5 percent, the PWAFRR of the solar expansion plan is only 0.5 percent higher than that of conventional expansion with high small power system costs. There are two primary differences in the expansion plans for these two reference utilities which account for the differences in results noted above. First, the 10-MW municipal without generation must add new capacity earlier in the study period in order to achieve and maintain the optimum generation mix. The 10-MW municipal with generation can defer these additions until some of the existing units are retired. Second, because the 10-MW municipal generation has no existing plant sites or operating staff, the first new unit added by this utility is more expensive both in terms of the additional capital costs required for site development and in terms of the additional cost of hiring an operating staff. The 10-MW municipal with generation was assumed to be able to add new generation at an existing site, thus avoiding these additional site development costs.

3) 35-MW Municipal Utility and Distribution Cooperative. The 35-MW reference utilities were expanded with small power system types I and II (2-MWe and 10-MWe parabolic dish concentrator systems) and with small power system type III (a 10-MWe variable slat concentrator system).

For the 35-MW municipal utility coal-fired generation, type I is only slightly competitive with an optimum conventional expansion plan that has low solar system costs and a 5 percent solar mix. As might be expected, type II is more competitive with the optimum conventional expansion plan, but is still competitive only with low small power system costs. Type III is not competitive with the optimum conventional expansion plan for this reference utility at any solar system cost level considered.

For the 35-MW municipal utility with oil-fired generation, type I is competitive with the optimum plan with low solar costs at all levels of penetration considered. With intermediate small power system costs, it is competitive with a 5 percent solar mix. Type II is competitive at 5, 10, and 20 percent solar mixes with both low and intermediate costs. Small power system type III is competitive with the optimum conventional expansion plan only with low solar costs.

The results for the 35-MW distribution cooperative are similar to those for the 35-MW municipal with coal-fired generation. System type I is slightly competitive with the optimum conventional

expansion with a 5 percent solar mix and low small power system costs. Type II is competitive up to 20 percent solar mix with optimum conventional plan with low solar system costs. Type III is not competitive with the optimum conventional expansion plan at any solar plant capital cost level considered.

There are two primary factors which make these three system types more competitive with conventional oil-fired generation than the other two 35-MW reference utilities. First, the existing oil-fired generation of this utility has a higher energy cost than the coal-fired generation of the other two utilities. Second, the 35-MW municipal with oil-fired generation was assumed to buy power from an investor-owned utility with oil-fired generation. Therefore, the purchased energy costs for this utility were higher than those for the two other 35-MW utilities.

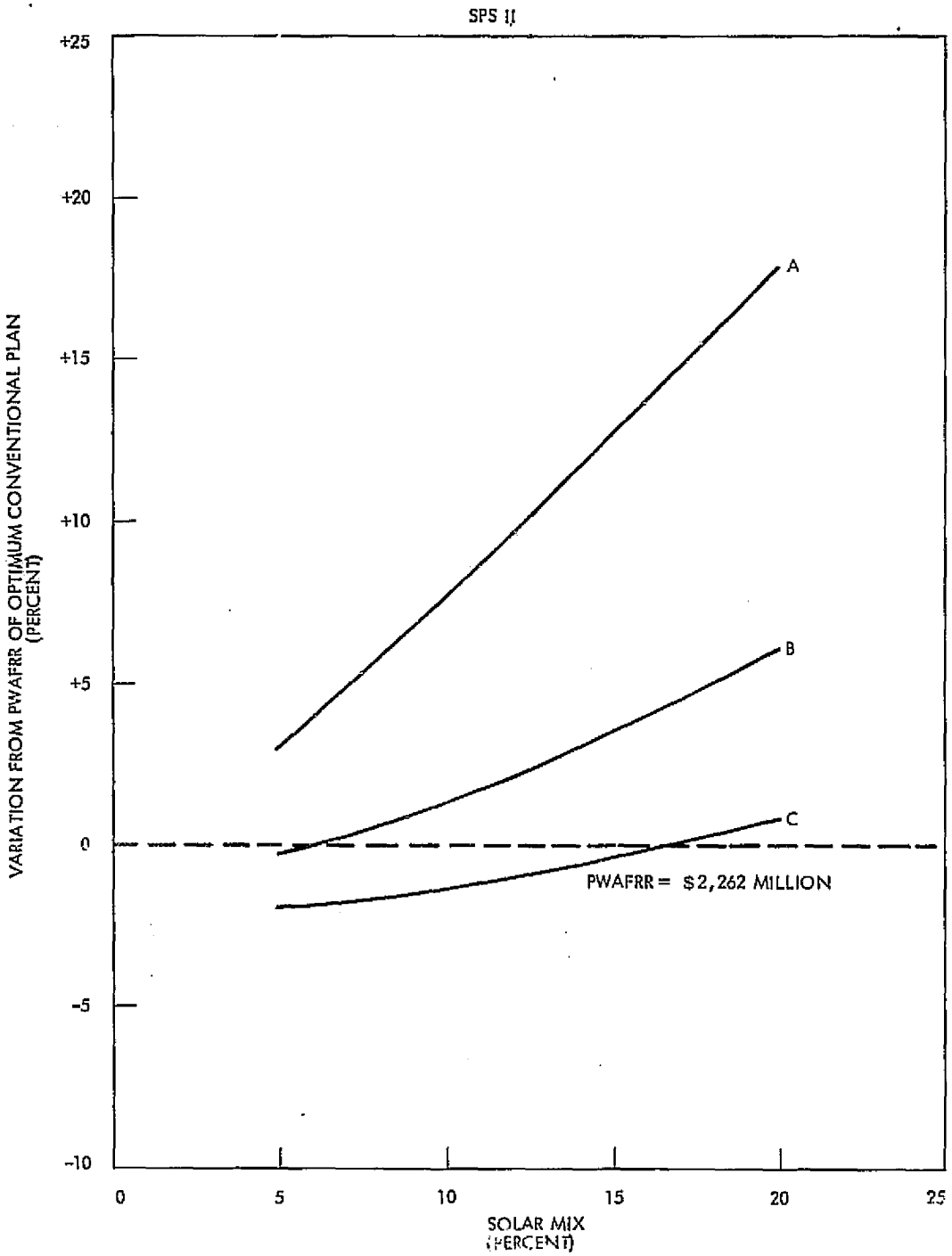
4) 200-MW Generation and Transmission Cooperative. The 200-MW generation and transmission cooperative was expanded with small power system types II, III and IV (a 50-MWe "power tower").

Figure 4-2 shows that type II is competitive with the optimum conventional expansion plan up to a 15 percent solar mix with low solar system costs. Type III is not competitive with the optimum conventional plan for any solar system cost level considered. Type IV is competitive with the optimum conventional expansion plan with low solar system costs and a 5 percent solar mix.

The study results can be summarized in breakeven capital costs. Breakeven capital cost was defined as the capital cost which would have to be achieved for the solar systems to have the economic potential to penetrate 10 percent of a small utility's generating capacity (i.e., achieve a 10 percent solar mix) by the year 2000. While three levels of penetration were studied, 10 percent was used in determining breakeven costs because it represents a significant market share, and it requires only modest increases in utility margin requirements.

Breakeven capital costs calculated for each reference utility and each SPS type for a 10 percent solar mix (10 percent penetration into the small utility market) are summarized in Table 4-8. As can be seen, the breakeven capital cost for type I ranged from $720/kW for the 35-MW distribution cooperative to $1307/kW for the 35 MW municipal with oil-fired generation. These breakeven costs fell within the range of assumed potential small power system costs (i.e., $578/kW to $2,312/kW).

Breakeven capital costs calculated for type II ranged from $713/kW for the 35-MW distribution cooperative to $1,238/kW for the 35-MW municipal with oil-fired generation. These costs are less than or in the lower part of the assumed cost range (i.e., $508/kW to $1848/kW).



A: HIGH CAPITAL COST, HIGH OVERHEAD COSTS
B: LOW CAPITAL COST, HIGH OVERHEAD COSTS
C: LOW CAPITAL COST, LOW OVERHEAD COSTS

Figure 4-2. Range of Small Power Systems Expansion Plan Costs, 1980-2000 200 MW Generation and Transmission Cooperative

Table 4-7. Economically Attractive Applications

Synthetic Utility				Technology			
				Dish Electric			
Size	Type	Peaking Season	Primary Fuel	I	II	Slats-Thermal III	Central Receiver IV
1.3 MWe	Municipal	Summer	Oil	L,L (20%)	-	-	-
10 MWe	Municipal	Summer	Oil	L,L (20%)	-	-	-
10 MWe	Municipal	Summer	None	L,L (20%) L,H (11%)	-	-	-
35 MWe	Municipal	Summer	Coal	L,L (15%)	L,L (20%)	NC	-
35 MWe	Municipal	Winter	Oil	L,L (20%) L,H (8%)	L,L (20%) L,H (20%)	L,L (20%)	-
35 MWe	Dist. Coop.	Summer	Oil	L,L (7%)	L,L (20%)	NC	-
200 MWe	G&T Coop.	Summer	Coal	-	L,H (6%) L,L (16%)	NC	L,L (9%)

NC = Not competitive
L,L = Low capital cost, low site development cost
L,H = Low capital cost, high site development cost
(X%) = Solar mix

The breakeven capital cost for type IV was $1,075/kW for the 200-MW generation and transmission cooperative. This was the only reference utility for which type IV was considered. The value was $28/kW less than the lower limit of the assumed cost range ($1,103/kW to $2,759/kW).

Breakeven capital costs are compared with estimated capital costs in Figure 4-3. Note that 10% penetration is assumed. At that penetration level, the central receiver system was not competitive. However, Table 4-7, which summarizes economically attractive applications, shows the central receiver (type IV) is competitive at penetrations of up to 9%, provided low capital and site development costs are achieved.

A comparison of values in Table 4-8 with the range of study input capital costs shown in Table 4-5 yields the following conclusions:

(1) Small power system types I and II (dish-electric) could be economically competitive with conventional generation if the low values of capital costs used in this study are achieved.

(2) Small power system types III and IV (III: variable slats with central heat engine; IV: central receiver) would have to achieve lower capital and O&M costs than the lowest values assumed in the study to become economically competitive.

(3) All of the small power system types potentially are more competitive in oil-dependent utilities (represented in the study by a 35-MW municipal utility with oil-fired generation) than in coal-dependent utilities.

The study results indicate that a configuration consisting of a parabolic dish concentrator and heat engine at the focus is more likely to be economically competitive in small utilities than other small power systems configurations.

Factors not considered in performing the evaluations include: availability of petroleum fuels, environmental conditions and other non-economic issues. To determine their impact on the potential of solar thermal small power systems in small utilities, such factors must be studied separately.

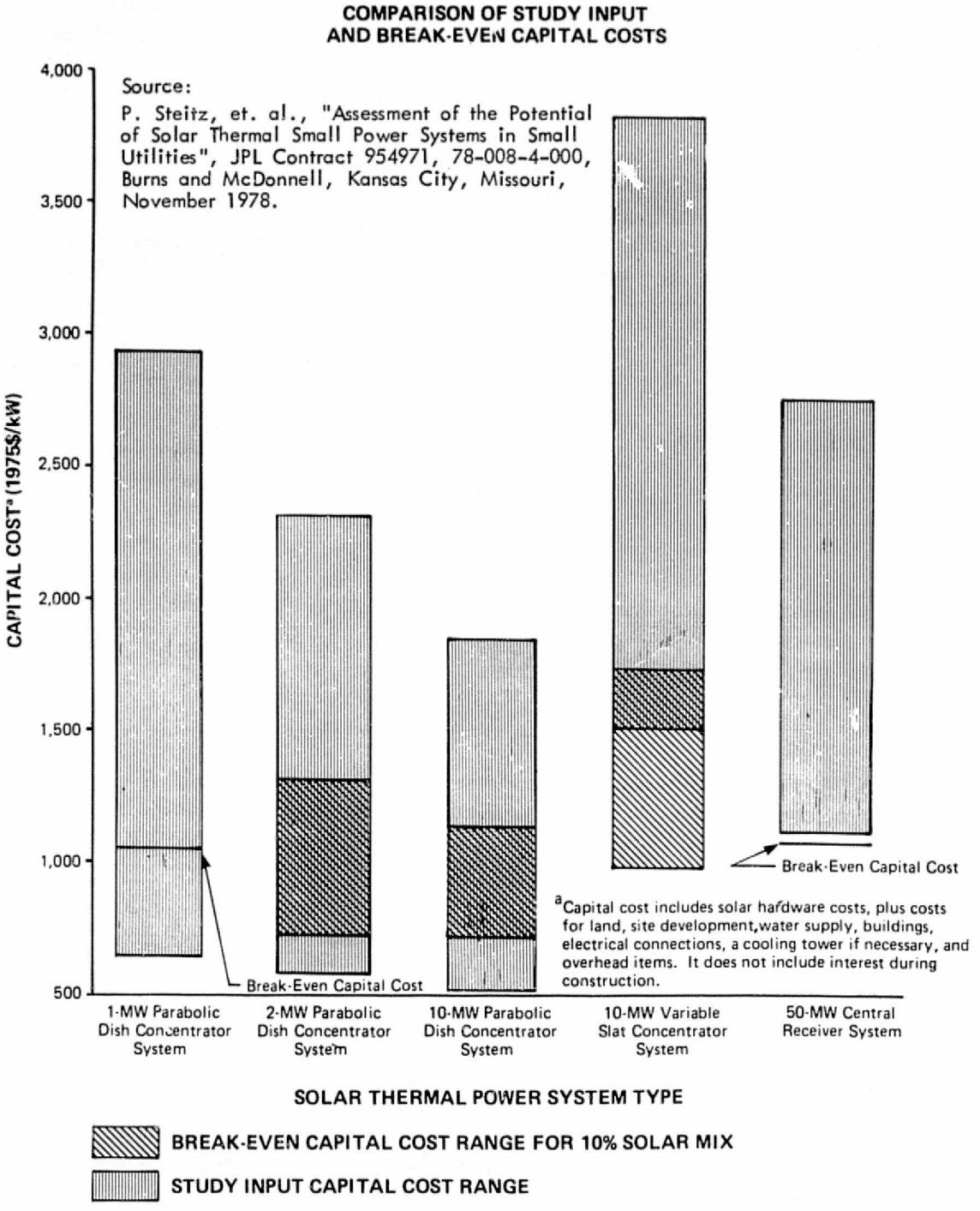


Figure 4-3. Solar Plant Versus Utility Applicable Costs

Table 4-8. Breakeven Capital Cost[1] for 10% Solar Mix (1975 $/kW)

Reference Utility	Small Power System Type			
	I	II	III	IV
1.3-MW Municipal	-[2]	-	-	-
10-MW Municipal With Generation	968.6	-	-	-
10-MW Municipal Without Generation	1,070.1	-	-	-
35-MW Municipal With Coal-Fired Generation	746.4	716.2	1,137.4	-
35-MW Municipal With Oil-Fired Generation	1,307.3	1,138.8	1.720.1	-
35-MW Distribution Cooperative	720.7	713.0	976.8	-
200-MW Generation & Transmission Coop.	-	771.6	1,069.8	1,075.5

[1] Excluding interest during construction.

[2] For a 1-MW Small Power System with all other characteristics identical to Type I, the breakeven capital cost is $1050/kW

Note: Small Power System Types

Types I & II: Parabolic dish - electric transport
Type III : Line focusing variable slat concentrator with central heat engine (Rankine)
Type IV : Central receiver (Rankine)

2. User Integration

Workshops and seminars with small power systems user groups are an important means of SPSA information gathering and dissemination. Bringing a user group together to help formulate plant requirements for their particular application gives the group members a sense of "ownership" of the application. These groups tend to become strong project supporters and early customers for hardware.

A very successful small utility user workshop was held in Aspen, Colorado, October 10-12, 1977. The workshop was designed to accomplish four primary objectives:

(1) To introduce utilities to small solar thermal power technology, its potential and the programs for its development.

(2) To pinpoint developmental issues involved in the adoption of small solar thermal power.

(3) To establish communication channels with utilities, which will assist the Jet Propulsion Laboratory in developing technology that will meet the needs of small utilities.

(4) To provide input for making upcoming RFPs for experimental projects attractive to various types of utilities, particularly the small electric utilities.

A general purpose of the workshop was to establish an effective interchange of ideas among electric utility representatives, the Department of Energy, and the Jet Propulsion Laboratory. To achieve this goal, the format for this workshop included formal presentations, panel discussions, small group interactive discussions, and informal gatherings.

Formal proceedings were prepared to comprehensively document the presentations and dialogue at the workshop. The proceedings are available through the United States Government Technical Information Center, DOE/JPL-1060-78/1 (Ref. 4-2). Results and conclusions appear in Volume I, Executive Summary. Principal results are in the following paragraphs.

When electric utility executives plan for future electric generating capacity, solar equipment is considered alongside other advanced and conventional types of energy conversion systems. The capital cost of solar equipment presently is high. Electric utility planners have many considerations when evaluating the purchase of solar electric generating equipment. Such detailed evaluation particularly is needed when comparisons with other, better known, proven power-generation equipment are made. In planning for the adoption of solar power systems, it is difficult to predict users' attitudes as they relate to purchase of high-cost and high-risk technologies.

A primary impediment to the practical implementation of solar power plants is the statistical variability of insolation. Plants of the future will require major equipment redundancy, employing conventional technology and/or large energy storage capacity. This requirement will increase the cost of solar electric power plants.

Once technical feasibility and reliability have been proven, solar equipment most likely will be implemented in hybrid power plants. The hybrid plants will contain some conventional fossil fuel generating capacity for use when the sun is not available. The need to save oil continually increases the attractiveness of solar energy as an option for generating electricity and tends to raise the risk acceptance level in planning decisions.

Retrofitting existing steam electric generating facilities with a solar heat source is a near-term solar energy option. However, several difficulties may be encountered, including the high cost of developing the solar steam electric generating equipment interface.

Decisions to use solar technology when a utility expands generation capacity will be strongly influenced by local economic, institutional, and environmental considerations. However, consideration of regional and national objectives must accompany each decision. The Federal Government and the Department of Energy must clarify and communicate their objectives to assist utilities in planning.

As scarce fossil fuels are consumed, attention must be directed toward choosing electric power options based on renewable energy sources. Solar energy is renewable and, therefore, should be developed.

The size of an electric utility company and whether or not it is publicly or privately owned has a direct effect on the acceptable risk level in planning, developing and purchasing new equipment. In order for many utilities to actively participate in high-risk solar research, development, and demonstration, they need to devise innovative schemes for increasing flexibility in the planning process. When considering new generation capacity, the small utilities often band together to share ownership or pool power. This sharing may be in conjunction with larger electric utility operations. Consequently, the large and small utilities may see a way to combine efforts in a fashion mutually beneficial for the development of solar power.

The Department of Energy may speed acceptance of solar plants by finalizing solar-related siting regulations, thus firming up the planning basis for developers and utilities. As the major source of financing solar electric development, the Federal Government must commit suitable amounts of public funds.

To facilitate siting of urban and rural plants, environmental regulations and licensing processes must be clearly defined by local and federal agencies. These regulations should include consideration of special applications, such as hybrid solar-fossil fuel power plants and distributed versus central receiver-type solar thermal systems.

Siting new power generating facilities within the constraints of future environmental, socio-economic, and land use requirements is a difficult job. Public acceptance of planned power systems will continue to be important when planning additional generation capacity. Siting regulations are particularly difficult to anticipate, in the case of solar thermal power, due to a lack of experience and established technical regulatory guidelines. Therefore, making pertinent guidelines available for developers to use in planning for siting, construction, and operation of solar thermal power plants will expedite acceptance.

Solar thermal power presently is a high-risk, capital-intensive, long term investment. Due to stiff competition with lower-risk investments for limited funds, new means of financing must be developed to assist utilities and industrial owners in planning to own and operate solar power plants.

The opportunities for financing solar electric power equipment and facilities will increase as a self-sustaining solar electric power industry develops. The long term stability of a solar industry will be enhanced when manufacturers and reputable design engineering firms can offer technically and economically feasible solar electric power systems. During the formation of a solar electric power industry, the financing status of solar technology would be greatly enhanced by a reduction in capital costs and a demonstration of equipment reliability. Therefore, effective and efficient research, in both the government and private sectors, should be continued to support the establishment of competitive technology.

At the conclusion of the workshop, the participants were surveyed to solicit their evaluation of the workshop. The results indicated that all of those in attendance benefited from their participation. The major benefits that were reported included:

(1) Understanding of the purpose, goals and plans of the Small Power Systems Applications Project.

(2) Better understanding of the state-of-the-art of solar thermal power technology.

(3) Opportunities to influence solar power development through ongoing participation in the program.

The workshop was viewed as successful and productive by nearly all individuals involved. It opened a communication channel between Jet Propulsion Laboratory and the utility community, and aided in the initial definition of requirements. Nearly all participants indicated a desire for further involvement with the Small Power Systems Program through a variety of means.

As another part of the SPSA electric utility involvement process, twelve staff members from the Pasadena Department of Water and Power toured JPL on the afternoon of April 19, 1978. After viewing subjects of general interest, they received a more detailed briefing on selected

energy and solar energy programs under management by JPL. The visitors heard presentations on solar thermal applications and photovoltaic devices, the electric vehicle, and thermal power systems. The tour and briefing were well-received and the group showed particular interest in commercialization studies now in progress.

The Pasadena Department of Water and Power provided a tour of their facilities for ten JPL attendees on May 30, 1978. Participants viewed the dispatch center, the base load steam plant, power conditioning and distribution equipment, and combustion turbines used for peaking. Following the plant tour, a discussion period was held with Department engineers. Chief topics covered were dispatching, scheduling, power wheeling, and general problems facing small utilities.

3. Market Potential

Market potential work this year was limited to preliminary examination of three market areas; the U.S. domestic market, less developed countries, and the U.S. military market.

a. Application Studies, U.S. Market. The U.S. application studies are being carried out presently as a part of the goals analysis work and the most significant findings are reported at the end of this section. A brief market segment potential overview is being accomplished now to identify the best early U.S. small power systems applications and to assess their market potential.

b. Less Developed Country (LDC) Market Potential Analysis. This work recently was initiated as a part of the goals analysis early application potential studies.

One activity of this sub-task was to establish and maintain communications with JPL Low-Cost Solar Array Project personnel assigned to analyzing LDC markets. Discussions have indicated that the solar thermal role might be to accelerate rural electrification by stimulating demand in outlying areas. These areas will then become markets of sufficient size that the power grid could be expanded to serve them profitably. A balanced network of interconnected central and dispersed plants operating on a variety of fuel sources, including solar energy, then would provide high quality electric power to most of the population. This view is in sharp contrast with the photovoltaic approach, which emphasizes hundreds of thousands of independent micro-systems (< 10 kWe) competing with the grid.

c. Military Market Potential Analysis. Investigation of the market potential and power plant requirements within the Department of Defense were begun in March, 1978. Discussions were held with BDM Corp. and the Defense Advanced Research Projects Agency to assess Department of Defense needs. Also, potential Department of Defense funding of

power plant studies and hardware specifically oriented toward military requirements was discussed. Requirements identified as critical in the military scenario were size, weight, modularity, reliability, and simplicity of maintenance. The SPSA Project has considered military applications in the FY 1979 Annual Operating Plan and is aiming at the deployment of at least one military oriented power plant experiment by 1983.

4. Plant Requirements

Plant requirements work this year provided significant in-house support to the other SPSA tasks. There were specific subtask activities in preparation for a requirements definition and solar plant impact study, hybrid solar/fossil fired plant study, and requirements evaluation for the planned Navy CEL experiment (EE#2a).

a. Electric Utility Expansion Planning, Non-utility Load Definition, and Solar Plant Impact Study. The combined Solar Thermal Plant Impact Analysis and Requirements Definition Study will be a major contractual effort to evaluate the potential impact of solar thermal power systems on electric utility systems and non-utility loads of the United States. The scope of the study specifically excludes central plants in large utilities. The main emphasis is on near-term applications (1985-1989). This implies smaller utilities, dispersed siting, and non-utility loads. The output of the study will be directly applicable to project experiments (EE#1 and EE#2) by providing functional and design requirements essential to successful operation of a solar plant in a particular region (e.g., Southwest) and for a particular application (e.g., rural industrial site, commercial site, or small utility substation).

The Commerce Business Daily announced the RFP in April 1978, and the RFP was released in June 1978. Three proposals were received. Contract award is scheduled for early FY 1979.

In this study, the small solar thermal power system is viewed at the subsystem-level, such as "central heat engine" and "storage". Each subsystem will be assigned functional characteristics by the contractor in cooperation with JPL, based on the best available technological data. The subsystems will be integrated into a functional model of the plant.

The customer will be represented by a synthetic utility or non-utility load located in a specific region of the United States. The region will be characterized using the best available insolation data and other relevant data.

In the impact analysis the purpose is to find out how functional characteristics of small power system plants, for various levels of

capacity penetration, impact the most important considerations of the user; namely, back-up requirements and economics. The study will provide insights into the following issues:

Cost of Solar Thermal Plants

- Capital Costs
- Operating Costs

Economic Value of Solar Thermal Plants

- User Operating Costs (Fossil Fuel Displacement)
- Capacity Credit
- Capacity Mix Change

Reliability Impact of Solar Thermal Plants

- Plant Size (MWe)
- Amount of Storage/Hybrid
- Location of (Weather/Insolation)
- Multiple Plant Dispersion (Primarily Utility-Related)
- Equipment Reliability

Solar Thermal Plant Penetration Level

- Economic Value
- Reliability Impact
- Electric Grid Capacity (Primarily Utility-Related)

Operating Problems

- Correlation of Solar Thermal Plant Output Degradation
- System Spinning Reserve Requirements
- Solar Thermal Plant Output Ramp Rate
- System Safety Considerations and Drop-Out Protection

In the requirements definition task, the user's functional requirements will be translated into plant requirements. All requirements for the various subsystems will be integrated on the basis of trade-off studies and engineering judgement. The final output will be a functional description of a small power systems plant that satisfies customer requirements.

b. Hybrid Solar/Fossil Fired Plant Study. The Public Service Company of New Mexico is performing a study for DOE (managed by Sandia Livermore Laboratories) on the feasibility of solar hybrid repowering of existing power plants. Phase I of this study includes a technical and economic assessment of the solar hybrid repowering of selected existing facilities from the perspective of a utility company. This study effort has been followed and contact maintained with the participants. The solar hybrid repowering concept is a versatile idea. It is expected that the techniques developed and lessons learned in this study will be transferrable to the Small Power Systems Application Project.

Work has begun on requirements definition studies for a solar-fossil fired hybrid power plant. The outline for an in-house system analysis of the hybrid plant concept was reviewed. The study will examine the engineering and economic feasibility of hybrid plant operation in the 1-10 MWe range during 1985-1990. Also, the net economic benefit of hybrid plant operation in various scenarios will be quantified.

c. Navy CEL Plant Requirements. The Civil Engineering Laboratory (CEL), in anticipation of U.S. Navy energy policy, recognized the potential of solar thermal power. A monitoring and evaluation program was implemented in 1977 with the goal of reducing non-renewable energy consumption within the Shore Establishment. Since the inception of that program, CEL has studied several options appropriate for modular shore-based solar power generation. The Brayton cycle solar air turbine generator with paraboloidal dish concentrator has been identified as a promising concept with sufficient technical merit to justify a near-term development program and deployment of an experimental system for testing and evaluation. Discussions beginning in April 1978 between the Civil Engineering Laboratory and the Jet Propulsion Laboratory have revealed many similarities between the requirements of the DOE Small Power Systems Program and the U.S. Navy requirements for electric power generation. This commonality of requirements presents the opportunity for synergism between the two programs.

The Navy program will benefit from JPL expertise in small power systems. The near-term deployment of a Brayton cycle machine to the DOE Small Power Systems Program will provide sound operational and economic data on a small power system option within reach of present technology. Benefits to the DOE program will include a more rapid development of commercial power plant applications as military interest and military markets are developed. A joint U.S. Navy/DOE Military Application Project has been proposed to design and deploy a small scale solar electric power generating experiment (100 kWe minimum) to meet Navy requirements. The program will be managed by the Jet Propulsion Laboratory and funded jointly by the U.S. Navy and the DOE. The experiment will be known as the Joint DOE/USN Solar Thermal Power Program. It will be the first of the JPL Engineering Experiment No. 2 Series and is designated EE#2a. In FY 1978 an Interagency Agreement was signed by the Navy, DOE, and NASA to implement this program.

5. Cost Goals Analysis

This activity, begun in December 1977, initially analyzed the Southwest U.S. utility market segment and pumping needs for the California water aqueduct system.

a. Southwest U.S. Utility Cost Goals Study. SPSA requires an understanding of the cost of electrical generation by conventional sources in the 1985-2000 period. In order to prepare a basis for

determining the cost of electricity that small power systems must meet, nine electric utilities located in high isolation areas of California, Arizona, New Mexico, and Texas were visited. Each utility was surveyed to determine present capabilities, plans for future generation and transmission, environmental constraints, fuel supply, water availability, reserve requirements, costs, and reliability. This investigation showed that these utilities plan to double their installed generating capacity by 1995. In Arizona and New Mexico the utilities will rely almost exclusively on new mine-mouth coal plants located in northern Arizona and New Mexico and a massive 5-unit 6500-MW nuclear power plant near Phoenix. Transmission lines of from 200 to 600 miles will carry the power to the load centers.

The two California utilities also plan to double their generation resources by relying on oil and geothermal sources. They would like to share in any large coal or nuclear complex in the area. Their transmission lines are under 100 miles. They are both inter-tied with the bulk power grids in the southwest.

The energy cost in the southwest from these new systems will depend upon numerous factors. Several estimates were made based upon a variety of scenarios, including: investor-owned and municipal utility operation; startup dates of 1986, 1995 and 2000, various fuel prices; various fossil and nuclear technologies, multi-year delays in construction, plant capacity factors of 0.3 and 0.6; and fuel escalation rates of 1% and 2% above a 6% inflation rate. Using five different fuel price forecasts, energy costs in the 1985-2000 period were computed as 40 to 100 mills/kWhr for baseload plants and 70 to 195 mills/kWhr for intermediate load plants (1978 dollars).

Factors other than cost will figure heavily in determining the rate at which small power systems gain acceptance in the national economy. The outcome of the energy policy debate will strongly influence the rate of solar development. Institutional factors control the rate at which new coal fields can be opened, fuel transport systems built, and new plants constructed. Many of these already have impacted the nine utilities studied.

The utilities represent a potentially large market for small power systems. However, the utilities may utilize several types of power plants, including conventional designs for fossil-fired and nuclear systems. By the end of the century, the utilities also may have a choice of advanced technologies, such as fluidized bed combustion, geothermal, nuclear reactors, wind, central receiver solar, and photovoltaics. Thus, the problem for the cost goals study can be stated in terms of two questions:

(1) What competition do small power systems face among utilities in the 1985-2000 period?

(2) What economic goals must the SPSA Project achieve in order to compete sucessfully in this environment?

The approach taken is as follows:

(1) Identify utilities in the southwest that might buy small power systems during 1985-2000 and beyond. Analyze their publications for resource plans.

(2) Visit utility planners to obtain their perspectives on solar electric applications as well as their outlook for conventional power generation technology growth and costs.

(3) Create realistic scenarios for load growth escalation, power plant technologies, fuel costs, and other economic factors based on the utility visits.

(4) Compute levelized busbar energy costs under these scenarios for conventional technologies competing with solar.

(5) Compare these results with findings of other analysts in the literature.

The first utility market for solar thermal electric systems in the U.S. consists of firms in the Southwest, an area of high insolation. Because of many factors like terrain, capital, equipment, service area, management, regional history, and local government, each utility has a different perspective and set of priorities. When examined in detail, their variability becomes apparent. The system developer must have an awareness of the diversity of outlooks found among these utilities.

1) Energy Cost Analysis. The cost of power from new power plants is expected to rise rapidly over the next decade. Thus, determining the most plausible scenario for energy costs is difficult. The objective of this study was to provide such a scenario. The range of estimated energy costs, based on the best information available in the first half of 1978, is shown in Figure 4-4. Stated in 1978 dollars, the range varies from 40 mills/kWhr for baseload plants to 200 mills/kWhr for combustion turbines operating at intermediate load.

In the analysis, the average busbar energy cost was developed for units coming on line in 1986, 1995, and 2000, using a capacity factor of 0.6 for baseload and a capacity factor of 0.3 for intermediate to peaking duty units. This analysis considered plants on order and projected plants and technologies using estimated future fuel costs. Escalation rates considered were from 0 to 2% above general inflation.

The capital costs, transmission costs, and tax rates shown are typical of an investor-owned southwestern utility. They are based on data from utility annual reports and financial prospectuses (Refs. 4-3 to 4-14).

The capital costs of power plants refer to actual nuclear and coal plants. Palo Verde #3, a 1270 MW light water reactor, is scheduled to be on line in 1986. This unit will be located west of Phoenix near Wintersburg #2 and is owned by 6 utilities (Public Service of New Mexico, El Paso Electric Co., Arizona Public Service, Salt River Project, Los Angeles Department of Water and Power, and Southern California Edison Company, see Reference 4-9). San Juan #4, a 466 MW mine-mouth coal steam plant, scheduled to be on line in 1981, will be

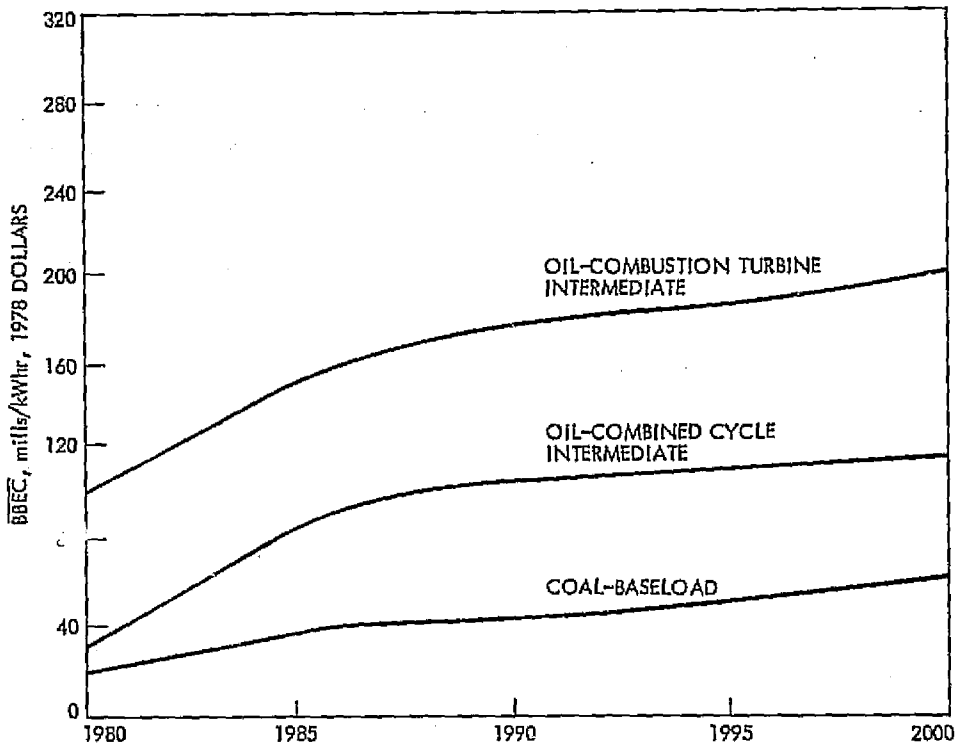


Figure 4-4. Small Power Systems Energy Cost Targets for Levelized Busbar Energy Costs for First Year Operation of Plants Constructed Between 1985 and 2000, Inflation 6%, Escalation 1%

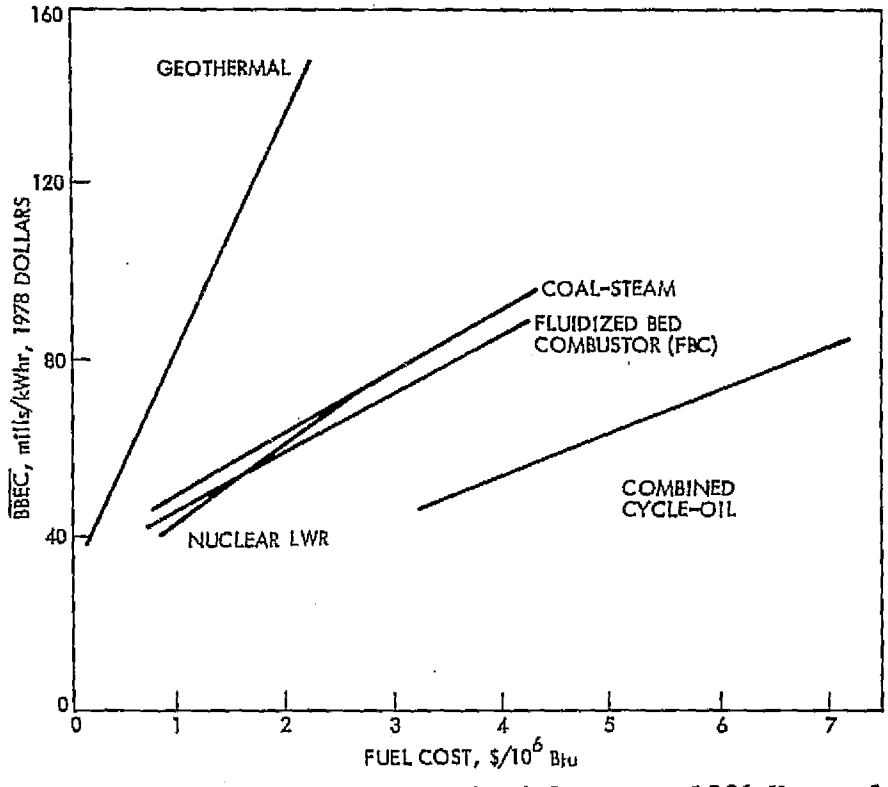


Figure 4-5. Energy Costs for Baseload Systems, 1986 Year of Commercial Operation, Fuel Escalation 1%

located in the Four Corners area of New Mexico. It is owned by Public Service of New Mexico and Tucson Gas and Electric Company. Data for these plants are shown below in 1978 dollars.

	PV #3 ($/kW)	SJ #4 ($/kW)
Capital Cost	425	593
Interest during construction and escalation (30% of capital cost)	127	178
Transmission	158	45
Total	710	816

Other plant capital cost data were obtained from the EPRI Technology Assessment Guide (Ref 4-1). A 30% charge for interest during construction and escalation was applied to LMFBR, Fluidized Bed Combustor, and MHD plants. Transmission line capital costs of $100/kW also were applied. All computations included annual maintenance and operating costs totaling 3% of capital costs. Energy costs were based on heat rate, capacity factor, and fuel price forecasts.

Table 4-9 summarizes the plant description data common to the cases examined. Cases run included:

(1) Fuel, capital, and labor costs escalated 1% above inflation.

(2) Fuel, capital, and labor costs escalation 2% above inflation.

(3) Plant construction delays of 5 years, in addition to the typical lead time for the type of plant.

Figure 4-5 shows the energy cost of baseload systems with fuel escalation 1% above inflation, considering capital cost, operations, and maintenance. This is for initiation of operation in 1986. Figure 4-6 shows similarly, the costs of power for intermediate load plants commencing in 1986.

Energy costs of conventional plants are more sensitive to changes in fuel prices for systems with high heat rates than they are for thermally efficient systems. Advanced combined cycle plants with heat rates of 7000 Btu/kWhr are least sensitive to increases in fuel prices: about 15 mills/kWhr for each $\$1/10^6$ Btu change. MHD plants with heat rates of 7400 Btu/kWhr are less sensitive to fuel prices. These plants will not be available until 1995. Coal and nuclear LWR plants operate approximately at 10,000 Btu/kWhr with sensitivities of about 20 mills/kWhr for each $\$1/10^6$ Btu fuel price change.

2) Fuel Price Forecasts, Energy Costs, and Goals. The preceding figures represent the busbar energy cost in 1978 dollars, as functions of fuel price and technology. Estimates of fuel costs during the 1986-2000 period also were tabulated. For this analysis, fuel price forecasts of five independent studies were used. Kent Anderson (Ref. 4-15), DRI and SRI (Refs. 4-16 and 4-17)

Table 4-9. Plant Cost Assumptions

Plant Cost Assumptions (1978 Dollars)

Technology	Heat Rate (Btu/kWhr)	Construction Time (Years)	1986: Year of Commercial Operation			1995: Year of Commercial Operation			2000: Year of Commercial Operation		
				1st Year Cost[2]			1st Year Cost[2]			1st Year Cost[2]	
			$/kW[1]	Oper (x 10^6)	Maint (x 10^6)	$/kW[1]	Oper (x 10^6)	Maint (x 10^6)	$/kW[1]	Oper (x 10^6)	Maint (x 10^6)
Coal	10,000	9	$ 816	2.4	2.4	$ 888	2.6	2.6	$ 991	2.7	2.7
Combined-Cycle Oil	7,000	4	317	.9	.9	344	1.0	1.0	361	1.1	1.1
FBC	9,500	4	737	2.2	2.2	802	2.4	2.4	841	2.5	2.5
Gas Turbine	14,000	4	227	.5	.5	247	.6	.6	259	.6	.6
Geothermal	29,000	4	721	2.1	2.1	785	2.3	2.3	823	2.4	2.4
LMFBR[3]	9,000	6				1251	3.6	3.6	1311	5.8	3.8
MHD[3]	7,400	7				880	2.6	2.6	922	2.7	2.7
Nuclear-LWR	10,000	11	700	2.1	2.1	733	2.3	2.3	809	2.4	2.4

NOTES

1. Value of capital expenditures plus interest during construction; based on 200 MW capacity of most efficient plant size for each technology. Also, all plants except gas turbine, combined cycle, and geothermal include the capital cost of transmission. Costs of coal, combined cycle turbines and LWR plants based on utility survey; others come from Ref. 4-1.
2. Taken as 3% of capital cost, divided equally between operations and maintenance.
3. LMFBR and MHD will not be available options until 1995 or later.

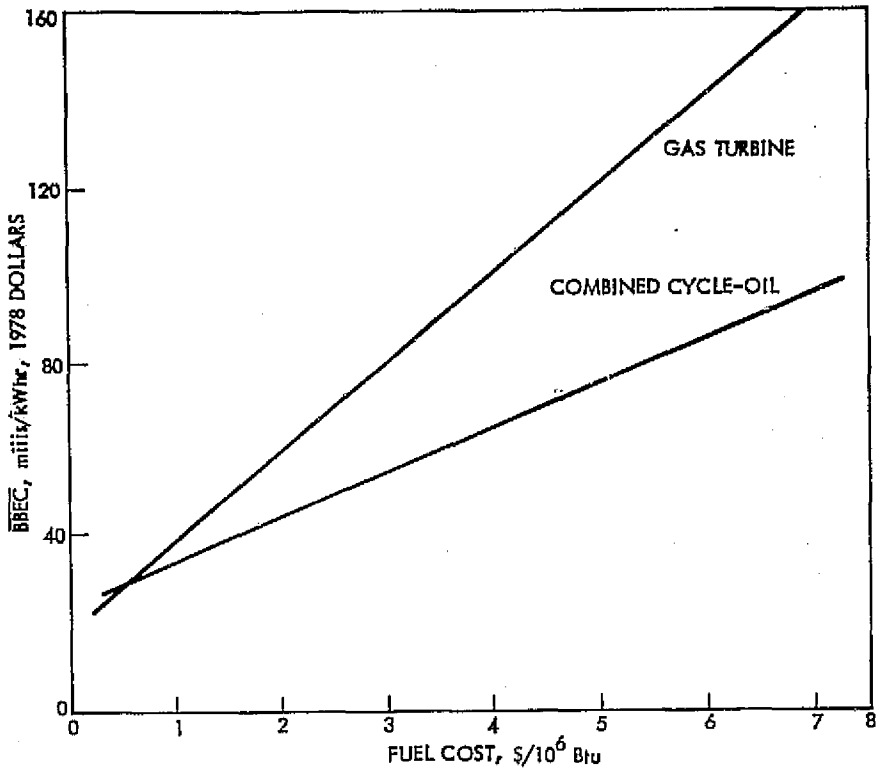


Figure 4-6. Energy Costs, Intermediate Load Systems 1986 Year of Commercial Operation, Escalation 1%

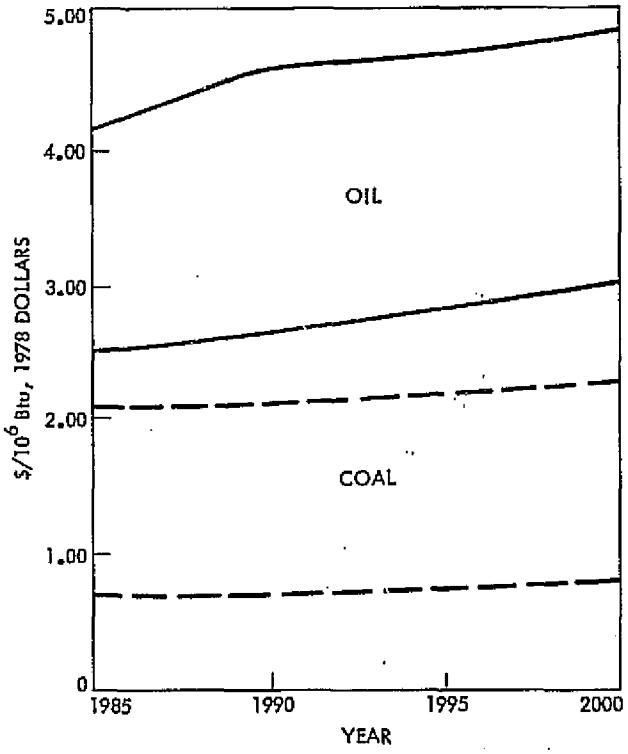


Figure 4-7. Fuel Price Forecast Extremes

reported ranges of prices for coal and oil, but none of these show real price growth between 1985 and 2000. (That is, prices increase only at the general rate of inflation.)

The SYNFUELS (Ref. 4-18) interagency task force study also estimated a price range for coal and oil, and a 1%-above-inflation price growth for these fuels. The FEA-PIES (Ref. 4-19) study showed no real growth in oil prices but a 2% annual price increase for coal. Figure 4-7 shows the envelope curves made up of the lowest and highest prices for coal and oil. Coal costs are in the range of \$0.69 to \$2.20/10^6 Btu (1978 dollars). Oil costs are in the range of \$2.50 to \$4.84/10^6 Btu (1978 dollars).

Using Figure 4-7 envelope curves on fuel prices, energy costs were computed as shown in Figure 4-4. In the baseload case for 0.6 capacity factor plants - using coal in fluidized bed combustors and MHD plants, and oil in combined cycle plants - energy costs ranged from 50 to 97 mills/kWhr (1978 dollars).

Intermediate load plants with 0.3 capacity factor have higher energy costs. Combustion turbine energy costs may range from 100 to 194 mills/kWhr (1978 dollars) and combined cycle costs range from 69 to 106 mills/kWhr (1978 dollars). Both plant types burn petroleum.

3) Capital Cost Forecasts. Other analysts have generated plant cost scenarios for 1985. A comparison of JPL Cost Goals Analysis results with results from six other sources is shown in Table 4-10. The values of unit capital costs all are expressed in 1978 dollars. The upper values in the ranges for coal plants include precipitators, scrubbers for use with high sulfur coal, and cooling towers. All values include interest during construction, except those from SRI.

The capital costs for oil, nuclear, and gas turbines of all these studies are comparable. The JPL estimate of \$816/kW for coal plants is 10% higher than the next highest value reported by EPRI. The JPL nuclear plant cost estimate of \$710/kW is 20% lower than the EPRI estimated costs. The JPL oil and gas turbine costs are within the extremes reported by other investigators. The values for coal plants in the JPL Cost Goals Analysis reflect cost estimates for coal and nuclear-fired steam plants reported in recent prospectuses and annual reports of southwestern utilities (Refs. 4-3 to 4-14).

4) Findings, Interviews and Summary of Generation Plans. A summary of the present electrical generation mix and the planned additions for nine selected utilities in the southwest by 1986 is shown in Table 4-11.

The utilities plan to increase their present generation capacity of 13,400 MW to almost double in 1986 to 24,200 MW. They plan most of the increase to come from nuclear and coal additions. Looking at California as a whole, nuclear generation plays a dominant role in future resource plans in that state. Sixty-four percent of the additions planned between 1985 and 1995 will be nuclear, 16% coal combined fired, 8% geothermal, 7% combustion turbine, 3% cycle, and 2% for hydro, fuel cells, wind, and direct solar combined. These additions total 51,000 MW (Ref. 4-23). (These plans were formulated before the

Table 4-10. Seven Capital Cost Forecasts
($/kW - 1978 dollars)

Source	Coal	Oil	Nuclear	Gas Turbines
JPL Analyses of Utility Data	816	317	710	227
Joskow & Baughman, Ref. 4-20	426	368	585	152
Electric Power Research Institute (EPRI), Ref. 4-1	739	464	878	219
Stanford Research Institute (SRI), Ref. 4-17	344-438	287	631	140-206
Arthur D. Little Co. (ADL), Ref. 4-21	368-561	339-376	543-693	-
Atomic Energy Comm. (AEC), Ref. 4-22	91	362	482	-
National Energy Outlook (NEO), Ref. 4-19	413-551	356	574-631	161

action of the state energy commission, CERCDC disapproving construction of nuclear power plants within the state boundaries.)

Each utility has a different resource base, financial condition, and geography for managing generation transmission and distribution. Therefore, the perspectives they shared with us reflect conditions their individual company anticipates. The differences among utilities and their outlooks should not be minimized. It is for that reason that the extensive Appendix I of the JPL report covering this work provides an in-depth profile of each of the nine utilities. The remainder of this section, however, presents only highlights of the differences and similarities found among the companies in this industry.

The two utilities surveyed in the southern extremity of California look to geothermal and oil-fired plants for future power generation. Their transmission distances typically are under 100 miles and they operate under very severe environmental controls by the state and local governments. Earlier plans called for greater reliance on nuclear power. They anticipate partnership in any future major power plant in the southwestern part of the state.

Arizona and New Mexico utilities typically have transmission distances of 200 to 600 miles from coal mine-mouth plants and nuclear

Table 4-11. Present Generation Mix and Planned Additions by 1986 Selected Southwest Utilities

Selected Utilities	Ownership	Present Generation	Generation Capacity MW	Planned Additions (By 1986)	Total Capacity MW
San Diego Gas & Electric San Diego, Calif.	Investor	17 steam 1 nuclear (20%) 20 combustion turbines	1921	Nuclear	2848
Imperial Irrigation District Imperial, Calif.	Public Water District	1 steam 1 diesel 2 gas turbines 6 hydroelectric (purchase)	391	Geothermal	791
Burbank Water & Power Burbank, Calif.	Municipal	6 oil - Steam 3 gas combustion turbines purchase hydro	251	Coal Nuclear Geothermal	384
El Paso Electric El Paso, Texas	Investor	8 oil steam 3 oil steam 1 combined cycle 2 coal (7%)	999	Nuclear Coal Combustion Turbine Pumped storage	1892
Public Service of New Mexico Albuquerque, N.M.	Investor	2 coal (1[illegible]%) 5 natural gas steam 1 coal (50%)	893	Coal Nuclear Pumped storage	1897
Southwestern Public Service Amarillo, Texas	Investor	1 coal 15 natural gas steam 4 gas turbine	2559	Coal	4689
Tucson Gas & Electric Tucson, Arizona	Investor	1 diesel 1 oil steam 7 coal (7%-50%)	1348	Coal	2104
Arizona Public Service Corp. Phoenix, Ariz.	Investor	3 combined cycle 9 coal 7 oil steam 11 turbine	2561	Coal Nuclear	5143
Salt River Project Phoenix, Arizona	Agricultural Improvement District	5 hydroelectric 9 steam 7 combustion turbine 4 combined cycle 8 coal	2444	Coal Nuclear	4834

plants to urban load centers. Management of this network imposes severe logistical demands on these companies. In addition, large amounts of land must be devoted to surface mining and plant facilities. Also, water requirements, transmission problems, and environmental restraints will increase progressively. These factors are not yet included in the power cost of reliability forecasts, but concern about them will increase in the region.

Two utilities, i.e., San Diego Gas and Electric Company and Tucson Electric Company, have considerable experience operating small dispersed units - oil and gas-fired turbines. These units are used primarily for intermediate and peaking service. Solar thermal electric systems (e.g., parabolic dish with Rankine, Brayton, or Stirling engines) would be particularly suitable in these applications.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

b. Energy for California Water System Study. Water pumping on California Aqueducts represents possible applications of small solar thermal power systems technology toward the end of the 20th Century. In order to establish a basis for evaluation, Requirements Definition determined the pumping requirements, energy sources, and expected energy costs for the years 1985-2000. Areas for further study that hold potential for early small power system deployment were suggested.

The brief study presents a preliminary view of the California Aqueducts System and prospects for small power systems application. The Aqueducts System uses up to 2.5% of the electrical energy consumed in California. There are three major aqueducts, all bringing water from areas north of Sacramento, the Sierras, and the Colorado River to Los Angeles, Orange, and San Diego Counties. The oldest, the Owens Valley Aqueduct, is operated by the Los Angeles Department of Water and Power (LADWP). It operates by gravity flow and generates power. The Colorado Aqueduct, owned by the Metropolitan Water District (MWD), requires pumping power, most of which is hydropower from Parker, Hoover, and Davis Dams. Since MWD owns portions of Parker and Davis Dams, this power supply is assured for a long time. MWD purchases supplementary power from Southern California Edison Company at almost ten times the cost of its own hydro-power. MWD also purchases a portion of its water requirements from the California Department of Water Resources (DWR) for delivery to its customers, 27 municipalities in Southern California.

MWD and LADWP are two of the State Water Project's largest customers. They want to see DWR obtain an assured energy supply at the lowest possible cost, so that they can continue to meet their retail commitments. The water agencies have supported all of the proposed nuclear and coal central power plants to serve Southern California.

The California Aqueduct is a major component of the State Water Project. It requires power to move the water uphill enroute to Southern California as shown in Figure 4-8. Current contracts provide power 2-10 mills/kWhr, but they expire in 1983. DWR anticipates that its annual power costs will multiply by 5 after 1983. So far, it has not been able to negotiate a firm, long-term power supply for the post-1983 period.

The State Department of Water Resources purchases power for pumping on the California Aqueduct from the Pacific Northwest and from four utilities in California - Southern California Edison Co., Pacific Gas & Electric Co., San Diego Gas and Electric Co., and the Los Angeles Department of Water and Power (Figure 4-9). DWR has a favorable contract for power for the state project at a cost of three mills/kWhr. Thus, the state can deliver water, using off-peak power, into Southern California for about $10 an acre-foot. When on-peak pumping occurs, the cost per acre-foot increases. The state will have to obtain extra capacity in power plants to meet the growing demand for water to be delivered through the California Aqueduct. It is estimated that in 1985 the state will use 5.5 billion kilowatt hours of purchased energy - equivalent to 8.5 million barrels of oil - and need about 600 to 1000 megawatts of electric generating capacity for this water pumping application.

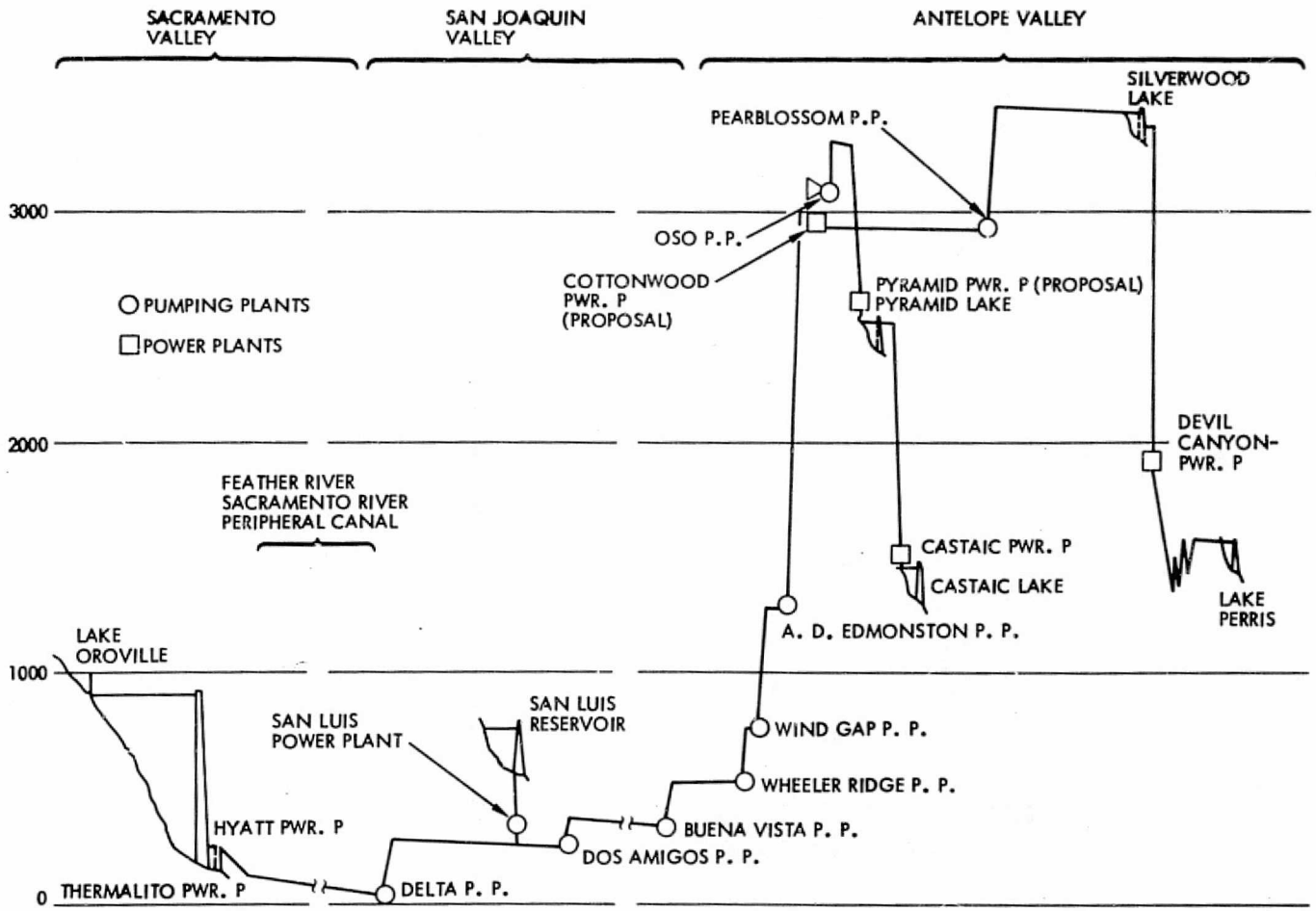


Figure 4-8. California Aqueduct Elevation Profile

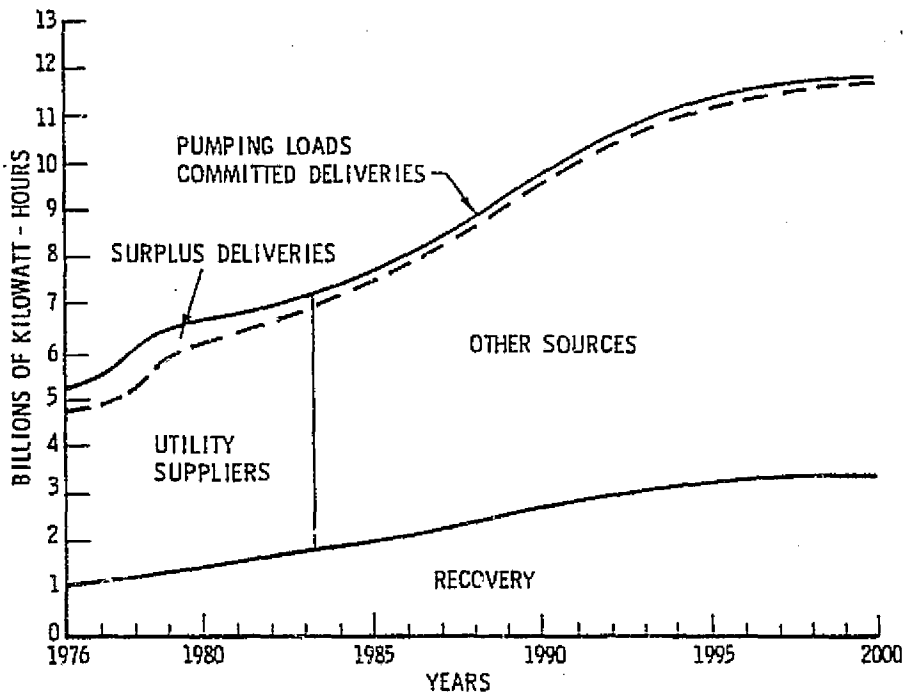


Figure 4-9. State Water Project Estimated Loads

In seeking additional power for pumping on the California Aqueduct, DWR participated in planning and feasibility studies for two new nuclear power plants - the San Joaquin Nuclear power plant near Wasco in the San Joaquin Valley and the Sundesert Nuclear Power Plant near Blythe in the eastern Mojave Desert.

Using the results of the utilities cost goals report, realistic estimates are that power from new baseload plants coming on line in the 1985-2000 period would cost 80-100 mills/kWhr (1978 dollars). The DWR and its water customers will be needing an assured source of power for the next 50 to 100 years. This may work to the advantage of solar if the decision makers in the department and Sacramento take a long-term view of their need to secure adequate power.

The DWR has investigated wind and solar power tower alternate energy source systems. To date they have not built any plants. As a large consumer of electric power, the DWR is a potential user of small power systems provided that solar thermal electric power can help solve their post-1983 power needs and provide a long-term power source at viable rates.

An additional application possibility lies at the retail end of the California Water Project. The municipal water utilities, which distribute water to the end user, have local storage and pumping facilities along the distribution system. They typically buy power from a local utility. Perhaps some of the local water companies would be candidates for small power system repowering of their pumping plants. The power requirements of individual water companies and their suitability for SPSA would have to be determined in future work. To understand this market, pumping requirements of the local companies would have to be investigated through direct contracts with them.

In order for the Department of Water Resources to build a plant, solar or other, it needs to obtain the strong recommendation of the governor. One scenario might begin with a new technology showing itself economical and environmentally acceptable. Then the governor would endorse its use for state power requirements and seek both the legislative approval for implementation as well as authority to market the bonds. The department by itself is not able to undertake a large R&D program or a major capital program without firm state support.

In conclusion, it is apparent that the State Water Project uses a great deal of electricity that must be obtained from outside sources. While small solar power systems may represent a potentially viable alternative in the 1980's, the likelihood is that these power needs will continue to be served by conventional baseload plants in the near future.

6. Contract Review Activities

DOE has let contracts to the University of Oklahoma to study solar hybrid repowering of the New Mexico Electric Service Company, Hobbs, New Mexico plant; to the city of Bridgeport, Texas for a solar electric plant feasibility study; and to Team, Inc. for an energy systems study of Detroit Lakes, Minnesota. Various reports from these studies were received by DOE and sent to JPL for

evaluation. These reports were reviewed by the SPSA Project for engineering and economic content and comments were transmitted to DOE. In this way, JPL screened such reports and compared their content with continuing work in the small power systems area for consistency and accuracy. Also, JPL is able to keep DOE informed of Small Power Systems progress.

REFERENCES

4-1 Technology Assessment Guide, 1977, Electric Power Research Institute, Palo Alto, CA, and Technical Assessment Guide, EPRI PS-866-SR, June 1978, Electric Power Research Institute, Palo Alto, CA.

4-2 Proceedings of Small Power Systems Solar Electric Workshop, Volumes I & II, DOE/JPL-1060-78/1, JPL Publication 78-10, Jet Propulsion Laboratory, Pasadena, CA, March, 1978.

4-3 1976 Annual Report, Imperial Irrigation District

4-4 1976 Annual Report, San Diego Gas & Electric Co.

4-5 Prospectus, San Diego Gas & Electric Co., March 16, 1977.

4-6 Prospectus, El Paso Electric Co., April 20, 1977.

4-7 1977 Annual Report, Southwestern Public Service Co.

4-8 Prospectus, Southwestern Public Service Co., March 8, 1978.

4-9 Prospectus, Public Service of New Mexico, November 8, 1977.

4-10 1977 Annual Report, Arizona Public Service Co.

4-11 Prospectus, Arizona Public Service Co., December 22, 1977, also September 1, 1977.

4-12 1977 Annual Report, Tucson Gas & Electric Co.

4-13 Prospectus, Tucson Gas & Electric Co., January 10, 1978.

4-14 Prospectus, Salt River Project, November 17, 1977.

4-15 Anderson, Kent P., A Simulation Analysis of U.S. Energy Demand, Supply and Prices, Rand Corp., Santa Monica, CA, October 1975.

4-16 DRI Energy Forecast, Data Resources, Inc., Cambridge, Massachusetts, March 10, 1978.

4-17 A Western Regional Energy Development Study: Economics, Vol. II - SRI Energy Model Data Base, Stanford, CA, pp. V-1 to V-13, December 1975.

4-18 Recommendations for a Synthetic Fuels Commercialization Program, Synfuels Interagency Task Force, Vol. II - Cost/Benefit Analysis of Alternate Product Levels, November 1975.

4-19 National Energy Outlook, Federal Energy Administration, FEA-N-75/713 1976.

4-20 Baughman, Martin L. and Joskow, Paul L., "The Future Outlook for U.S. Electricity Supply and Demand," Proceedings of the IEEE, Vol. 65, No. 4, April 1977, pp. 529-561.

4-21 "Economic Comparison of Base Load Generation Alternatives for New England," Arthur D. Little, Cambridge, MA, March 1975, pp. 72-94.

4-22 Power Plant Capital Costs: Current Trends and Sensitivity to Economic Parameters, Atomic Energy Commission, Washington, D.C., October 1974, WASH-1345, pp. 51-52.

4-23 Electricity Forecasting and Planning Report, California Energy Resources Conservation and Development Commission, Vol. II, October 1976.

SECTION V

SYSTEMS DEFINITION

A. INTRODUCTION

The principal objectives of the Systems Definition task are to determine technologies and systems designs that meet the needs of selected applications in the power range of 10 MWe or less and to characterize these systems in terms of design, performance, and cost. An additional objective is to determine the best designs by actually constructing engineering experiments. The experiments will be designed based upon application-related requirements and specific selection criteria.

B. TASK AREA ORGANIZATION

The Systems Definition activities are subdivided into four major subtask areas: Design Support and Integration, Technology Comparison Studies, Systems Development, and Systems Analysis, as shown in Figure 5-1. Management of the contractor-developed engineering experiments is the responsibility of the Systems Development subtask. Analytical support to the Systems Development activities is provided by the Systems Analysis subtask. Studies conducted to determine the relative ranking of seven selected solar thermal power plant concepts are performed by the Technology Comparison Studies subtask. Analytical support that provides subsystem hardware cost, performance data, and integration of plant designs with user interface requirements, as well as preparation of engineering experiment RFPs, is a function of the Design Support and Integration subtask.

C. TECHNICAL APPROACH

1. Technology Comparisons

An overall objective of the SPSA project is to develop and foster the commercial readiness of solar thermal power systems of 10 MWe or less for a variety of applications. In order to identify and define appropriate systems, an analytical effort was mounted to 1) identify the spectrum of solar concepts for collecting and converting solar energy to electrical power using thermal conversion technologies, 2) collect and evaluate performance and cost data for each of the subsystems necessary to the solar thermal approach, 3) further modify and develop an existing computer code to simulate more adequately the generic system concepts to be studied, 4) synthesize power plant concepts for converting sunlight into electrical energy in sufficient detail to determine their system performance and cost, and 5) develop a relative ranking of the concepts studied and a suitable methodology to do so.

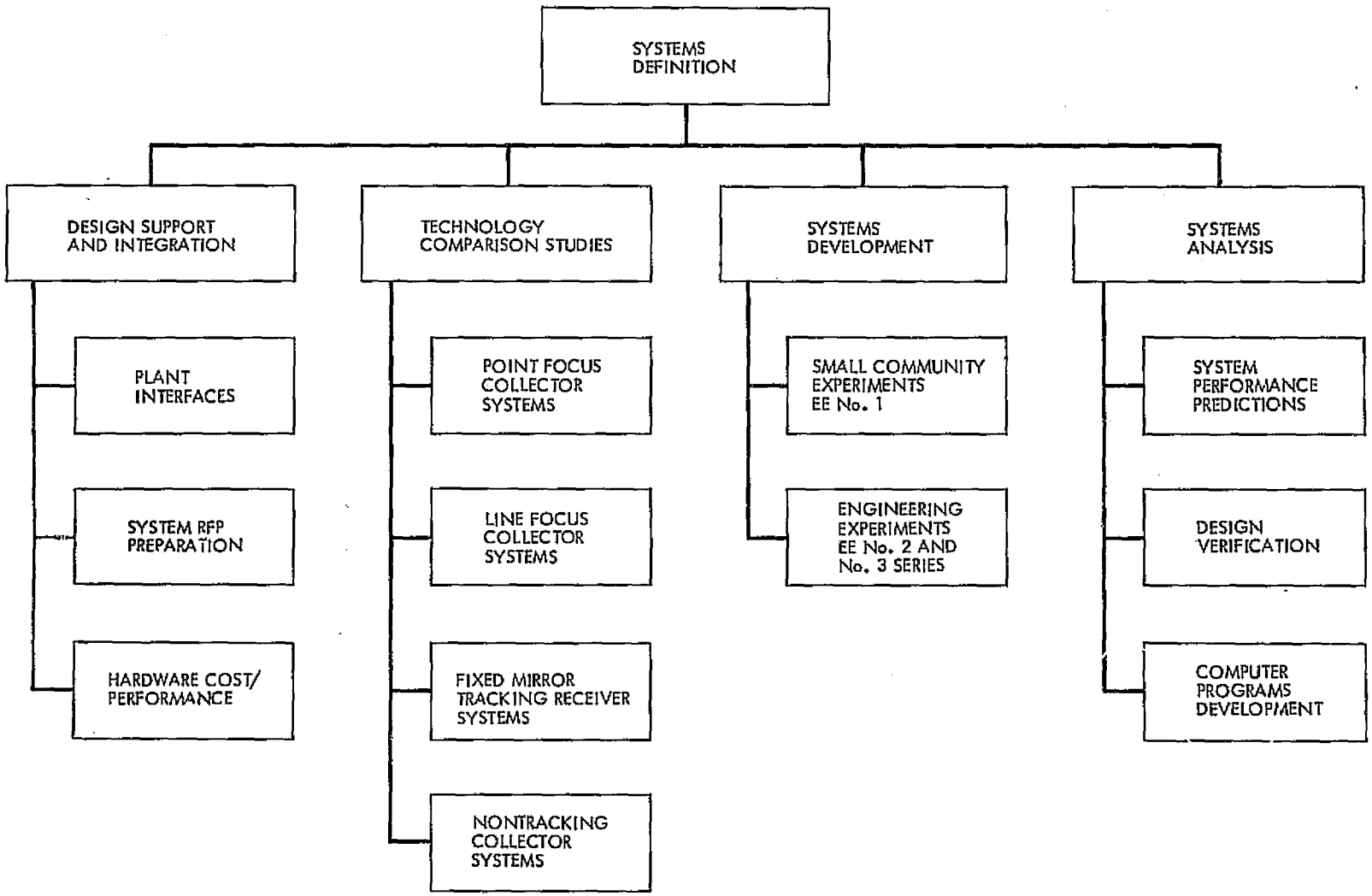


Figure 5-1. Systems Definition Work Breakdown Structure

A similar effort was funded by DOE at SERI and BPNL so that three independent, objective comparison and ranking studies of solar thermal concepts will assist DOE in developing future courses of action. The Systems Definition task area assists DOE in the coordination of the SERI and BPNL study efforts. To this end, three coordination meetings were held to develop consistent study ground rules, identify concepts to be studied, share information on existing analyses and computer programs for systems simulations, and develop a compatible ranking methodology.

2. Engineering Experiments

To develop cost, performance, and design requirements for solar thermal power plants in a particular set of applications, a series of engineering experiments will be designed, fabricated, installed, and implemented at a field test site. The purpose of these experiments is to gather actual cost and performance data from plants in actual operating environments.

The first experiment (Engineering Experiment No. 1) will be designed to meet the needs of a small utility that requires plants in the 0.5 to 10 MWe power range. Near-term technology will be emphasized and design concepts appropriate for various start-up times (i.e., 3.5, 4.5, and 6.5 years) will be identified. Currently, three companies have been funded for a Phase I system study that is to determine a preferred system concept, a Phase II subsystem design, development and testing plan, and a Phase III plant fabrication. It is planned that one or more of the three study contractors will be funded for Phase II and Phase III efforts. These efforts will be aimed at developing a solar thermal power plant that will produce electrical energy as early as 1982.

As additional applications for small power systems are developed, matching engineering experiments will be developed. Although Engineering Experiment No. 1 (EE No. 1) will emphasize near-term technology, later experiments (EE Nos. 2 and 3) will incorporate new technology developed by parallel DOE programs.

D. TECHNICAL ACTIVITIES FOR FY 78

1. Technology Ranking Methodology

a. Background. One of the major responsibilities of the SPSA Project is to investigate the technical, economic and institutional feasibility of selected applications and small power system technologies. In order to provide an objective assessment of the many proposed approaches for solar thermal power plants, technology comparison studies involving JPL, SERI, and BPNL were initiated by DOE. The purpose of these studies is to compare, on a relative basis, seven generic types of solar thermal power plant concepts. The types selected for study are:

(1) Point-focus distributed receiver systems

(2) Point-focus central receiver systems

(3) Line-focus distributed receiver systems

(4) Line-focus central receiver systems

(5) Fixed mirror distributed-focus systems

(6) Fixed mirror line-focus systems

(7) Low concentration non-tracking systems

A brief description of each generic concept follows:

1) Point-Focus Distributed Receiver Systems. Among distributed systems, the point focus distributed receiver (PFDR) systems are capable of generating the highest temperatures and are the most optically efficient systems.

A point focus distributed receiver module is shown in Figure 5-2. Two-axis tracking virtually eliminates the cosine loss since the aperture is always normal to the direct beam radiation. The paraboloidal shape allows for concentration ratios as high as 30,000. The point focus concentrator can be used to generate steam for conversion to electricity at a central location or may be used with a heat engine at the focal point to generate electricity.

2) Point-Focus Central Receiver Systems. The point focus central receiver (PFCR) system, often called a power tower, is a concept in which reflected sunlight is concentrated on an elevated heat absorbing receiver. This absorbed energy is used to heat a fluid which, in turn, is used to operate a turbine. Figure 5-3 illustrates the central receiver design concept. The large field of mirrors, or heliostats, provides two-axis solar tracking. Two major design concepts exist for the placement of the heliostat field. One design places the tower near a central location in the heliostat field, and the other has a heliostat field only on the north side of the tower. Several options also exist in the selection of the thermodynamic cycle and coolant. Possibilities are the Brayton cycles, and the conventional steam Rankine cycle. All of the central receiver design concepts are characterized by high temperatures. Turbine inlet temperatures in excess of 526°C (980°F) and pressures of 7 MPa (1,000 psia) are typical design values for steam Rankine cycles. The open cycle Brayton systems have inlet temperatures of 677°C (1800°F).

3) Line-Focus Distributed Receiver Systems. The line focus distributed receivers (LFDR) systems can utilize several major collector types. The first of these is the parabolic trough which is pictured in Figure 5-4. The parabolic trough has a linear receiver fixed relative to the concentrator mirror. This trough tracks around its axis of symmetry, but the axis can be oriented in several ways to yield different

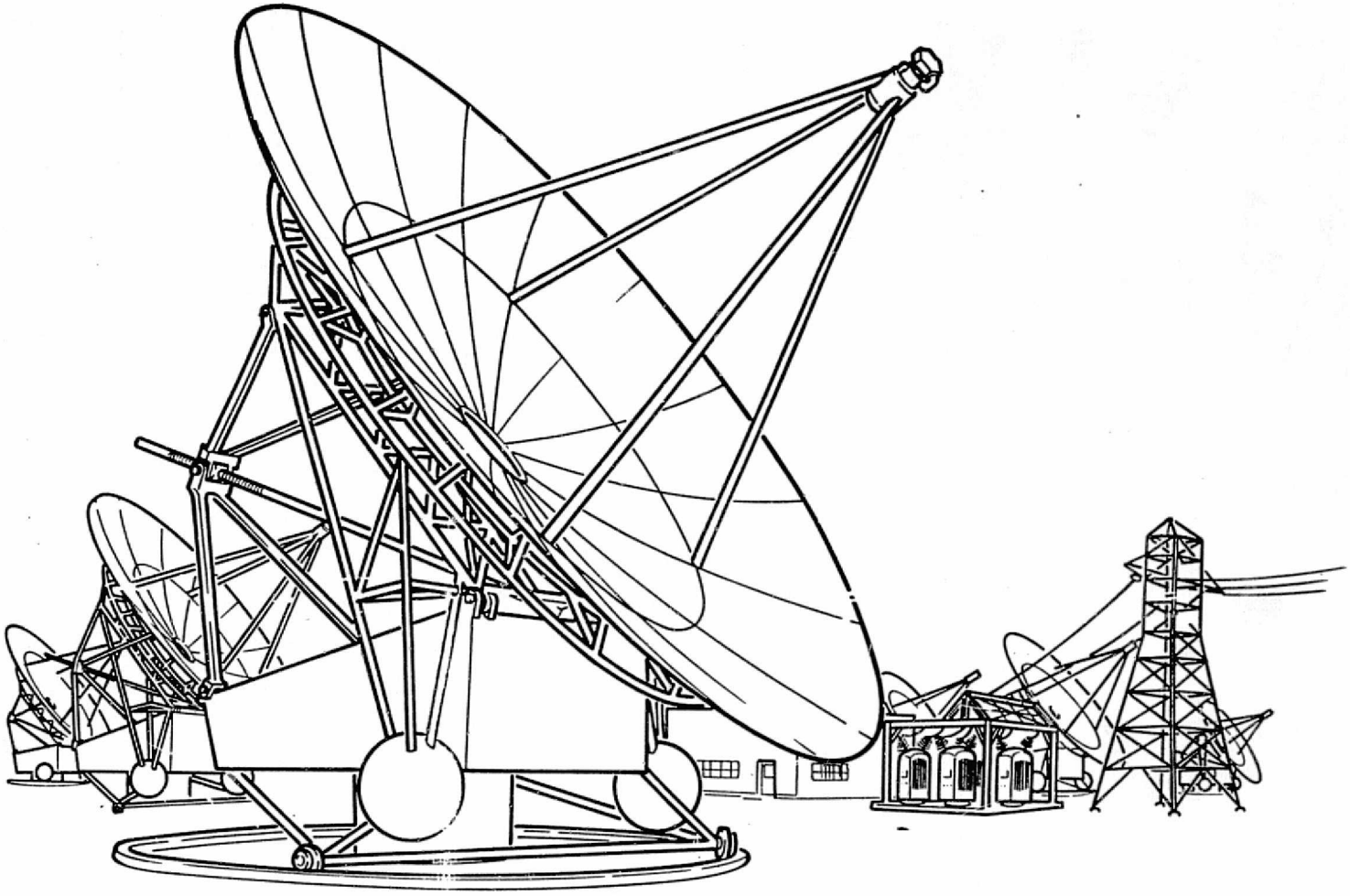
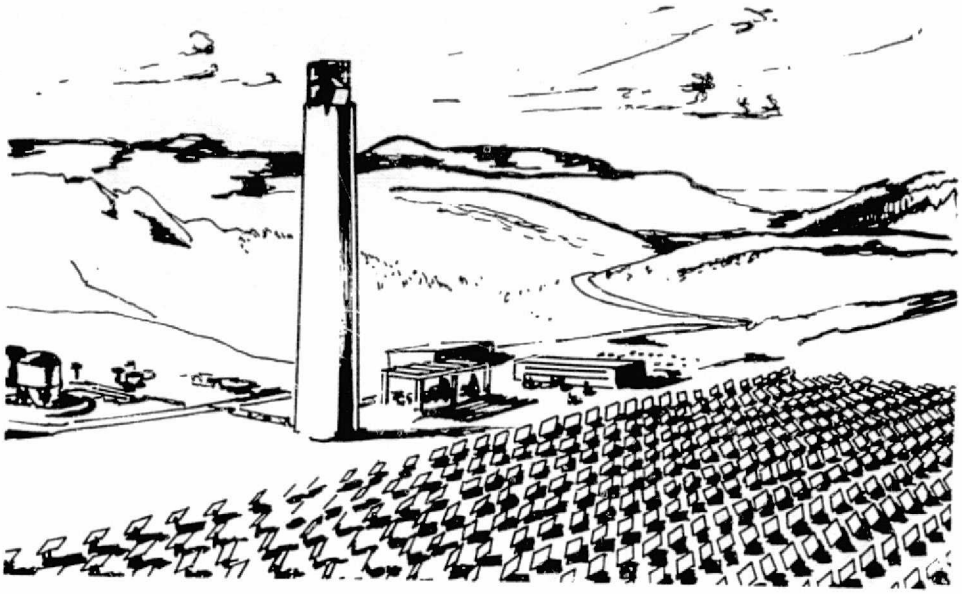


Figure 5-2. Point Focus Distributed Receiver Concept



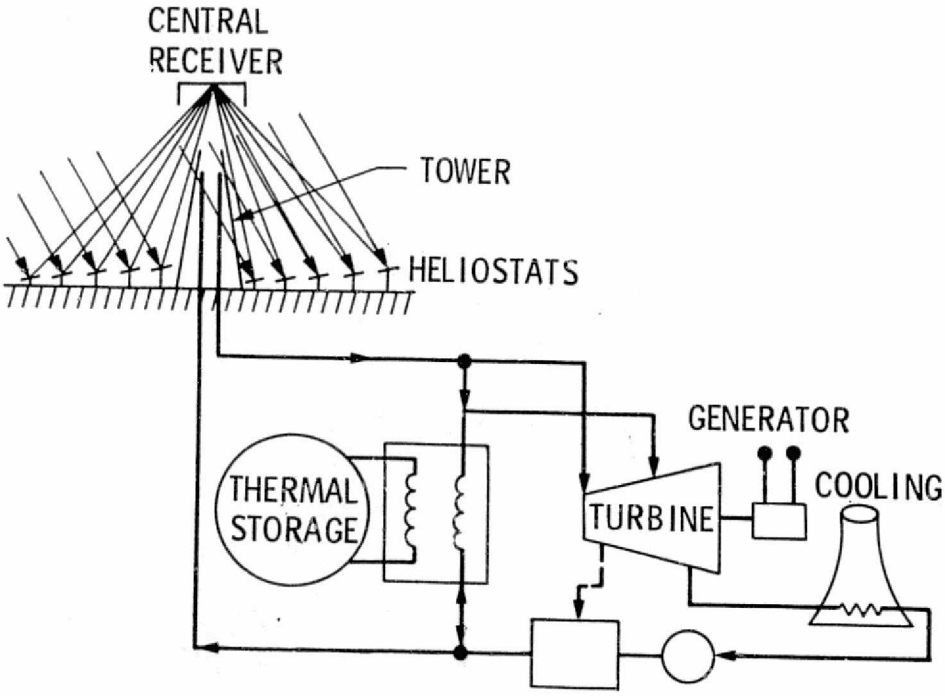


Figure 5-3. Point-Focus Central Receiver Concept

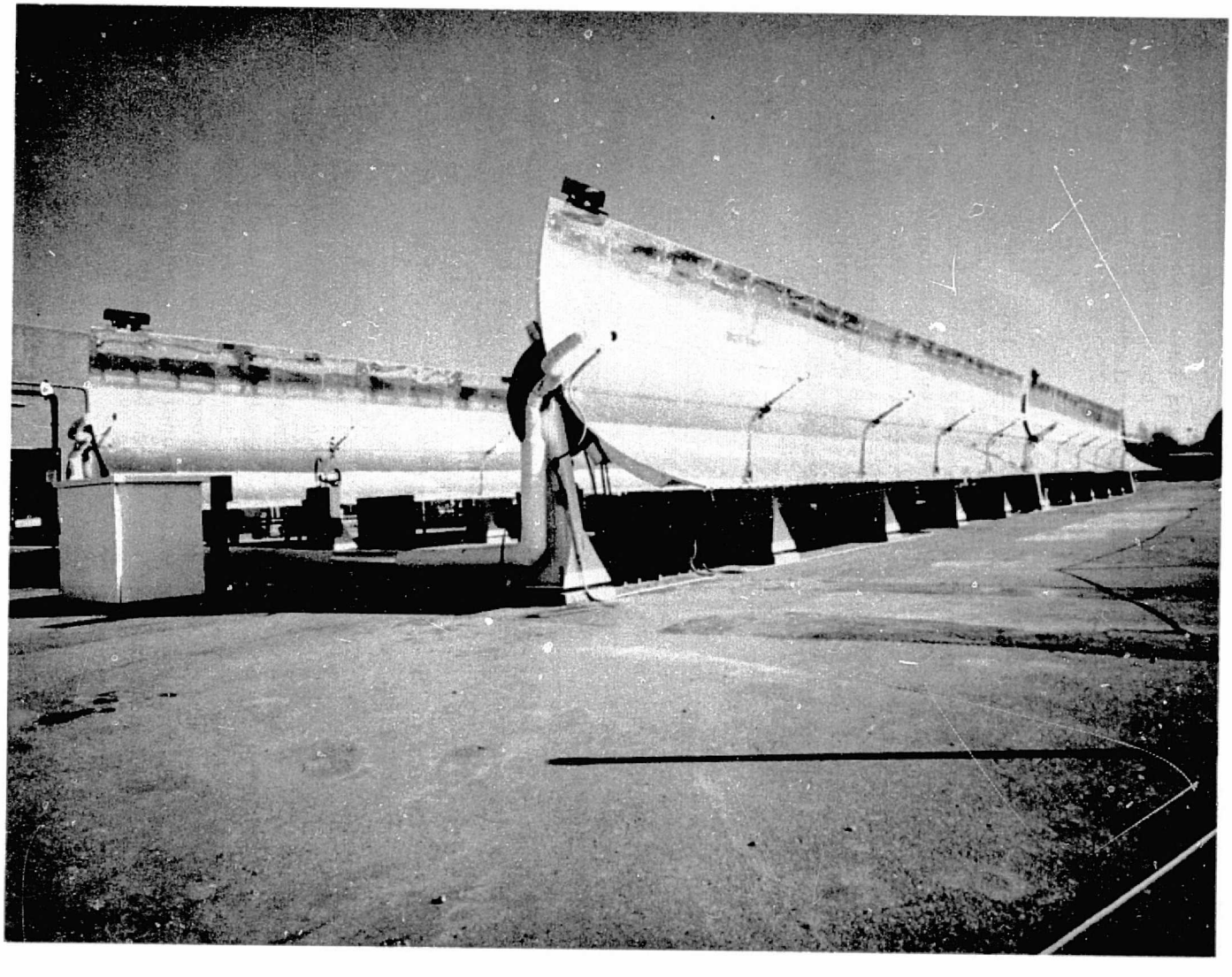


Figure 5-4. Line-Focus Distributed Receiver Concept Using Parabolic Troughs

tracking losses. Three common axis orientations are east-west, north-south, and polar (parallel to the earth's axis). The second type of collector in this generic type is the line focus distributed receiver using moveable segmented mirrors. This system is shown in Figure 5-5. In this system, rows of mirrors independently track the sun to focus energy onto the linear receiver. Both systems have concentration ratios between 30 and 40. The parabolic trough and the moveable segmented mirrors are designed for optimum operating temperatures of approximately 315°C (600°F).

4) Line-Focus Central Receiver System. The line focus central receiver (LFCR) system is similar to the PFCR concept in that heliostats are used to reflect solar energy onto an elevated receiver. In this case, however, the receiver is linear and is supported on a series of towers as shown in Figure 5-6. The receiver cavities extend along the east-west axis of the heliostat field, with the heliostat field flared at the ends to enhance early morning and late afternoon reception. Steam design operating temperature and pressure of the linear focus central receiver are 495°C (925°F) and 7 x 10^3 kPa (1,000 psi) respectively.

5) Fixed Mirror Distributed-Focus Dish Systems. The fixed mirror distributed focus (FMDF) dish is a concept in which the concentrator remains stationary and the receiver tracks the focused solar energy. A drawing of this system is shown in Figure 5-7. The large, fixed aperture, hemispherical dish is not as optically efficient as a tracking paraboloidal dish. The hemispherical dish concentrates reflected energy along the focal axis and requires a cylindrical receiver. The distributed focus hemispherical dish can have concentration ratios of between 200 and 300, depending on the orientation of the focal axis, which varies as a function of declination and time of day. A steam temperature of 570°C (950°F) and pressure of 6 MPa (850 psi) are projected for the fixed hemispherical dish.

6) Fixed Mirror Line-Focus Systems. The fixed mirror line focus (FMLF) concept uses a system that fixes the aperture of the concentrator, and the receiver tracks the focused solar energy about one axis as shown in Figure 5-8. As such, it is similar to the line focus distributed receiver except that the receiver tracks about one axis. This concept can be designed for optimum operating temperatures as high as 315°C (600°F). Concentration ratios can be as high as 40.

7) Low Concentration Non-tracking Systems. This generic type includes nontracking concentrators such as the Compound Parabolic Concentrator (CPC) and V-trough. These concepts employ a variety of receiver designs to absorb solar heat and transfer the heat to a secondary fluid. Optimum operating temperature is approximately 225°C (437°F) with a concentration ratio of five. A CPC distributed collector module is shown in Figure 5-9.

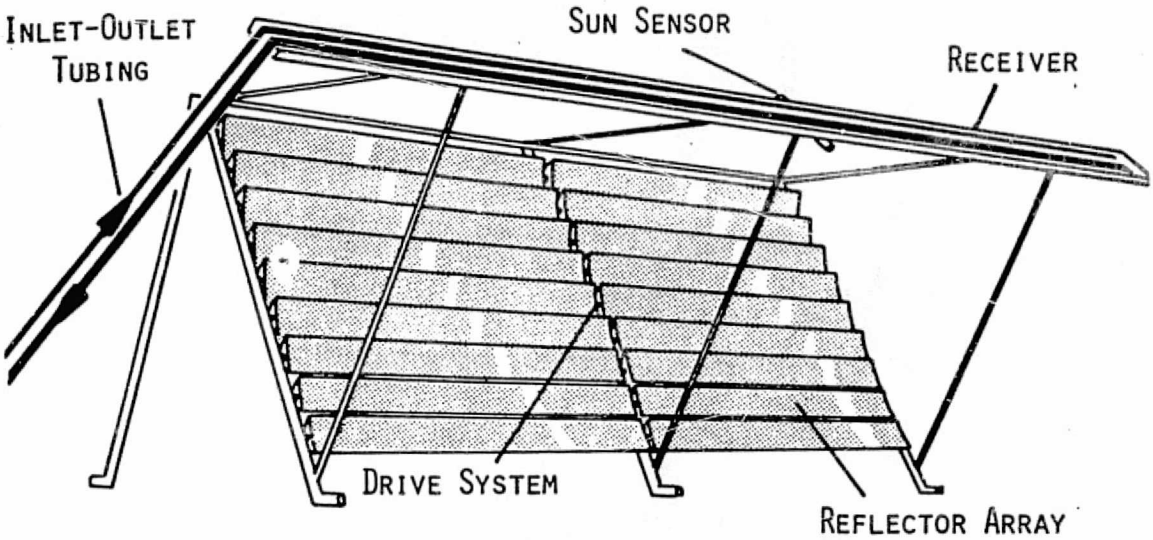


Figure 5-5. Line Focus Distributed Receiver Concept Using Moveable Segmented Mirrors.

b. Methodology. The methodology for ranking the selected design concepts is discussed in detail in Section IV D4. In support of the ranking activity, relative plant performance and costs are required. Plant performance is determined according to the behavior of the various subsystems and and their interactions under varying insolation and meteorological conditions. The sizes of the different components will be used to determine plant capital and operational costs. Once performance and plant costs are evaluated, the energy costs can be determined.

At this point, very little actual performance and cost data are available. It is necessary, therefore, to formulate cost/performance values based on experience with similar types of equipment in similar applications. In some cases, no prior experience is available. Estimates then must be based on theoretical predictions and engineering judgment. Nonetheless, if consistency is maintained among performance and cost assumptions for the seven generic types of solar plants, the relative position of the concepts should remain valid. Thus, while these studies will not necessarily provide the absolute levelized busbar energy costs (BBEC) for each plant, the relative position on a scale of BBEC will result.

c. Simulation Model Description. The performance of systems from each of the seven generic system categories was evaluated by means of a computer simulation model in order to perform the analysis in a

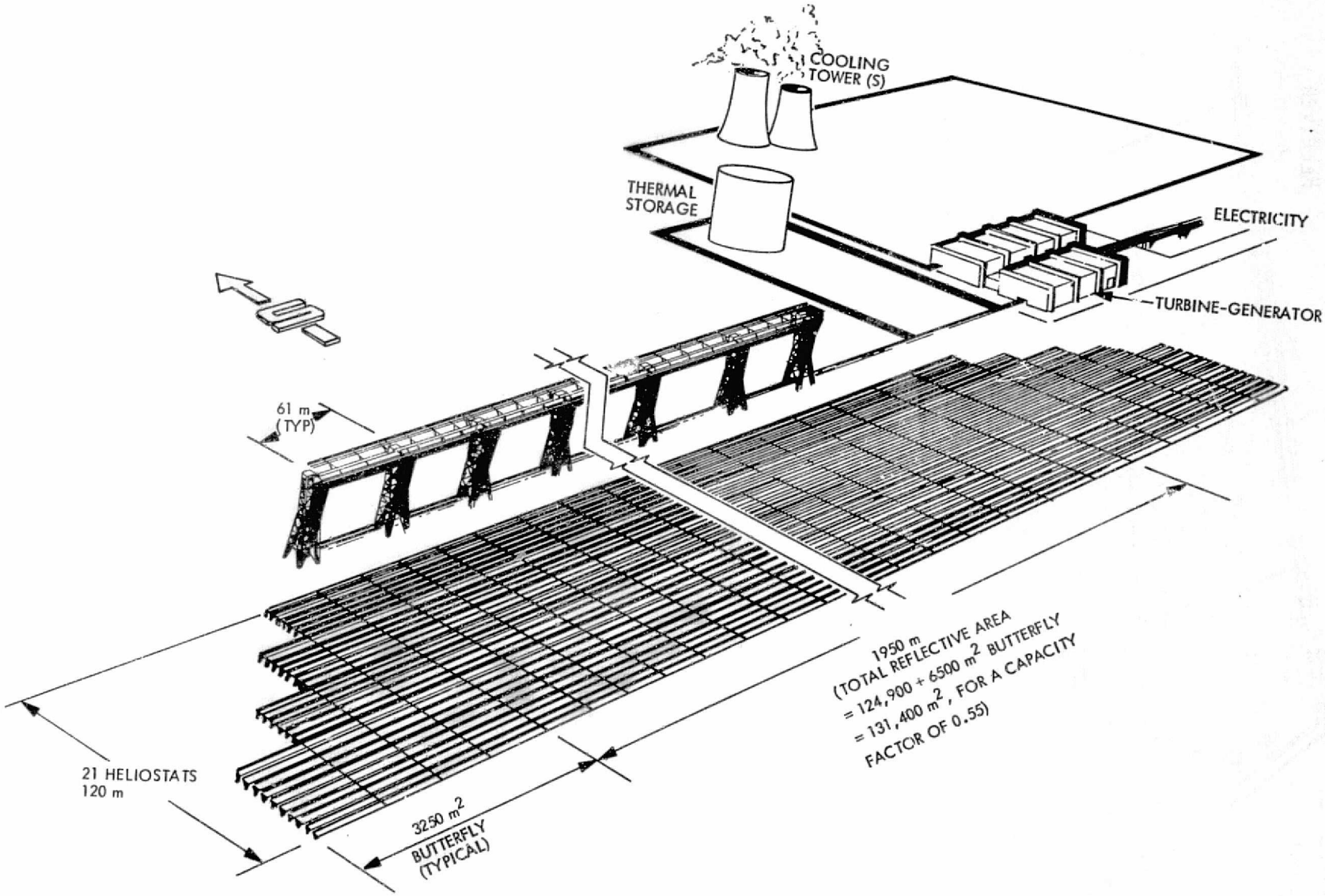


Figure 5-6. Line-Focus Central Receiver Concept (Adapted from Ref. 5-2)

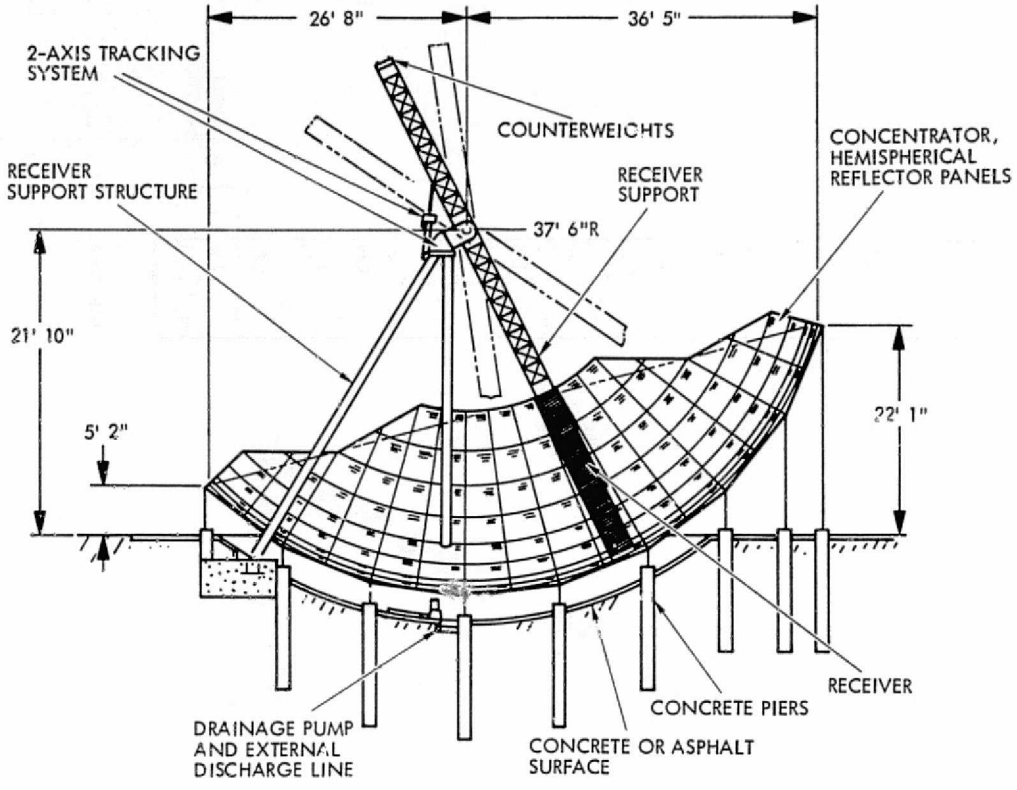


Figure 5-7. Fixed Mirror Distributed-Focus Concept

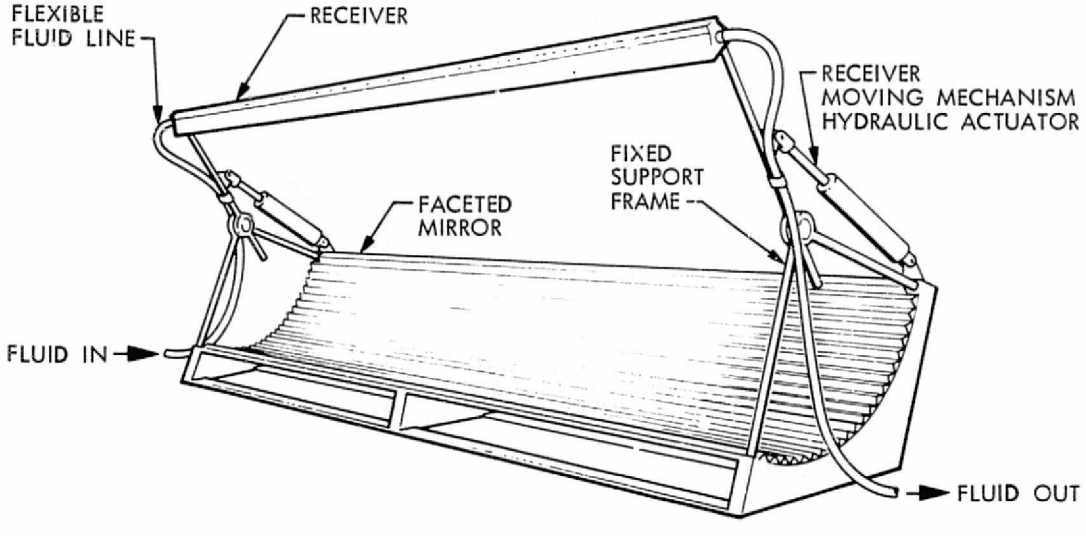


Figure 5-8. Line-Focus Distributed Receiver Concept Using Fixed Mirrors and Moveable Receivers

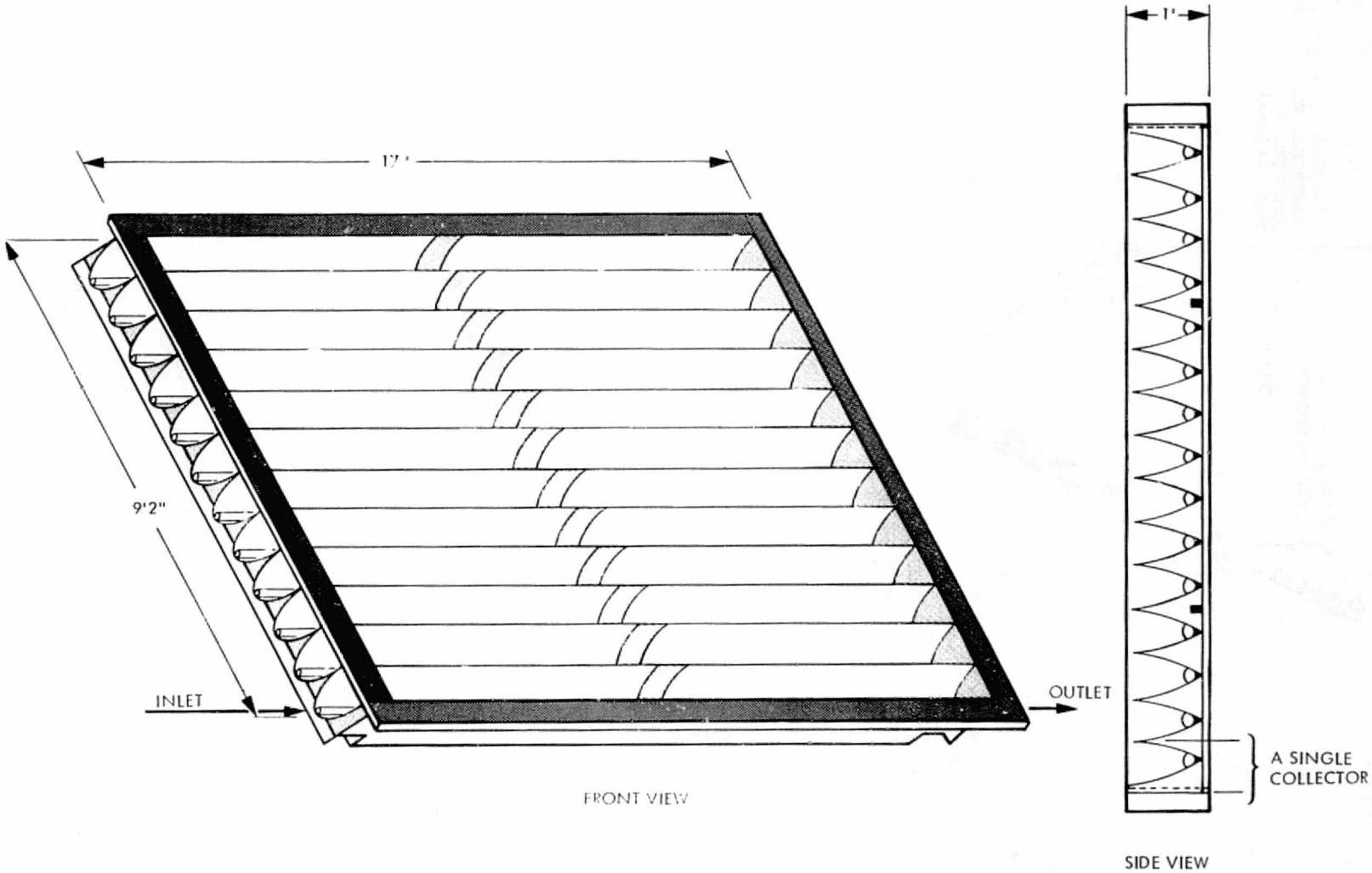


Figure 5-9. Low Concentration Non-Tracking Concept (CPC)

consistent and comprehensive fashion. The simulation model, known as the Solar Energy Simulation (SES), consists of three major programs: the FIELD program evaluates collector field performance for specific insolation and meteorological conditions; the POWER program determines performance of the fixed-rated power plant under specified conditions for various collector and storage sizes; and the ECONOMICS program evaluates the minimum energy cost for the plant. This model, through a supervisor program, transmits data between the performance and economics codes, and automatically optimizes the system.

The complete simulation of a solar power plant is accomplished by consecutive application of the three main programs, which are linked to operate as one. Even though each one can be executed independently, the second and third programs (POWER and ECONOMICS) require inputs that ordinarily are transferred from the first and second programs, respectively. Thus, POWER requires input from FIELD, and ECONOMICS requires data from POWER. In the following discussion of the three major programs, Figure 5-10 illustrates operation of the SES model.

1) Field. In order to calculate solar collector field performance, the FIELD program requires input of insolation and meteorological data pertinent to a specific geographical location. The input generally is provided to the FIELD program in the form of data tapes. There are several other parameters that relate either to collector field characteristics or to the use of weather data that are supplied by the user in what is known as "NAMELIST" inputs. Also, several user generated subroutines and functions are required. The characterizing features of collector field performance, determined by FIELD, are contained in various modular subroutines and functions. They define the performance of the collector field subsystems and components. These subroutines and functions can be defined in various ways: by mathematical formula, by constants, or by tabular form, depending on the degree of sophistication required.

2) Power. When linked to operate in sequence, most of the FIELD program output is used as input to the POWER program. Time, solar insolation, ambient temperature, net energy output, and efficiency of the collector field are transferred from FIELD to POWER. Additionally, inputs are generated by the user in the NAMELIST form and several user-supplied functions also are required.

The POWER program is divided into two main parts. One section evaluates power plant configurations that have one fixed-rate power output and parametrically varied collector field and storage sizes. The other part, largely contained in subroutine FSCONT, determines the mode of plant operation.

The NAMELIST input consists of two sets of parameters: ENGS - provides data from which the design point operating efficiency of the engine is determined. POWER - provides data describing the design and off-design characteristics of the engine, storage system and the power plant in general.

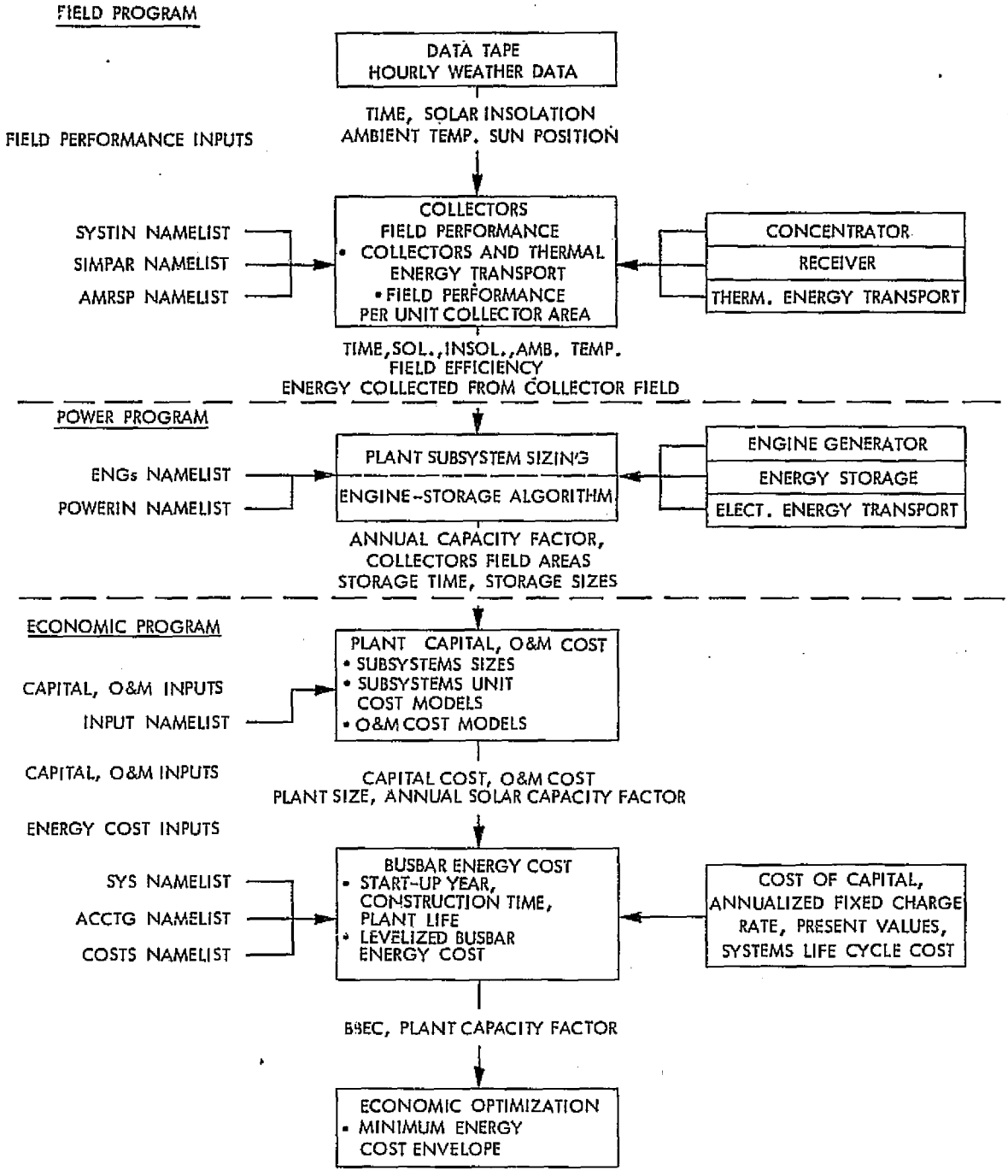


Figure 5-10. Flowchart Depicting the Operation of the SES Computer Program

3) Economics. When linked with the other two programs, much of the input required by the ECONOMICS program is provided as output from POWER. As in the case of FIELD and POWER, NAMELIST input is again required. This program performs three main functions:

(1) It determines capital and operating and maintenance costs for the power plant under study as determined by the user in POWER.

(2) It determines energy costs for the power plant.

(3) It determines an optimum energy storage size for each collector area.

Finally, given the geographic location and corresponding insolation and meteorological data, an optimum (lowest energy cost at a specific capacity factor) solar power plant of specified rated output can be selected from the program output.

4) Sample Results. Figure 5-11 illustrates a sample graphical output of the simulation model produced by the ECONOMICS program. The plot shows levelized busbar energy costs ($\overline{BBEC}$) versus capacity factor as a function of various collector field sizes and energy storage times. The program calculates the levelized busbar energy costs and capacity factor for each field size and storage time input by the user. In the example, field sizes of 40,000 to 120,000 m^2 and storage times from 0 to 14 hours were used. The program begins by calculating the $\overline{BBEC}$ for the first field size and storage time. It next increases the storage time and again calculates the $\overline{BBEC}$. This process is continued until the $\overline{BBEC}$ increases. At this point the program steps to the next field size input by the user. Again the $\overline{BBEC}$ is calculated for a zero hour storage time. Storage time is increased for the second field size until once again $\overline{BBEC}$ increases. This process is repeated for all field sizes and storage times input by the user. The envelope of the minimum $\overline{BBEC}$ costs, shown by the dotted line, represents the required field size and storage time as well as the $\overline{BBEC}$ for a given plant capacity factor. As shown in Figure 5-11, the optimal plant for a capacity factor of 0.5 would have a field size of 60,000 m^2 and a storage of time of 6 hours. The levelized busbar energy cost for this plant is 100 mills/kWe-hr.

d. Costing. A major cost element for a solar thermal power plant is the concentrator and receiver subsystem. Those systems presently under evaluation are not in a mass production mode as might be expected if the product were successfully commercialized. Therefore, it is necessary that a consistent approach be developed and used for costing the collector/receiver subsystems.

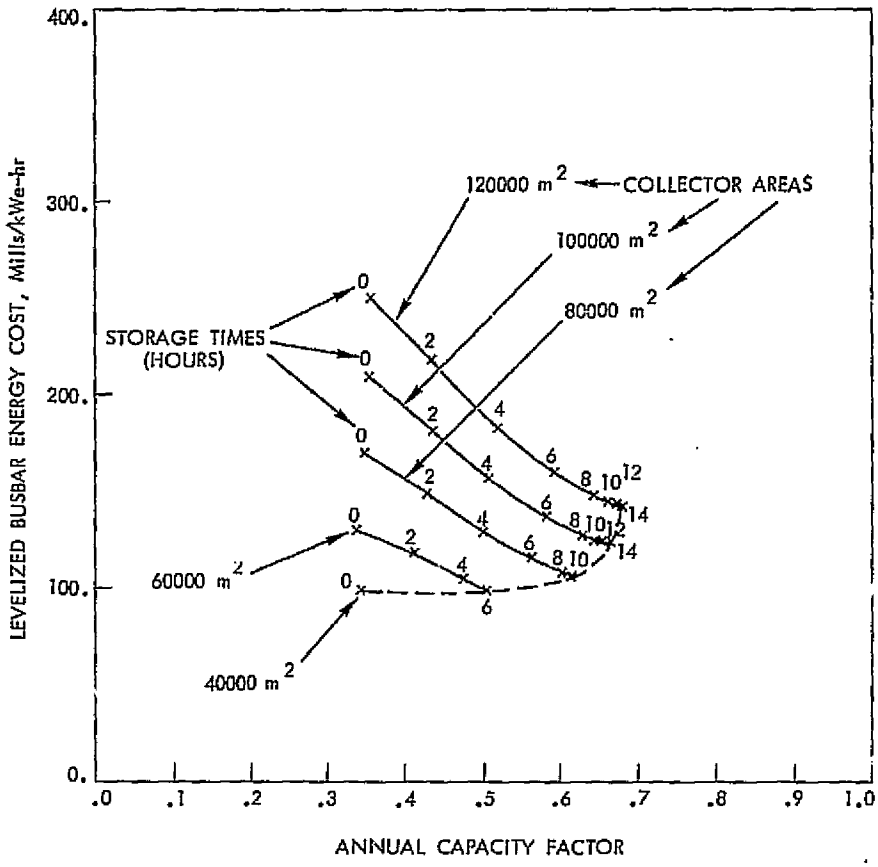


Figure 5-11. Energy Costs versus Capacity Factor for a Solar Thermal Power Plant

The approach taken by JPL for cost estimating addresses the following in detail:

(1) Preparation of parts lists for the system(s) under consideration.

(2) Manufacturing process to produce the part.

(3) Labor time required per operation for each part and/or assembly.

(4) Tooling required to produce parts, subassemblies and final assemblies.

(5) Capital equipment required to manufacture parts.

(6) Raw material costs.

During FY 78, cost analyses were executed for three different systems — namely:

(1) Low concentration nontracking compound parabolic concentrator (CPC) — Argonne National Laboratory design.

(2) Line focusing central receiver — FMC Corporation design.

(3) Line focusing fixed mirror — General Atomic Company design.

Each part, assembly and/or subassembly was reviewed and cost estimates were made by determining the raw material or purchased part cost. Detail parts were costed based on the manufacturing method selected. The manufacturing methods varied from castings, forgings, stampings, as well as machining, welding, joining, etc. Each operation was costed, based on manhour estimates to produce the part. Assembly costs were also based on manhour estimates to perform the operation. Data supplied by the aforementioned companies for their particular design were used in the cost estimates where practical. The balance of the estimates were provided by potential vendors and JPL estimates.

As an example, a cost breakdown is shown in Table 5-1 for the Compound Parabolic Concentrator (CPC). Table 5-1 shows that for the CPC system, the cost per square foot of aperture area is $13.10, of which raw material and/or purchased parts amount to 85 percent of the cost, and the labor cost is 15 percent. These costs were based on a production rate of 10,000 square meters of aperture area per year.

If it is assumed that capital equipment and tooling costs are $50,000,000.00 and that these costs are amortized over three million modules, the additional costs would be:

$16.66/module or,

$0.125/square foot of aperture area or,

$1,345/square meter of aperture area.

Similar cost analyses will be conducted on the collector systems for the other concepts under study. Not all systems will be defined in as much detail as the CPC. Nonetheless, based on prior experience in manufacturing similar components and material cost estimates indicative of actual costs it should be possible to arrive at reasonable system costs.

e. BPNL/SERI Coordination. This activity, as mentioned earlier, consists of an independent study of the potential for commercialization of several generic types of solar-thermal-electric power plants. The primary objective of the studies is to rank the generic types in order of their economic potential for small power system applications.

Table 5-1. CPC Cost Breakdown

Part	Variable Cost Per ft^2 Aperture	Raw Mat'l Cost	Mat'l Cost Per Module	Labor Cost Per Module	Mat + Labor Cost Per Module
Reflector-Parabolic 0.012 Thick Kinglux	2.17	$0.60/ft^2$	292.00	1.50	293.50
Reflector-End Panels	0.16	$0.60/ft^2$	20.40	0.80	21.20
Support-Reflector 14 Req/Module	0.18	1.00/lb	22.70	0.84	23.54
Tape/Solder	0.01	-	1.35	-	1.35
Angles (4 Req)	0.13	1.00/lb	17.68	-	17.68
Plate	1.02	1.00/lb	136.60	0.40	137.00
Support-Frame End	0.10	0.15/lb	11.88	1.30	13.18
Support-Frame Side	0.17	0.15/lb	22.03	1.30	23.33
Retainer-Glass End	0.02	1.00/lb	1.41	0.20	1.41
Retainer-Glass Side	0.02	1.00/lb	2.61	0.20	2.61
Panel Glass	1.06	$0.70/ft^2$	142.80	-	142.80
Rod-Shape Guide	0.045	$3.00/ea.	6.00	-	6.00
Shade Cover	0.70	$0.70/ft^2$	94.50	-	94.50
Real-Shade Retriever	0.045	$3.00/ea.	6.00	-	6.00
Switch-Thermal Release	0.008	$0.50/ea.	1.00	-	1.00
Beam-Frame Center	0.09	$1.00/lb	11.60	0.65	12.25
Insulation	0.01		1.00	-	1.00
Bracket-Frame Lifting End	0.041	0.25/lb	2.50	3.00	5.50
Bracket-Frame Pivot End	0.041	0.25/lb	2.50	3.00	5.50
Receiver-Assy.	3.00		405.00	-	405.00
Tube Fittings	0.27		36.25	-	36.25
Pump	Part of Transport System				
Hose-Flexible (req)	0.03	$2.50/ea.	3.75	-	3.75
Pipe	Part of Transport System				
Fitting	Part of Transport System				
Insulation	Part of Transport System				
Foundation	0.25	$50.75/ft^3$	33.00	-	33.00
Pipe, Support Foundation	0.18	$1.65/ft	23.92	-	23.92
Bracket	0.075		10.00	-	10.00
Belts/Fire/Etc.	0.045		6.00	-	6.00
Lifting-Pipe	0.28	$1.65/ft	37.62	-	37.62
Cap-Pipe	0.075		10.00	-	10.00
Bracket-Pulley	0.008		5.00	-	5.00
Pulley	0.082		11.00	-	11.00
Cable	0.15	0.50/ft	20.00	-	20.00
Bolts/Pins/Etc.	0.09		12.00	-	12.00
Drum-Cable Windup	0.06		8.00	-	8.00
Winch	0.21		27.54	-	27.54
Tube-Torque	0.21	$1.65/ft	27.54	-	27.54
Bracket	0.75		10.00	-	10.00
Handle-Winch	0.02		2.50	-	2.50
Pin-Locking	0.02		2.50	-	2.50
Collar Assy.	0.18		24.00	-	24.00
Assemble-Each Module 3 hrs at $7.00/hr	0.155		-	21.00	21.00
Assemble-Array (on Site) 3 hrs at $7.00/hr	0.155		-	21.00	21.00
Structured Support 8 hours at $15.00/hr	0.89		-	120.00	120.00
Site Preparation	0.30		-	40.50	40.50
Collector Mounting	0.30		-	40.50	40.50
TOTALS	$13.06	-	$1512.18	$256.19	$1768.37
COST/ft^2	$13.10	-	11.20	51.90	13.10
COST/m^2	$140.95		$120.51	$20.44	$140.95

Tools and Capital Equipment = $50,000,000.00 Amortize over 3×10^6 Modules = $16.66/module = $0.125/ft^2$ = $1.345/m^2$

In assisting DOE in the Technology Comparison Studies, JPL wrote the program plan, coordinated the technical meetings between the three agencies, and developed the study ground rules, so as to focus the study efforts on the critical elements of solar thermal power plants. A ranking methodology was also developed. The purpose of this effort was to develop selection criteria and attributes that provide a practical approach for evaluating and ranking the various technologies. The approach selected is based on multi-attribute decision analysis theory. For more details, see the Decision Analysis discussion later in this report (Section VI).

To assist BPNL and SERI in initiating their efforts, JPL has supplied listings of background literature in the field, current JPL reports and copies of the Barstow, CA insolation data selected by JPL for use in these studies. In addition, Systems Definition has supplied subsystem definitions, performance and cost breakdown structures (see Table 5-2) as well as an early version of the JPL Solar Energy Simulation (SES) computer code. The study ground rules were developed (see Table 5-3) and the ranking methodology iterated to mutual agreement with BPNL and SERI. Independence of the studies has been retained with each organization individually developing subsystem performance and cost data bases, and performing its own ranking analysis within the framework of the mutually agreed upon ranking methodology.

Three coordination meetings have been held to date subsequent to the initial meeting at DOE Headquarters on December 16, 1977. At these meetings, study ground rules were reviewed, ranking methodology details developed, modifications of computer codes for system simulations discussed, and system design progress compared.

2. Systems Analysis

a. Compound Parabolic Concentrator (CPC). The basic CPC design evaluated in this report has a concentration ratio of five and consists of thirty CPC collector units nested in an enclosure 9 ft wide x 17 ft long and 1 ft thick. Externally, the enclosure looks like a flat plate collector. The baseline 9 ft x 17 ft module was shown previously in Figure 5-9.

The CPC module has an evacuated receiver tube with a selectively coated absorber and a glass cover plate to prevent contaminating material from falling into the module. The optimum operating temperature of the collector is at a fluid outlet temperature of 225°C (437°F).

Table 5-2. Subsystems Definitions and Engineering Information Summary

Item	Efficiency %	Weights lb (kg)	Estimate 1978 $K Components	Estimate 1978 $K Subtotals
	x	x	x	x
Collector Subsystem			x	
1. Site Preparation/Foundation	x			x
2. Structural Framework	x			x
3. Reflector Surface and Support	x			x
4. Drive Mechanism and Local Control	x			x
5. Receiver and Support	x			x
6. Pipes, Valves, Fittings, etc.	x			x
7. Miscellaneous (Explain)	x			x
8. Field Installation	x			x
9. Field Supervision	x			x
10. Subsystem Checkout/Adjustment	x			x
Power Conversion Subsystem			x	
1. Heat Engine	x			x
2. Generator	x			x
3. Heat Exchanger/Boilers/Condensers	x			x
4. Control Valves and Local Control Elements	x			x
5. Pumps and Fans	x			x
6. Heat Rejection Equipment	x			x
7. Subsystem Buildings and Facilities	x			x
8. Switch Gear, Transformers, etc.	x			x
9. Concept Peculiar (Explain)	x			x
10. Miscellaneous (Explain)	x			x
11. Field Installation	x			x
12. Field Supervision	x			x
13. Subsystem Checkout/Adjustment	x			x
Energy Transport Subsystem		x	x	
Thermal	x	x	x	x
1. Piping	x	x		x
2. Insulation	x	x		x
3. Control Valves and Local Control Elements	x	x		x
4. Fluid Pumps and Drives	x	x		x
5. Site Preparation, Foundations, and Piping Support Elements	x	x		x
6. Miscellaneous (Explain)	x	x		x
7. Field Installation	x	x		x
8. Field Supervision	x	x		x
9. Subsystem Checkout/Adjustment	x	x		x
Electrical	x	x	x	x
1. Wiring (Material, Supports, Trenches, etc.)	x	x		x
2. Utility Interface Substation	x	x		x
3. Local Control Elements	x	x		x
4. Miscellaneous (Explain)	x	x		x
5. Field Installation	x	x		x
6. Field Supervision	x	x		x
7. Subsystem Checkout/Adjustment	x	x		x
Energy Storage Subsystem		x	x	
1. Tanks, Insulation, Storage Medium	x	x		x
2. Heat Exchangers/Boilers	x	x		x
3. Heat Transfer Fluid	x	x		x
4. Pumps, Valves, Piping, etc.	x	x		x
5. Local Control Elements	x	x		x
6. Site Preparation/Foundation	x	x		x
7. Miscellaneous (Explain)	x	x		x
8. Field Installation	x	x		x
9. Field Supervision	x	x		x
10. Subsystem Checkout/Adjustment	x	x		x
Control Subsystem		x	x	
1. Control Software	x	x		x
2. Processors/Computers	x	x		x
3. System Control Elements for Plant Operation	x	x		x
4. Subsystem Operation Control Elements	x	x		x
5. Control Lines to Subsystems and Plant Control Elements	x	x		x
6. Buildings and Facilities to House Equipment	x	x		x
7. Miscellaneous (Explain)	x	x		x
8. Field Installation	x	x		x
9. Field Supervision	x	x		x
10. Subsystem Checkout/Adjustment	x	x		x
Detail Design	x	x	x	
Plant Construction Management	x	x	x	
Special Features	x	x	x	
Related Items	x	x	x	
Other (Buildings and Other Utilities to Support System Functions, etc.)				
Testing and Evaluation	x	x	x	
Total Estimated Cost	x	x	x	

Table 5-3. Ground Rules Used for Systems Analysis

These ground rules are provided so as to limit the scope of studies in specific areas. This is being done to most effectively focus on the critical elements of the solar thermal plant concepts for a qualitative ranking of the various concepts rather than a complete series of studies considering all subsystem tradeoffs over the complete range of design parameters.

1. The nominal plant power rating to be used in conducting Task 2 of the work statement is 5 MWe. The plant power ratings to be used in the sensitivity analyses of Task 3 are 1.0 MWe and 10 MWe.

2. The plant concepts to be studied shall have the capability of delivering rated power from the collector field only to the utility grid for a direct normal insolation of 800 W/m^2 at solar noon at equinox at the reference plan location.

3. For these studies, Barstow, CA is the reference plant location (latitude 34.9°).

4. A service life capability of 30 years is assumed for all commercially available items or near-term technology items other than the collector/receiver combinations (unless a shorter life capability has already been identified for some items). This will permit the studies to focus on the technology concepts of the collector/receiver combinations and their projected life.

5. Barstow insolation data for 1976 collected by WEST Associates and analyzed by the Aerospace Corp. will be supplied by JPL at the outset of the studies.

6. Assume the power output of the plant when operating solely from the energy storage subsystem to be 0.7 of the rating of the plant for both thermal and electrical storage subsystems.

7. Assume that the electrical energy produced by the plant can be absorbed by the utility grid at all times without regard to matching the output to the load demand characteristics of the grid.

8. Use the following cost assumptions for the economic portion of the analyses to provide comparable costs for ranking purposes. (If any of the participating organizations feel strongly that one or more of these assumptions is not realistic, these assumptions should be further negotiated prior to use.)

a)	Raw Land		$5,000 per acre
b)	Cost of capital to a "typical" utility	k	0.086
c)	Rate of general inflation	g	0.060
d)	Escalation rate for capital costs	g_c	0.060
e)	Escalation rate for operating costs	g_o	0.070
f)	Escalation rate for maintenance costs	g_m	0.070
g)	Capital recovery factor (8.6%, 30 yrs)	$CRF_{k,\eta}$	0.0939
h)	Fixed charge rate, annualized	FCR	0.1565

1) Systems Description. A simplified layout of the CPC conceptual power plant is shown in Figure 5-12. Two fluid loops are employed: Therminol 66 for the collector field loop and toluene for the Rankine cycle power conversion loop. Organic fluids are used because of their relatively high cycle efficiency in comparison with steam cycles for low temperature operation. The output temperature of the collectors is set at 225°C (437°F), with a return temperature from the heat exchanger of 175°C (347°F).

As shown in Figure 5-12, the collector field modules heat the Therminol to 225°C. When the solar insolation is high, any excess heat is available to charge storage. The storage subsystem is used to supply heat to the Therminol loop when the collector field cannot because of low solar flux. The Therminol loop exchanges heat with the toluene loop in the heat exchanger shown in Figure 5-12.

In this study the effect of the heat exchanger on the engine performance was considered by correcting the engine efficiency due to temperature drops during the process of heat exchange. Details will be discussed in the chapter dealing with the Energy Conversion Subsystem.

2) Subsystems Descriptions. Subsystem performance and costs and the associated assumptions are described in this section.

a) Collector Subsystem. The 5X CPC collector which was previously defined, is assumed to operate under quasi-steady state conditions. Energy balances are calculated for hourly intervals. Thermal capacity of the collector module itself and that of the piping grid, insolation and transport fluid contained are neglected.

Physical properties of the materials and coatings used in the baseline design are tabulated in Table 5-4. The first column gives transmittance, absorptance, reflectance and other data used by Arthur D. Little Inc. (Ref. 5-1). Argonne National Laboratories built and tested a 5X CPC module having physical properties listed in the second column (Ref. 5-2). The third column lists property data used in the JPL performance evaluation. Advanced collector design parameters were used in these assumptions. No dust factor was considered. Although it is known that there will be a dust effect on the collector performance on the order of 5 to 10 percent, it was neglected so as to identify the ideal performance of a CPC.

Testing of the CPC module design up to 153°C (325°F) was conducted by ANL and the correlation of predicted versus test performance was good as shown in Figure 5-13. ANL extrapolated the test data to 225°C (437°F). Performance predictions used in this analysis are based on the properties in column 3 of Table 5-4 and are therefore somewhat better than those of Figure 5-13.

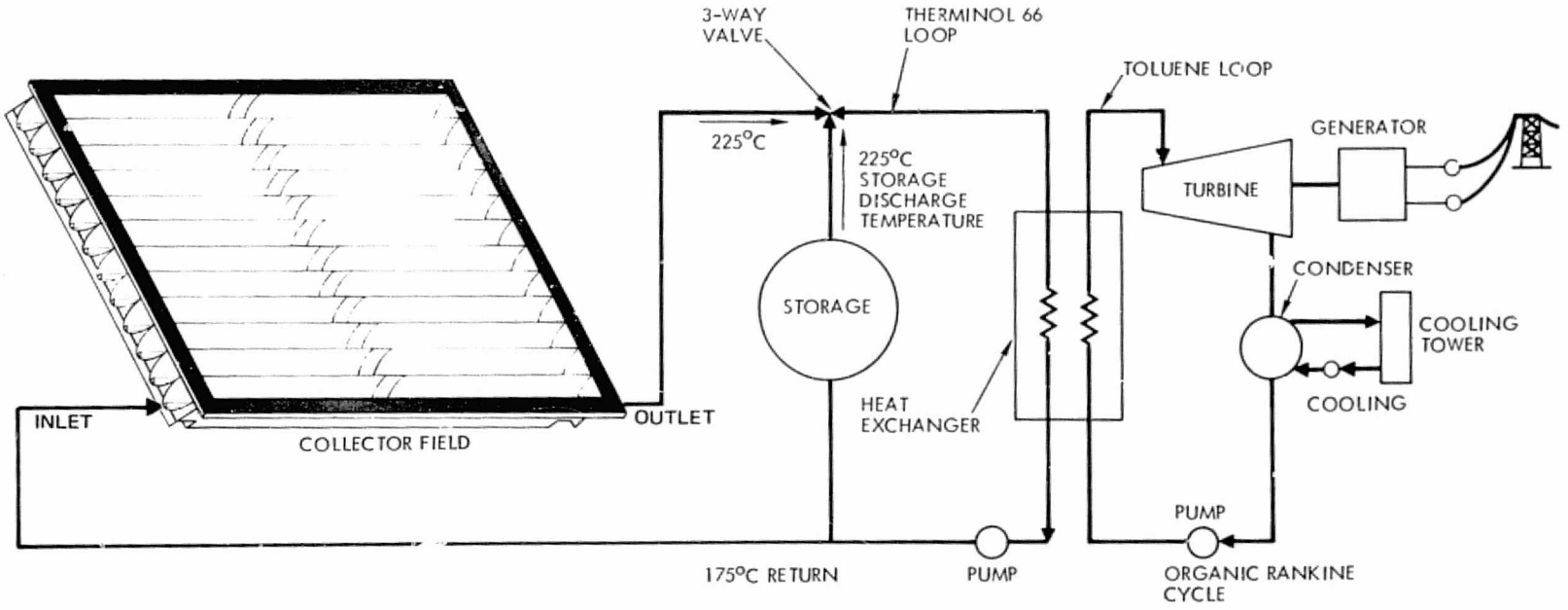


Figure 5-12. Simplified CPC Solar Power Plant Design

C-2

Table 5-4. Physical Properties of CPC 5X Design

	Units	ADL	ANL Experiment	Study Values
Transmittance of cover glass, τ_1, (anti-reflective coating)	L°	0.94	0.94	0.94
Mirror Reflectance, ρ, (total, silver)	L°	0.92	0.92	0.92
Average number of reflections, n	L°	0.9	0.9	0.9
Transmittance of vacuum tube, τ_2, (anti-reflective coating)	L°	0.92	0.92	0.92
Absorptance of absorber plate, α	L°	0.944[a]	0.92[b]	0.944
Gap loss between mirrors and absorber, η_{gap}	L°	0.975	0.975	0.975
Dust factor, d	L°	0.05	0.00	0.00
Optical efficiency, η_{opt}	L°	0.704	0.72	0.74
Emittance, ε of the absorber plate	L°	0.0665[a][c]	0.083[b][d]	0.079[e]
$\frac{d\varepsilon}{dT}$	$°C^{-1}$		1.05×10^{-4}[d]	9.9×10^{-5}
Combined conduction/convection coefficient, $U_{L(0)}$	$W \cdot m^{-2} \cdot °C^{-1}$		0.180	0.180
Temperature Coefficient of U_L, dU_L/dT.	$W \cdot m^{-2} \cdot °C^{-2}$		7.94×10^{-4}	7.94×10^{-4}

a. Per sample submitted by Optical Coatings Laboratory, Inc.
b. Black chrome
c. Does not include back losses from absorber
d. Adjusted for back losses from absorber
e. Includes the effect back losses of absorber
L° Dimensionless

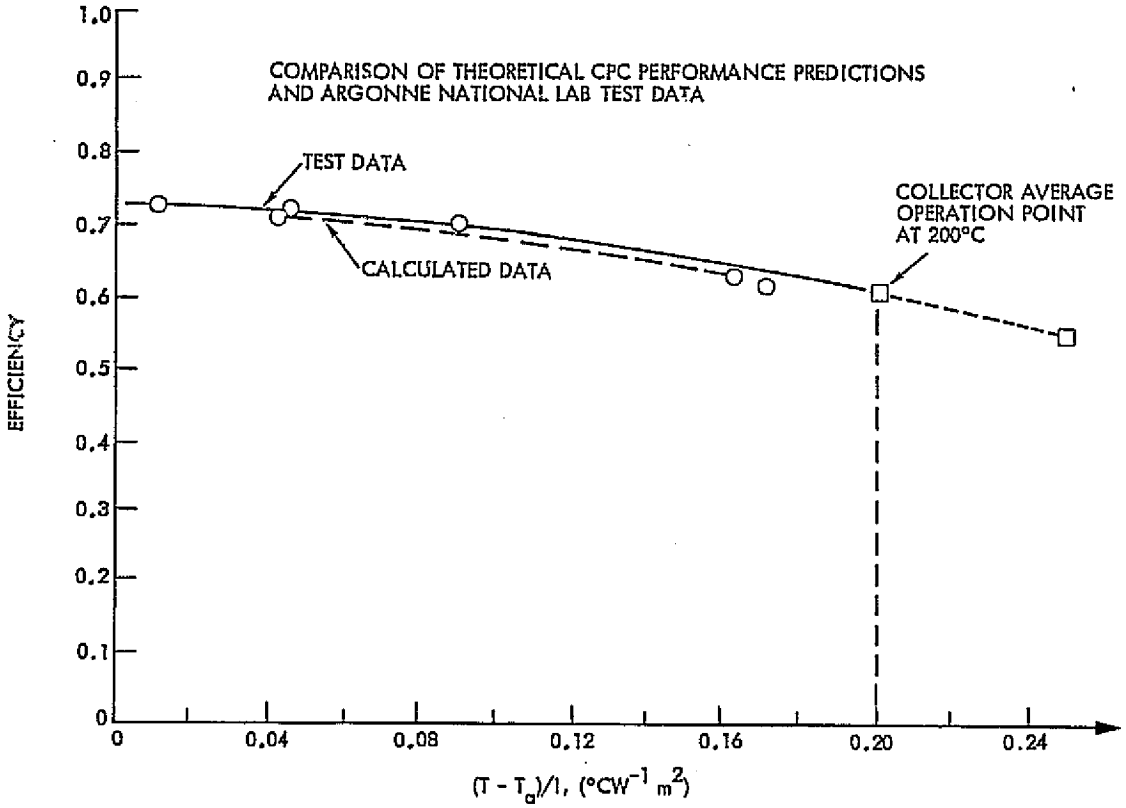


Figure 5-13. Thermal Efficiency of CPC Collector Versus $(T-T_a)/I$

The selective coating used is the one developed by OCLI (Optical Coatings Laboratories, Inc.) and represents the characteristics of the laboratory sample. There is potential for using the properties of this coating for a 30-year operation in the field.

b) Optical Efficiency. The CPC optical efficiency is defined as net useful heat collection if there were no heat losses from the collector and can be calculated from:

$$\eta_{optical} = \tau_1 \times \rho^n \times \tau_2 \times \alpha \times \eta_{gap} \times (1 - d) \qquad (1)$$

The elements of $\eta_{optical}$ are defined as follows:

τ_1 = transmissivity of the module cover plate

ρ = mirror reflectance

n = average number of reflections of incoming direct light rays

ρ^n = total reflected rays

τ_2 = transmittance of vacuum tube

α = absorptance of absorber plate

η_{gap} = correction factor for gap between reflector and absorber

d = dust factor

The values for the above parameters used in this study are tabulated in Table 5-4.

$$\eta_{optical} = 0.94 \times (0.92)^{0.90} \times 0.92 \times 0.944 \times 0.975 \times 1.00 = 0.74$$

c) Useful Heat. The retained useful heat per unit area for collector module at average working fluid temperature which is defined as: $T = (T_{in}+T_{out})/2$, can be calculated from:

$$Q_u = \eta_{opt} \times SS - \text{Thermal Losses}, \tag{2}$$

where:

$$SS = I_{beam} \times \cos(V) + I_{diffuse}/C, \tag{3}$$

and:

I_{beam} = the beam direct radiation solar flux

V = the angle between the solar beam vector and the normal to the collector plane (angle of incidence)

$I_{diffuse}$ = the diffuse solar flux $\cong I_{total} - I_{beam} \times \cos(Z)$

Z is the angle between the solar beam vector and the normal to the horizontal plane (zenith angle).

I_{total} = the total horizontal insolation (beam + diffuse)

C = the concentration ratio

The thermal losses (Q_L), as modeled in the CPC simulation, include a combined convective/conductive heat loss plus a radiation term as shown:

$$Q_L = Q_{conv/cond} + Q_{rad}$$

$$Q_L = U_L (\overline{T} - T_a) + \varepsilon\sigma (\overline{T}^4 - T_a^4)/C \tag{4}$$

where U_L is the convective/conductive heat transfer coefficient. U_L is a function of temperature as given below:

$$U_L = U_{L_{(0)}} + \frac{dU_L}{dT} \times \Delta T \qquad (5)$$

$\overline{T}$ is the absorber plate average temperature. T_a is the ambient temperature. ΔT is the absorber plate temperature minus 20°C ($\Delta T = T - 20$). It defines the temperature measured above the reference 20°C which is used to define $U_{L_{(0)}}$.

d) Computer Predictions of Annual Performance. In addition to the collector description and its physical properties shown in Table 5-4, ANL supplied JPL with a computer program capable of calculating the net useful heat per square meter of collector aperture area, and the collector efficiency with respect to the solar radiation for every hour of the day and day of the year (Ref. 5-3). The ANL code for the CPC performance evaluation was modified by JPL to read SOLMET insolation data and was run on the JPL Univac 1108 computer using an insolation data tape generated by the Aerospace Corporation, for Barstow, CA for the year 1976.

The annual useful heat and efficiency calculations obtained from the CPC code run at JPL are shown in Table 5-5 where it is noted that the yearly average collector module efficiency is 0.4. The efficiency figure of 0.4 is lower than the data shown in Figure 5-13, which is the instantaneous efficiency value at 900 W/m^2 solar flux. The reasons for this difference are: the incoming solar flux is usually less than 900 W/m^2 and not always within the acceptance angle of the collector.

3) Energy Transport Subsystem Performance and Costs. In the studies of the collector field designs, an analysis was made of the thermal energy transport system pressure drops, thermal losses and their impact on costs. The basis of the study is the Thermal Energy Transport Subsystem computer program, developed by JPL (Ref. 5-4). This program can be used for any distributed collector field to determine:

(1) Pressure drop for the optimum pipe size

(2) Thermal losses for the optimum insulation thickness

(3) Optimum cost of the transport system in \$/kW$_{th}$ based on optimum pipe size and insulation thickness.

Table 5-5. CPC Collector Field Size Calculations for a 5 MWe Plant

Solar Input	2850 kWh_{th}/m^2 year(1)
Yearly Useful Heat of a Collector Module	1130 kWh_{th}/m^2 year at 200°C(1) Average
Yearly Average Efficiency	1130/2850 = 0.398
Yearly Operation Period	2700 hours
Yearly Average Rating	1130/2700 = 0.418 kW_{th}/m^2
Predicted Transport Efficiency*	η_{TR} = 0.90
Net Heat at Turbine	Q = 0.418 x 0.90 = 0.376 $kWth/m^2$
Net Electricity Generation at η_{engine} = 0.20	P = 0.0752 kWe/m^2
Collector Area Required for 5 MWe	5000/0.0752 = 66,500 m^2
Number of Modules Required at 135 ft^2 (12.55 m^2) each)	= 5298
Field Array Size	72 x 74 72 rows, each row has 74 modules

(1) Based on the computer code supplied by ANL and 1976 Barstow, California insolation data.

Collector inlet/outlet temperatures are 175/225°C, respectively.

η_{coll} is defined at 200°C average temperature

*Consists of 4.6 percent thermal and pumping losses for the piping grid and 5.4 percent pumping losses internal to the collector module totaling to 10 percent energy transport loss.

Carbon steel piping and calcium silicate insulation were assumed for the energy transport subsystem materials for the CPC system. Transport fluid (Therminol 66) feeder/return temperatures are 232°C (450°F) and 176°C (350°F) respectively.

Cost data for the pipe material (plus erection costs) were obtained from Ref. 5-6. The installed costs of the insulation was estimated at $15/ft^3 from the insulation cost tables included in Ref. 5-6. These data were collected from industry in late 1973. Estimates of 1978 costs are currently being collected by JPL, but were not complete enough to be used for this evaluation. The 1978 costs appear to be substantially higher than the 1973 costs. Figure 5-14 shows the 1973 pipe costs for the basic material and for the installed cost per lineal foot.

Baseline collector modules which measure 9 ft x 17 ft and have a net collection area of 135 ft^2 (12.55 m^2) are laid out in rows 20 ft apart to minimize shadowing of collectors to each other. Several configurations were evaluated to find the layout which yields the lowest energy transport cost during the life span of the solar thermal power plant.

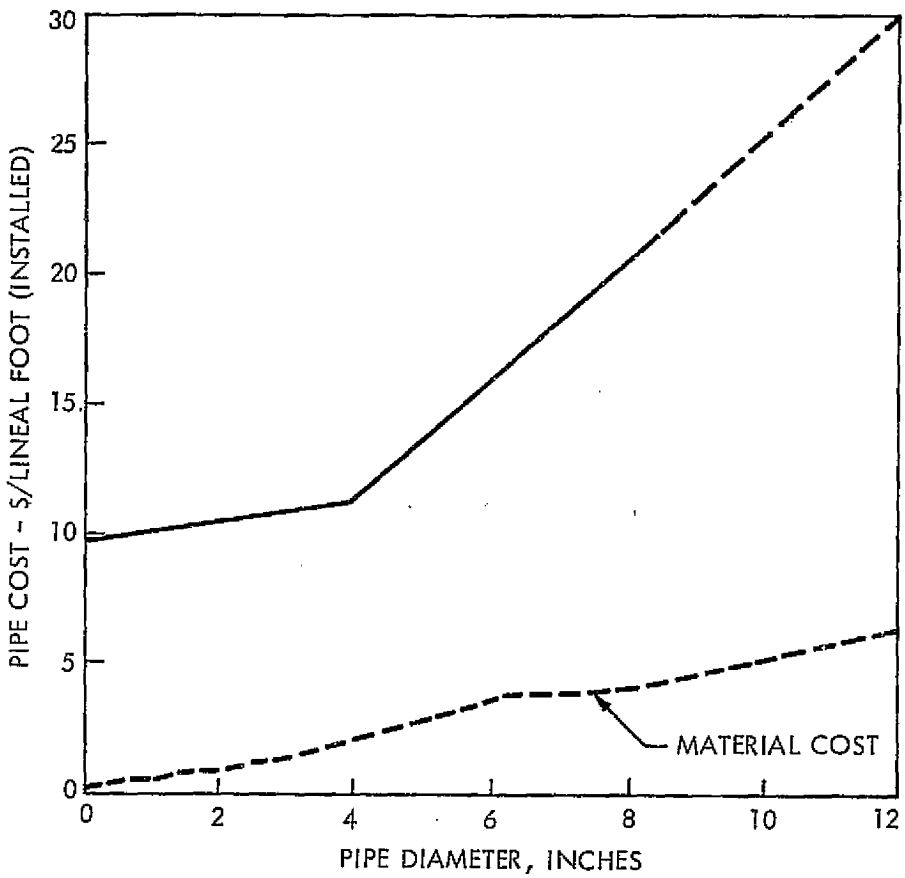


Figure 5-14. Pipe Cost Breakdown

Parallel arrangements offer half of the pressure drop inside the collector module observed for series arrangement. This however increases external piping requirements and the energy loss due to the transport grid is larger. The series configuration shown in Figure 5-15 wa. selected. This configuration was suggested originally by ADL and agreed upon by ANL and JPL.

a) Energy Transport Loss Within CPC Modules. The energy transport loss due to pressure within two 9 x 17 ft collector modules in series, where $\dot{m}$ = 0.123 kg s^{-1} (0.270 lbm s^{-1}) and total tube length in two modules being 295 m (970 ft) was considered only, since thermal losses were considered in collector performance.

The pressure drop, ΔP, can be determined by means of the equation

$$\Delta P = 4f \frac{\rho V^2}{2g_c} \frac{x}{D}$$

where,

f = fanning friction factor

x = pipe length

C = tubing inside diameter

g_c = gravitational constant

P = fluid density

V = $m/\rho A$ fluid velocity

Table 5-6 gives results of pressure drop calculations and pumping power requirements for two modules in series for both 1/2-inch and 1/4-inch tubing.

At nominal design point (200°C) the pressure drop per pair of modules having (1/2 inch OD) copper tubes inside 1-1/2 inch OD pyrex evacuated tubes is at an acceptable level, i.e., 0.103 kW. For start-up temperatures (10°C) the viscosity of the Therminol 66 results in very high pumping power requirements (3.18 kWe) per module. For the operating temperature the total plant requires a pump with an average rating of

$$\left(0.103 \times \frac{N}{2}\right) = 0.103 \times \frac{5180}{2} = 267 \text{ kWe}$$

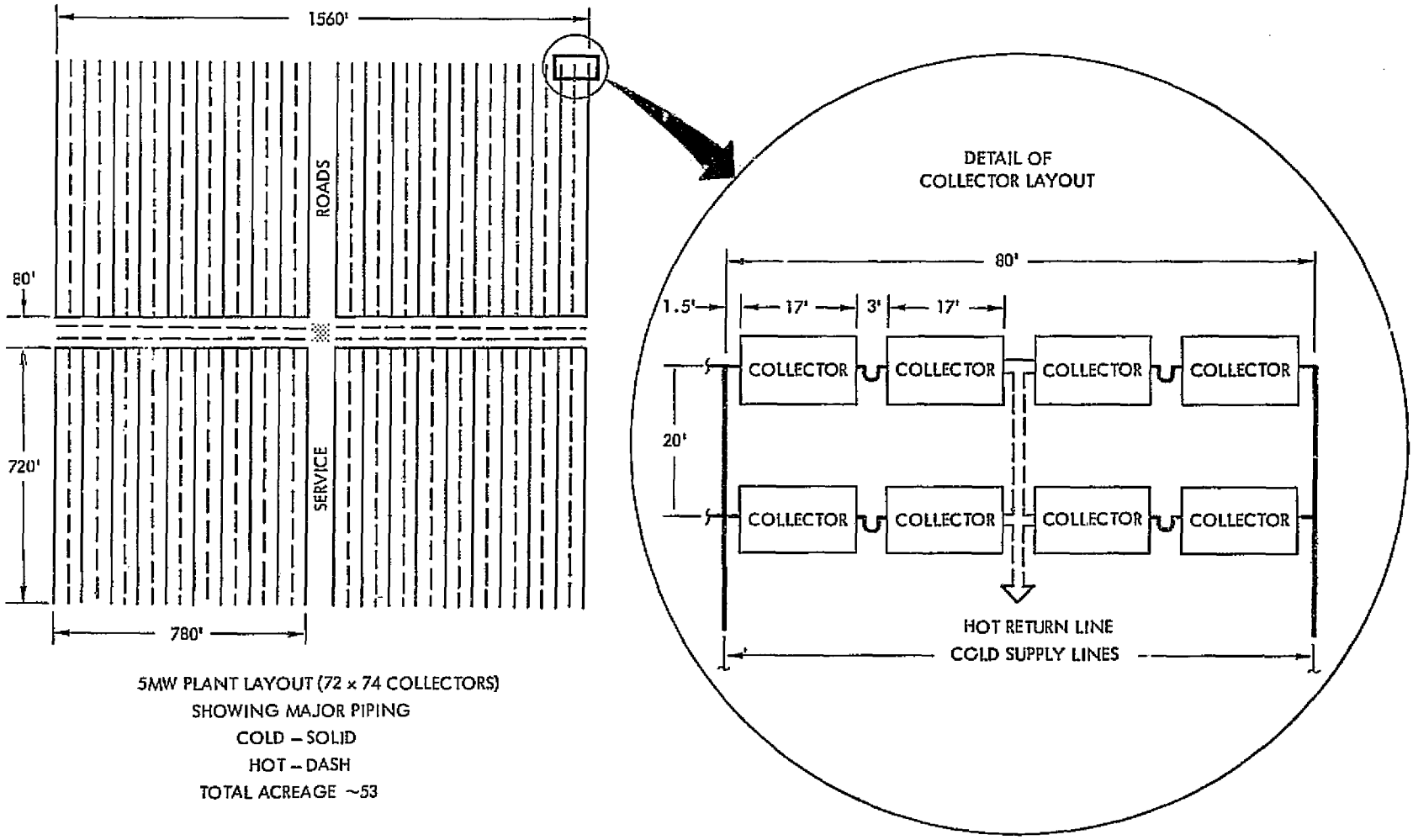


Figure 5-15. CPC Power Plant Field Layout

Table 5-6. Collector Module Pressure Drop/Pumping Power Requirements for Two Modules in Series

Temp (AVG) °C (°F)	Density ρ kg . m^{-3} (lbm . ft^{-3})	Viscosity M Pa s (lbm · h)	Reynolds Number, Re	Friction Factor f	Press Drop, ΔP kPa (psi)	Theo. Pump Power, kWe (HP)	η_{pump} = 0.75, Pump Power kWe (HP)	Tube Size (inches)
10(50)	1020 (63.6)	0.255 (617)	53.6	0.299	2.16×10^4 (3.14×10^3)	2.39 (3.49)	3.18 (4.65)	0.5
			107.3	0.149	3.44×10^5 (4.99×10^4)	38.0 (55.5)	50.7 (74.0)	0.25
100(212)	945 (59.0)	3.8×10^{-3} (9.1)	3.63×10^4	1.02×10^{-2}	7.93×10^2	0.094 (0.138)	0.126 (0.184)	0.5
			7.27×10^3	8.56×10^{-3}	2.13×10^4 (3.09×10^3)	2.52 (3.7)	3.37 (4.93)	0.25
200 (392)	863 (53.9)	8.3×10^{-4} (2.0)	1.65×10^4	6.97×10^{-3}	595×10^2 (86.3)	0.077 90.113)	0.103 (0.151)	0.5
			3.31×10^4	5.86×10^{-3}	1.60×10^4 (2.32×10^3)	2.08 93.04)	2.77 (4.05)	0.25

where

N = Number of modules.

This corresponds to a pumping loss of 267/5000 = 5.4 percent.

The piping grid configuration and 1/2 inch tube design selected has several problems which should be mentioned.

(1) Fitting two each 1/2 OD copper tubes into 1-1/2 inch OD pyrex tubes and attaching glass to metal seals may be a problem.

(2) Start up power requirements are excessive at 10°C: (3.18 x 10600/2) = 16854 kW for 1/2 inch tubes.

This will require preheating the working fluid prior to pumping as well as starting up at very low flow rates. Pressure drop through the module pair is also prohibitive at a level of 3140 psi for cold lines.

(3) Flow control among modules at different rows and lines will be a problem. Some modules may have reduced/or increased flow rates, flow may be reversed if pressures are not balanced.

b) Thermal and Economic Analysis of the Piping Grid. Various piping transport grids were studied to evaluate the pressure drop, thermal loss, and system cost associated with 1, 5, and 10 MWe rated plants of various field sizes.

The optimum configuration for a field was determined by executing a computer program which varied the pipe size, insulation thickness, and assumed plant cost. A typical result for an optimized 5 MWe 65,000 m^2 field is shown in Figure 5-16.

The results of these studies showed that over a collector field area ranging from 1600 m^2 to 180,000 m^2 the transport cost in $\$/m^2$ varied only 13.6 percent, the heat loss in kW/m^2 varied 30 percent, and the efficiency of the transport system piping grid changed from 96 to 95.3 percent for piping grid losses. If the module internal losses at 5.4 percent are added, the transport efficiency ranges from 91.2 percent to 89.9 percent.

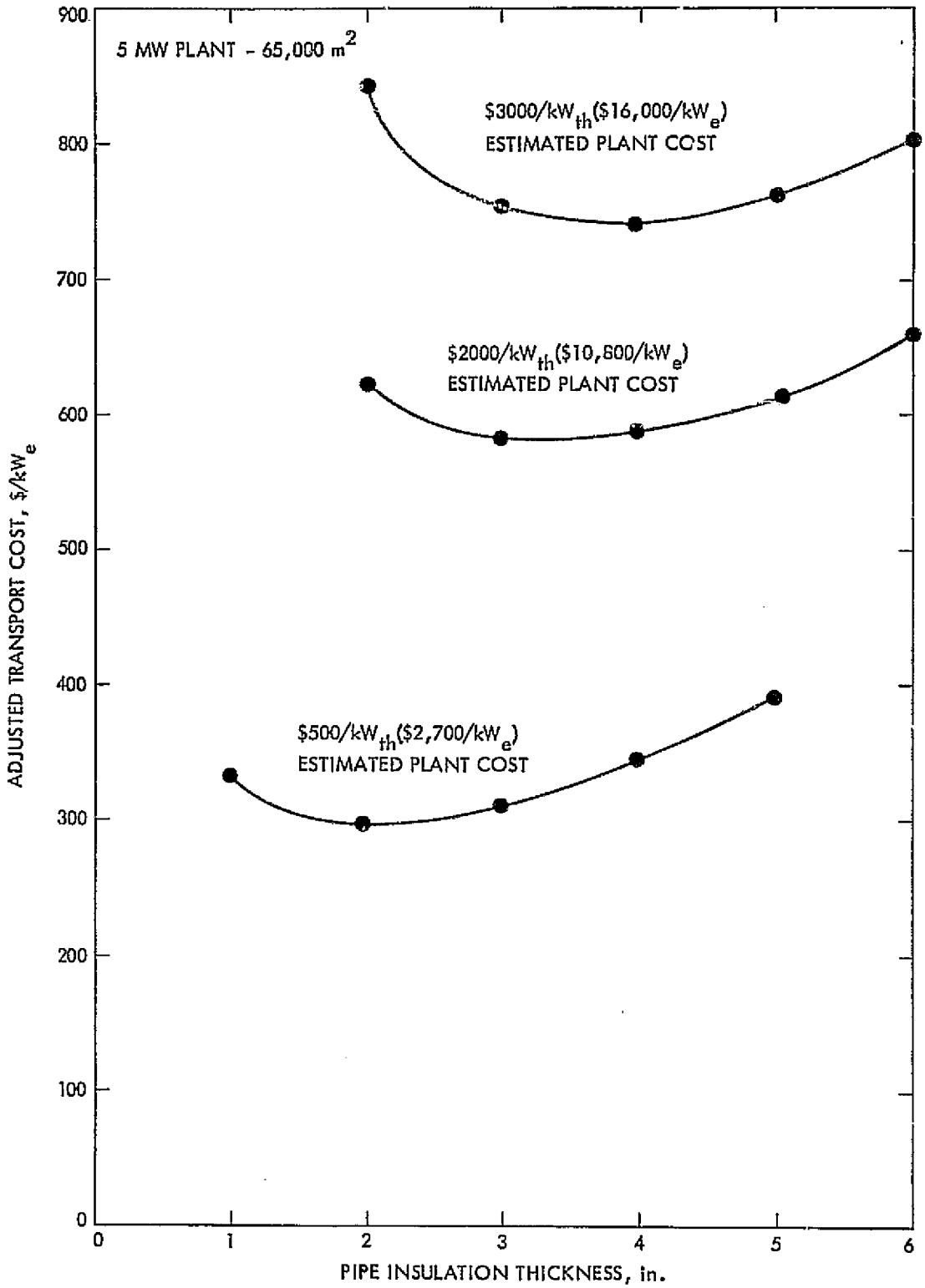


Figure 5-16. Thermal Energy Transport System (Piping Grid Only) Adjusted Energy Cost (in $/kWth) versus Insulation Thickness

4) Energy Conversion Subsystem Performance and Costs. For low concentration ratio collector fields developing outlet temperatures on the order of 450°F, an energy conversion subsystem utilizing an organic working fluid in a Rankine cycle offers higher conversion efficiencies than steam in a similar cycle. Therefore, for this evaluation, a turbine-generator combination using toluene as the working fluid was selected. Performance data were obtained from Refs. 5-6 and 5-7, and from personal communications with Sandia and Sundstrand personnel.

Turbine-generator combined efficiency as a function of size was based on the scale effect experienced with steam turbines and summarized in Table 5-7.

Conversion efficiencies listed in the second column of Table 5-7 refers to 225°C with no heat exchanger. Adjusted values for the ΔT during the transfer of heat in the heat exchanger are tabulated in the third column. $\Delta T = 15°C$ is assumed for the example and Rankine efficiency in the second column is multiplied by the ratio of Carnot efficiencies at 210° and 225°C.

Cost information was obtained from Refs. 5-8 and 5-9. Cost assumed for energy conversion for a 5 MWe plant is:

$$C = 367 \ \$/kWe$$

5) Energy Storage Subsystem Performance and Costs. In this study, the storage throughput efficiency is assumed to be 0.85 and the temperature level from storage is assumed to be the same as collector outlet at 225°C. The cost for thermal storage is assumed to be approximately $\$15/kW_{th}$-hr. The storage costs are comparable to those used in Ref. 5-10.

Table 5-7. Organic Rankine Energy Conversion Efficiency as a Function of Size

MWe Output	Conversion Efficiency Percent (No Heat Exchanger)	Adjusted for ΔT in Heat Exchanger
0.1	15 ± 3	14.5 ±2.3
1	18 ± 3.6	17.0 ±3.4
10	21 ± 4.2	20.0 ±4.0
100	24 ± 4.8	23.0 ±4.6

Sensible heat thermal storage was selected for this study based on the assessment of thermal storage systems in Ref. 5-10. Thermal storage interposed between the collector field and energy conversion system absorbs insolation variations and thereby allows a more uniform level of energy input to the conversion system. In addition, thermal storage is required to increase the time duration that energy is available from the solar plant. By providing collector fields larger than that required to meet the plants rated output, excess energy is provided to increase the plant's capacity factor.

6) Results of Analyses. Subsystem performance is shown in Table 5-8. The capital cost of a 5 MWe CPC solar plant, based on 1975 constant dollar values, for the year 1985 startup at a capacity factor of 0.55, is shown in Table 5-9.

The cost of service to the consumer as a function of plant size and capacity factor is shown in Figure 5-17. Figure 5-18 shows the variation of BBEC as a function of collector cost for capacity factors 0.55.

Table 5-8. Energy Transport Subsystem Performance Summary for Various Ratings and Field Sizes

		Collector Area, m^2		
	Units	1,600 m^2	65,000 m^2	136,000 m^2
Normal Rating	MWe	0.1	5	10
*Q_T	kWth	1,040	42,250	88,400
$\eta_{Transport}$		0.912	0.897	0.89
Q_{TNET}	kWth	948	37,898	79,471
Engine Efficiency		0.145	0.185	0.20
Maximum Output**	kWe	137	7,011	15,894

*The transport system is sized for the heat transport at maximum output. Performance is based on an insolation level of 1000 W/m^2 and collector efficiency of 65 percent.
**Since the engine will be loaded up to 120 percent of the rating during peak periods, the excess heat will be stored in the thermal storage or wasted for those systems with no storage.

Table 5-9. Five Megawatt Plant at 0.55 Capacity Factor

Subsystem	Collector cost $70/m^2 Cost x 10^6	Percent of Total	Collector Cost $140/m^2 Cost x 10^6	Percent of Total
Collector	14.3	54	28.6	69.9
Transport	3.5	13.3	3.5	8.5
Engine	2.8	10.7	2.8	6.9
Storage	5.0	18.7	6	13.3
Land	0.4	1.5	0.4	0.9
O&M	0.4	1.5	0.4	0.9
Total Energy Cost	212 mills/kWhr		305 mills/kWhr	

b. Line Focus Central Receiver. Solar energy can be focused into a line for conversion of photon energy into molecular (i.e., thermal) energy. There are two basic design concepts for implementing line focusing systems. One design approach is for each line focusing heliostat to have its own receiver; the other approach employs many heliostats, which focus the solar flux onto a single line receiver. This latter is known as a line focus, central receiver solar collector.

1) Systems Description. An example of a line focus, central receiver solar collector is the design developed by the FMC Corporation, Santa Clara, CA (see Ref. 5-11 to 5-15). The FMC concept consists of long, single-axis-tracking heliostats which reflect the solar flux into a cavity-type linear receiver (see Figures 5-6, 5-19, 5-20). In addition to an elevation axis tracking mechanism, the heliostats use a mechanism to flex the reflective surface and thereby change the focal length of the mirrored surface (see Figure 5-19). This is necessary since the illumination is generally off-axis and consequently off-axis astigmatism is introduced. With an adjustable radius of curvature, a line focus can be maintained for off-axis illumination. The length of a heliostat/receiver section is 61m (200 ft), the width is 3.05m (10 ft), and the tracking axis is oriented east-west. The preferred (i.e., more efficient) location of the heliostat field is on the north side only of the receiver.

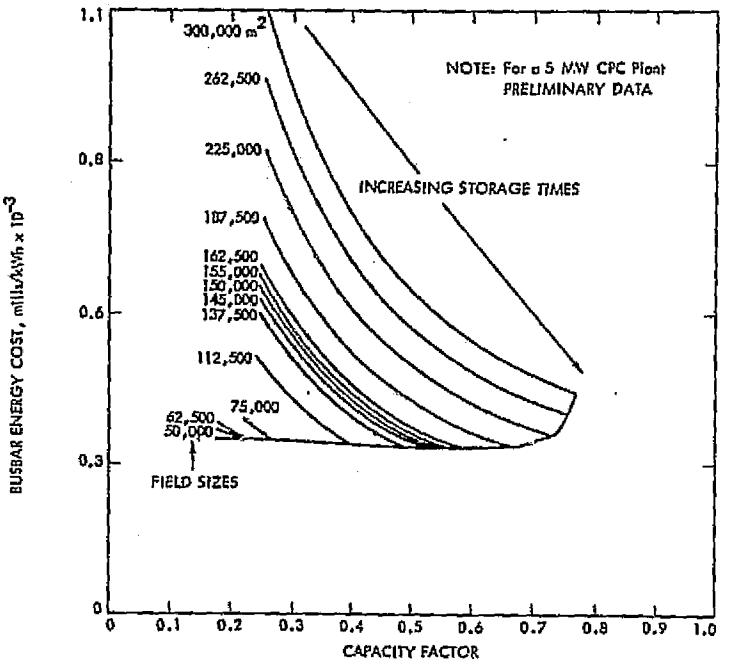


Figure 5-17. Effect of Collector Field Size and Plant Capacity Factor on Busbar Energy Cost for a CPC System

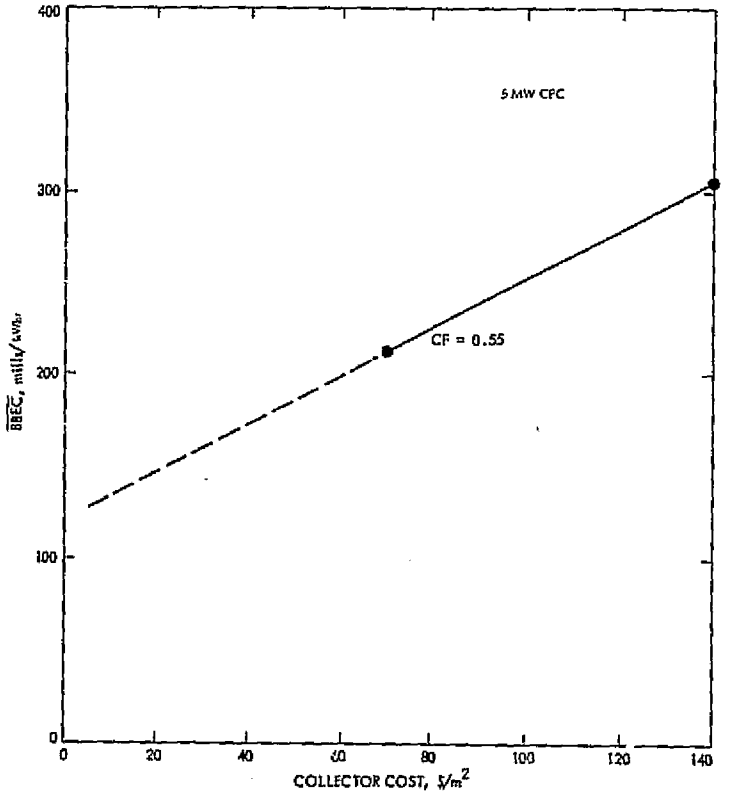


Figure 5-18. Busbar Energy Costs vs Collector Costs for a 5 MW CPC Plant

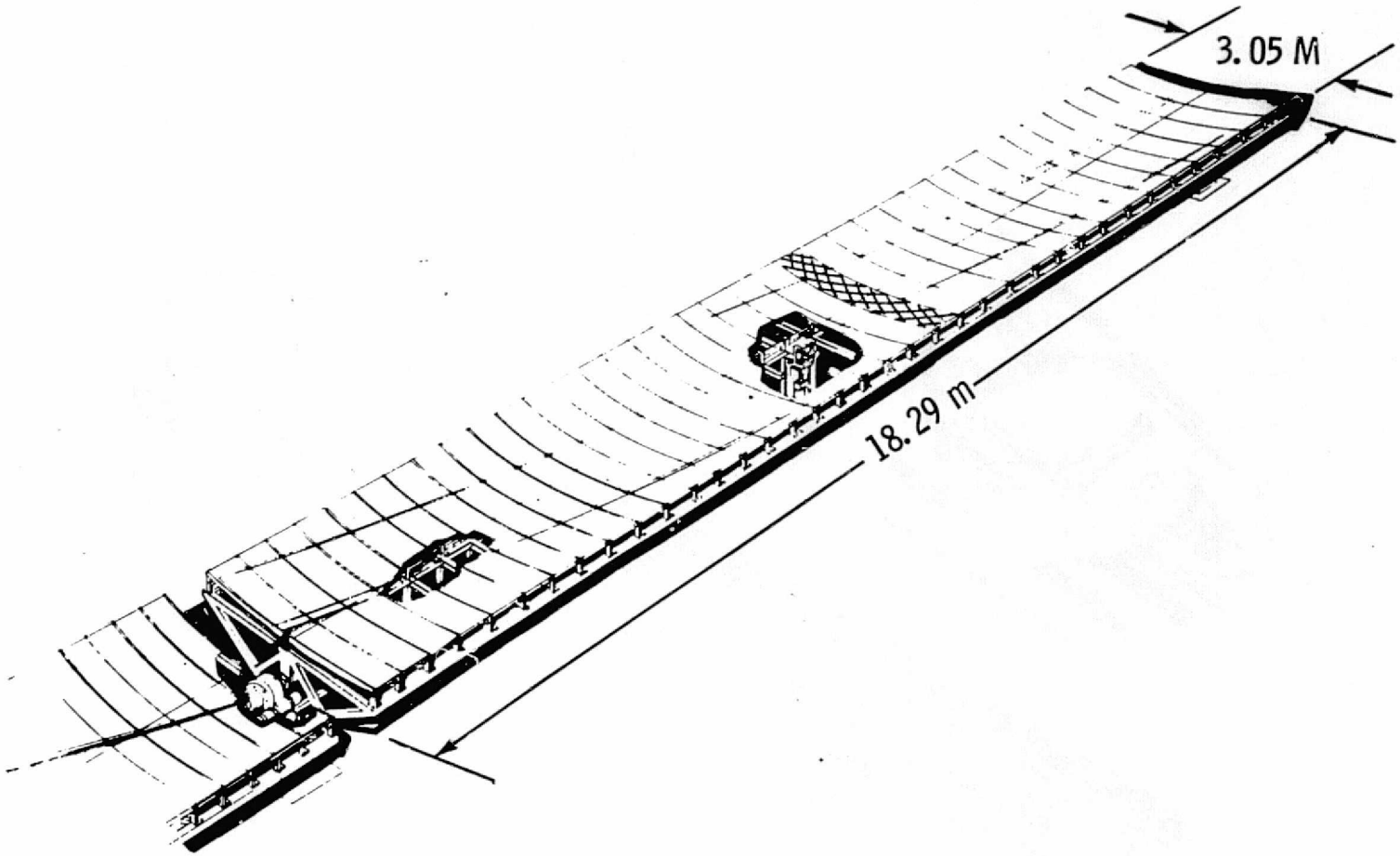


Figure 5-19. Heliostat Concept (from Ref. 5-12)

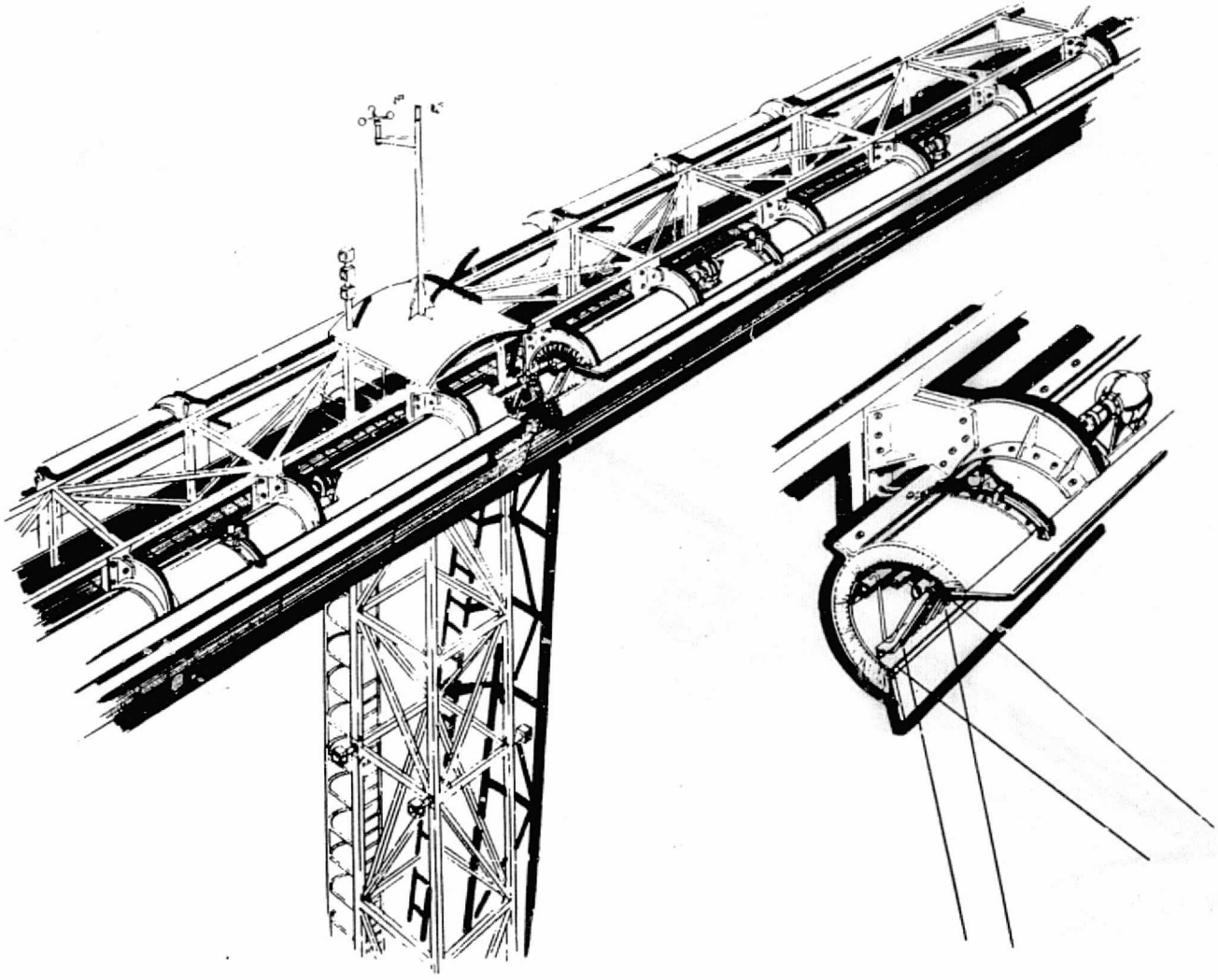


Figure 5-20. Line Central Receiver (From Ref. 5-12)

The cavity receiver, 1.83m (6 ft) in diameter, has eight banks of boiler and superheat tubes distributed circumferentially inside the receiver cavity (see Figure 5-20). The aperture width is 1.22m (4 ft). The receiver produces 496°C (925°F) steam at 6.9 x 10^3 kPa (1000 psi), which is fed into a steam turbine. When the solar insolation is high, any excess heat is routed to storage.

With a north field consisting of 21 heliostat rows, approximately nineteen 61-m sections are required to produce 10 MWe at solar noon. At times other than solar noon, a part of the reflected solar flux will miss the receiver altogether. The length of receiver not illuminated is a function of the angle between the collector and the sun. Triangular-shaped heliostat field sections (called "butterflies") are added at the heliostat field ends (see Figure 5-6). These serve to reduce the solar flux missing the receiver during off-noon hours. The butterfly area is sized such that the full length of the receiver is illuminated for the four hours centered about solar noon.

2) Performance. The FMC Corporation has developed two computer codes which characterize the performance of the FMC design. The collector field program computes the optical efficiency of the field as a function of time, for various input parameters (see Table 5-10). Similarly, the receiver thermal program calculates an efficiency, based on selected inputs, and for selected times (see Table 5-11). Results from

Table 5-10. Optics Program

Selectable Inputs	
Tracking error standard deviation (milliradians)	2
Surface roughness standard deviation (milliradians)	2
Mirror reflectance (dimensionless)	0.9
Latitude (degrees)	35
Field sizing design point (day of year)	355
Hour of day	14
First day (first day for which η_{opt} is to be calculated)	1-365
Last day (last day for which η_{opt} is to be calculated)	1-365
Starting time (hour)	12
Time interval (hours)	1

Table 5-11. Thermal Program

Selectable Inputs	
Steam flow rate (lbm/hr)	Variable
Hour of day for each season-same as for optics program (The program calculates thermal performance for four days of the year: summer and winter solstices, and spring and fall equinoxes.)	0-24
Tube emittance	0-1

these calculations are shown in Figures 5-21 and 5-22. The efficiencies of other system components are shown on Figure 5-23.

3) Systems Analysis Methodology. The values in Figures 5-21, 5-22, and 5-23, as well as other appropriate design and cost parameters were used as inputs for the JPL Solar Energy Simulation (SES) computer program. It was assumed that the collector field, for the plant power rating chosen, is all in-line so that the butterfly area is kept to a minimum. The insolation data for Barstow, CA in 1976 was employed in the program. Some other assumptions regarding the operation of the FMC collector are:

(1) Steam turbine design point temperature is 496°C (925°F), at a design efficiency of 0.325. At times other than solar noon the turbine efficiency and steam inlet temperature are lower.

(2) Thermal storage at 343°C (650°F), and operation of the turbine at 275°C (525°F) from storage.

(3) Steam transport efficiency is 0.997 for direct turbine operation; 0.85 for routing to and from storage.

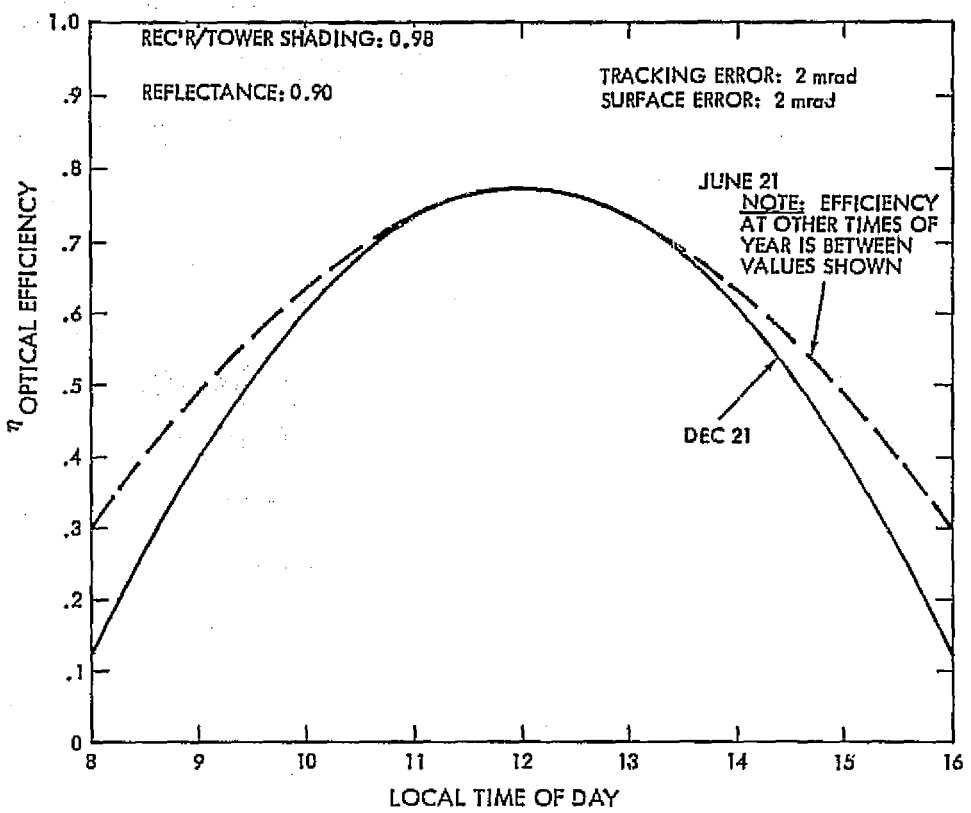


Figure 5-21. Collector Field Optical Efficiency

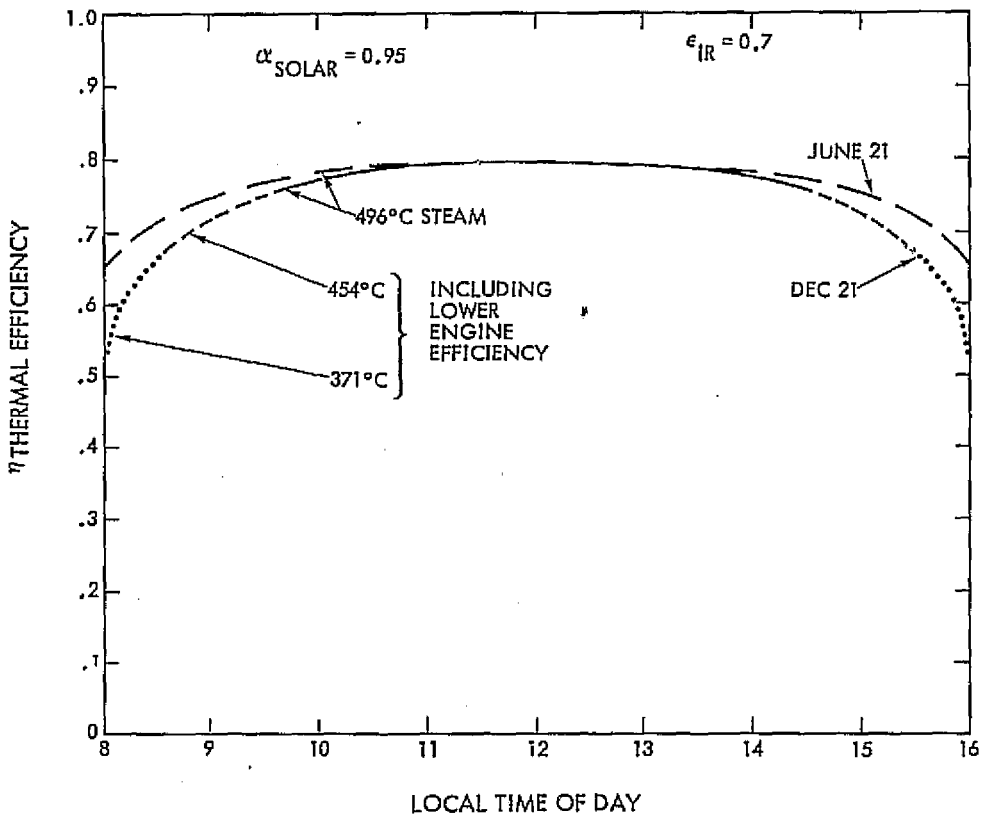


Figure 5-22. Receiver Thermal Efficiency

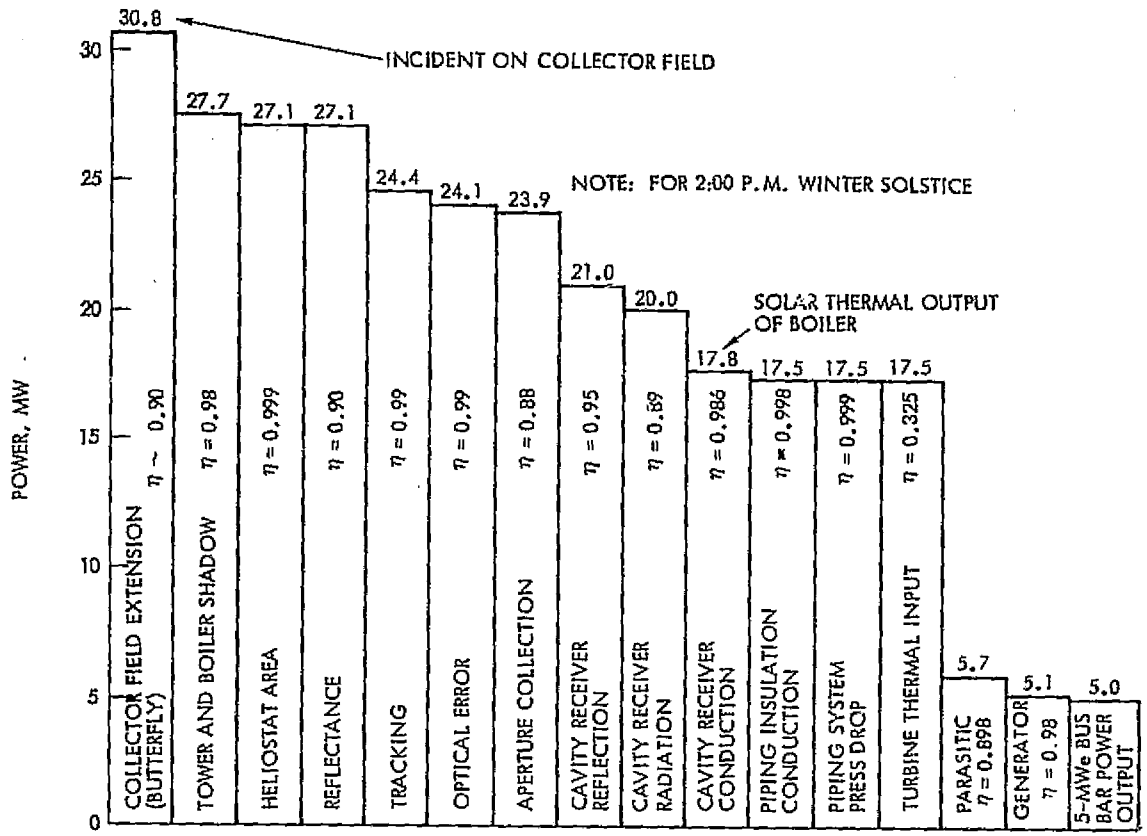


Figure 5-23. Power Flow (Adapted from Ref. 5-12) for Line Focus Central Receiver

4) Systems Thermal Performance Check. The heliostat field layout is optimized for maximum annual energy collection. This corresponds to a design point of December 21, 2:00 pm, for a north-only field. A single, 61m long section of such a field yields 3182 kg/hr (7000 lbm/hr) steam, at approximately 7 x 10^3 kPa (1000 psi) and 496°C (925°F), as determined by the FMC computer codes. This performance level can be verified, as shown by the calculations below.

The thermal power, $\dot{Q}_T$, available to heat the fluid is

$$\dot{Q}_T = \dot{Q}_S - \dot{Q}_R - \dot{Q}_C$$

where

$\dot{Q}_S$ = available solar power at the receiver per 61m section, in watts

$\dot{Q}_R$ = thermal radiative loss from the receiver, in Watts

$\dot{Q}_C$ = thermal conductive loss from receiver, in Watts

$$\dot{Q}_S = I_B \, \eta_{opt} \, h_l \, h_w \, N$$

where

I_B = direct (beam) normal insolation, W/m^2 (as measured at Barstow, CA, on December 21, 1976, 2:00 pm)

η_{opt} = field optical efficiency, including losses at the receiver, as calculated by the FMC optics program

h_l = length of a heliostat/receiver section, m

h_w = heliostat width, m

N = number of heliostats per section

Therefore, using numerical values

$$\dot{Q}_S = (920)\ (0.61)\ (61)\ (3.05)\ (21) = 2.19 \times 10^6 \text{ W}$$

$$\dot{Q}_R = A \, \varepsilon \, F \, \sigma \, T^4$$

where

A = aperture area, m^2

ε = emittance of receiver interior

F = view factor of receiver interior to the ambient environment

σ = Stefan-Boltzmann constant, $W/m^2\ K^4$

T = temperature, Kelvin

Therefore,

$$\dot{Q}_R = (1.22)\ (61)\ (0.70)\ (5.67 \times 10^{-8})\ (260 + 273)^4$$

$$= 2.38 \times 10^5\ W$$

The average steam temperature, 260°C, was used in the above as representative of the entire length of receiver. Also, the view factor and receiver emittance have been combined into a single value, 0.70, which is taken as the apparent aperture emittance. The inherent emittance of the boiler tubes is on the order of 0.7, while the relatively large cavity does not appreciably increase this value.

$$\dot{Q}_C = \frac{A\ k\ \Delta T}{tk}$$

where

A = insulation area, m^2

k = thermal conductivity of insulation, $Wcm/m^2\ °C$

ΔT = temperature difference across insulation, °C

tk = insulation thickness, cm

$$\dot{Q}_C = \frac{\pi(1.83)\ (61)\ (7.2)\ (260 - 22)}{15} = 4.0 \times 10^4\ W$$

thus the thermal power available to heat the fluid is:

$$\dot{Q}_T = \dot{Q}_S - \dot{Q}_R - \dot{Q}_C$$

$$= (2.19 - 0.24 - 0.04) \times 10^6$$

$$= 1.91\ MWth$$

No attempt has been made here to calculate the convective heat loss from the receiver aperture. The computer program also does not take this loss into account at present.

The heat rate required to heat the steam is:

$$\dot{Q}_T = \dot{m}\,\Delta h, \text{ where } \dot{m} = \text{mass flow rate and}$$

$$\Delta h = \text{enthalpy change}$$

$$\dot{Q}_T = \frac{(3182\ \text{kg/hr})}{(3600\ \text{s/hr})}\,(3.36 - 0.93) \times 10^3\ \frac{\text{kJ}}{\text{kg}}$$

$$= 2.15 \times 10^3\ \frac{\text{kJ}}{\text{s}} = 2.15\ \text{MWth}$$

Since $\dot{Q}_T$ (required) $\cong$ $\dot{Q}_T$ (available), the thermal performance of the receiver, as determined by the FMC computer programs, is validated.

5) Economics. The costs of the major collector items, used as inputs to the JPL Solar Energy Simulation program, are as follows:

Heliostat	\$38 to 142/m^2 reflector
Receiver	\$12 to 47/m^2 reflector
Power plant	\$404/kWe rated
Thermal energy storage	\$12.5/kWth-hr
Land	\$1.25/m^2 land

6) Results. The performance of the FMC collector, with inputs into program SES as described above, is shown on Figure 5-24. A range of collector costs and load factors illustrate the influence of these parameters on the levelized bus bar energy cost, BBEC, (in 1978 dollars).

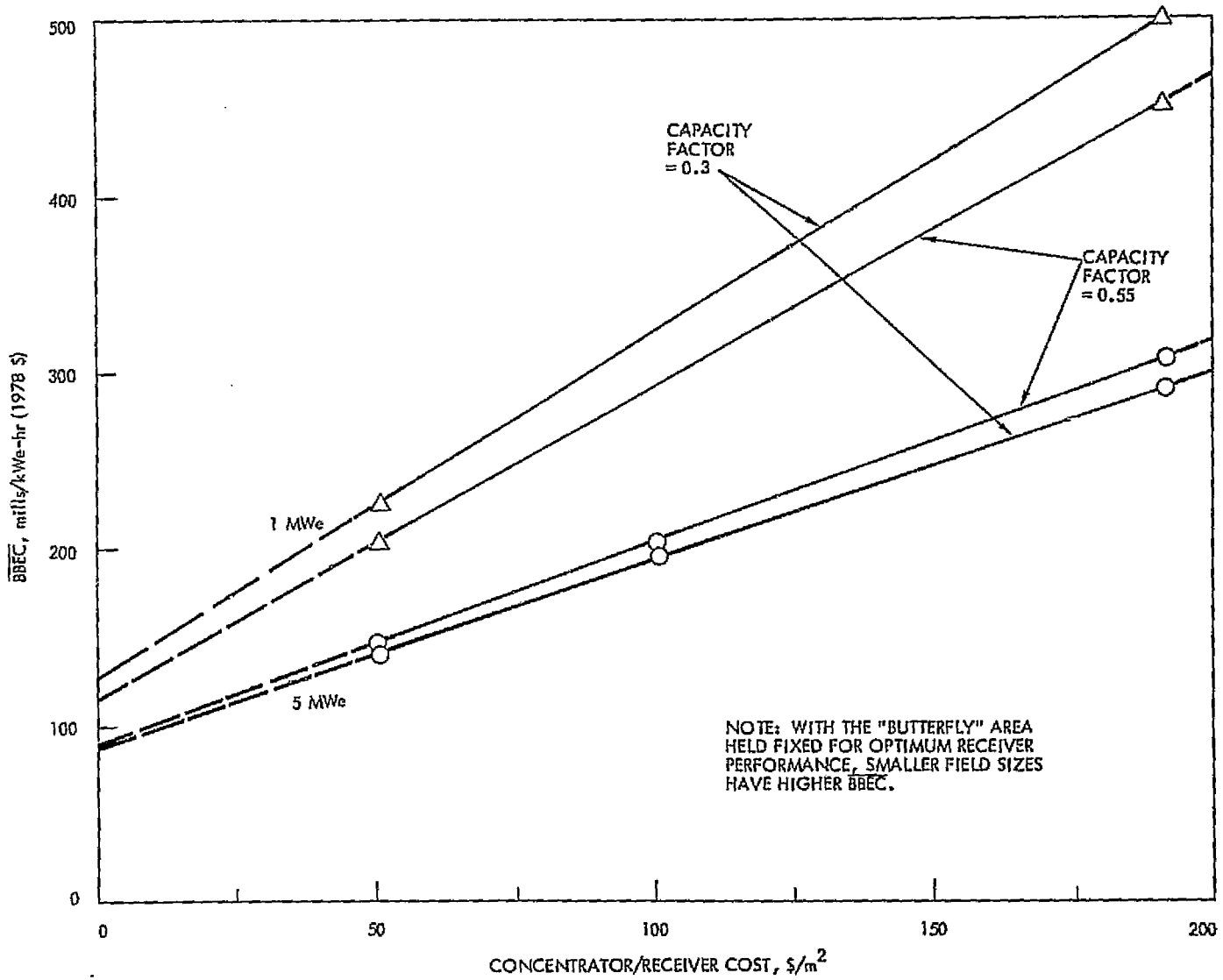


Figure 5-24. $\overline{BBEC}$ versus Collector Cost

c. Point Focus Distributed Receiver. Point focus distributed receiver systems generally consist of a parabolic dish reflector, with a receiver mounted at the focal point of each dish. The heat engine-generator can be either of two types: small, individual units at each receiver, or a large, central unit (see Figures 5-25 and 5-26). The particular heat engine selected tends to determine which of these two designs is the more efficient. Brayton and Stirling cycle engines are generally considered as small, individual units, while Rankine systems are favored for large central units.

In the near term, the system which offers the most promise utilizes closed-cycle Brayton engines. Small Brayton engines are already quite efficient ($\eta \geq 0.30$, at an inlet temperature of 815°C), and this efficiency can be significantly improved with higher inlet temperatures. Brayton engines have proven themselves in many applications; they offer good durability, light weight, and rapid start-up capability. These are highly desirable characteristics, for a solar thermal plant.

1) System Description. The point focus distributed receiver system which has been chosen for analysis consists of the following: a parabolic dish, 11m (36 ft) in diameter and with a mirror reflectance $\cong 0.85$; a Brayton engine, operating at 815°C (1500°F) with a cycle efficiency of 0.32; a 3600 RPM alternator and a cavity-type receiver. The dish size was selected based on engine efficiency/size data, and on incremental dish cost, which is highly nonlinear in the larger diameters. Thus, the largest cost-effective dish size is used here.

The selected engine, an experimental unit which has been extensively tested and reported on in the literature (Refs. 5-16 and 5-17) operates in a closed-cycle, recuperated mode. It could readily be adapted for solar use. Efficiency could be further improved to $\eta = 0.36$ if an Xe - He mixture were substituted for the argon working fluid.

It appears that the item requiring the greatest development is the receiver. For preliminary study and costing purposes, a straightforward cavity receiver with a tubular heat exchange bundle was selected (see Figure 5-27). This design has a number of drawbacks:

(1) Operation near the extreme temperature limit of the material selected (Inconel)

(2) Numerous welds/joints

(3) Fairly high cost (estimated to be $\$28/m^2$ collector, for production runs of 10^5/yr (Ref. 5-18).

A better, more realistic receiver would probably be constructed of ceramic materials, such as SiC (Ref. 5-19). This would allow a large safety margin for any temperature excursions, as well as permitting higher operating temperatures. Unfortunately, ceramic technology is not as well advanced as that for metals, so a considerable effort will have to be expended to develop a viable ceramic receiver. It is felt that this technology is about 10 years away (Ref. 5-20).

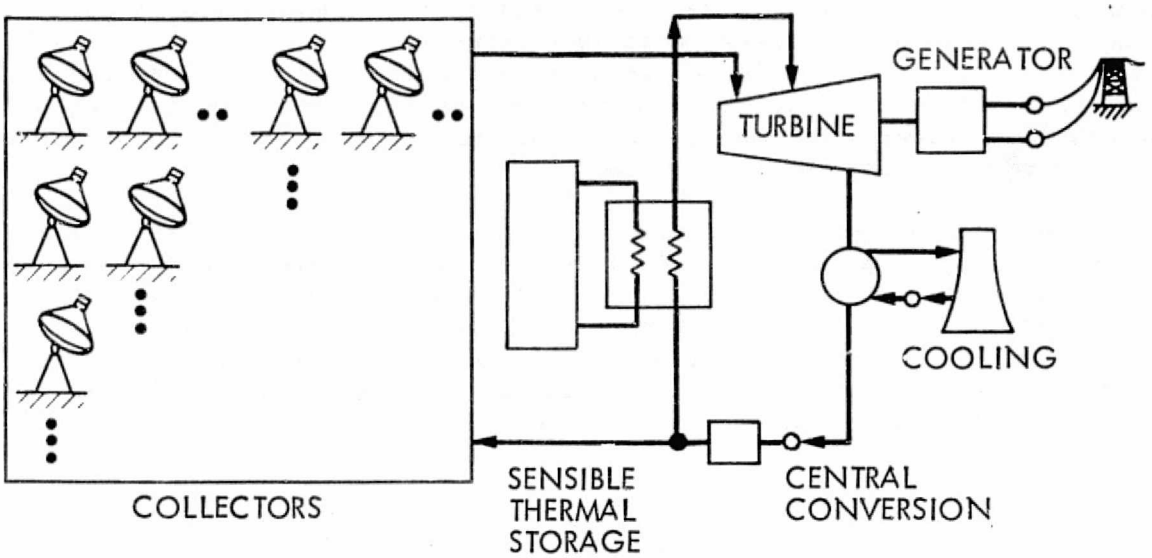


Figure 5-25. Parabolic Dish-Steam (Rankine) System

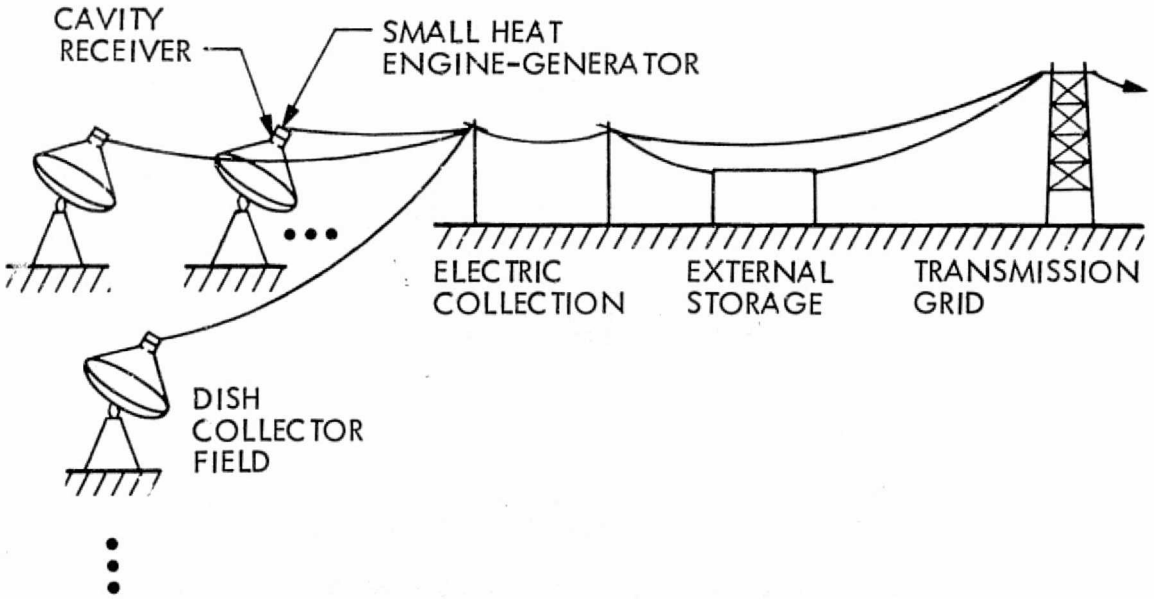


Figure 5-26. Parabolic Dish-Electric (Brayton or Stirling) System

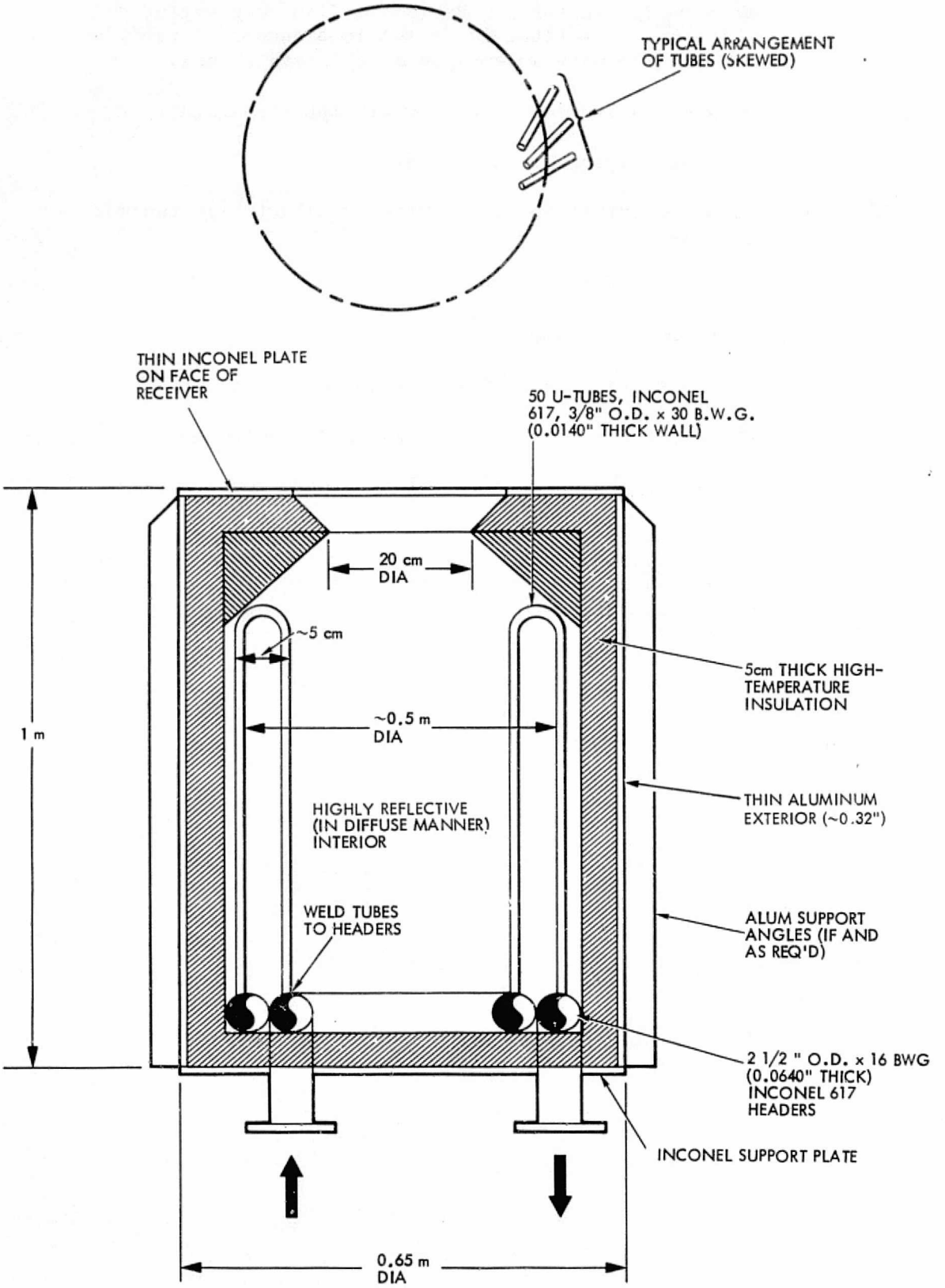


Figure 5-27. Cavity Receiver (Brayton)

2) Main Design Features. Parabolic dish/heat engine solar power plants have been described in detail in a number of publications (e.g., Ref. 5-21). The main advantages of this system are:

(1) Maximum collection of energy at high temperatures

(2) No time varying cosine losses

(3) High concentration ratio, with resultant high thermal efficiency

(4) Inherent modularity

On balance, some negative aspects are:

(1) Two-axis tracking, which must be quite accurate

(2) Stringent reflector surface quality requirements

(3) Relatively high cost for collector and receiver

3) Performance. The performance of the selected dish/Brayton design was calculated by JPL. The optical efficiency is constant with time. The thermal efficiency of a given receiver design is a function almost wholly of its temperature, if a negligible wind loss is assumed. Thus the thermal efficiency is determined from material properties and calculated radiative and conductive heat losses. The various efficiencies are shown on Figure 5-28, while the more important design parameters are listed in Table 5-12.

4) Systems Analysis.

a) Methodology. The values in Figure 5-28, as well as other design and cost parameters have been used as inputs for the JPL Solar Energy Simulation (SES) computer program. Insolation data for Barstow, CA (1976) were employed in the program. Electrical energy storage was assumed, and all costing was done by JPL.

b) Systems Thermal Performance Check. The thermal power, $\dot{Q}_T$, available to heat the fluid is (neglecting the convective loss from the aperture)

$$\dot{Q}_T = \dot{Q}_S - \dot{Q}_R - \dot{Q}_C$$

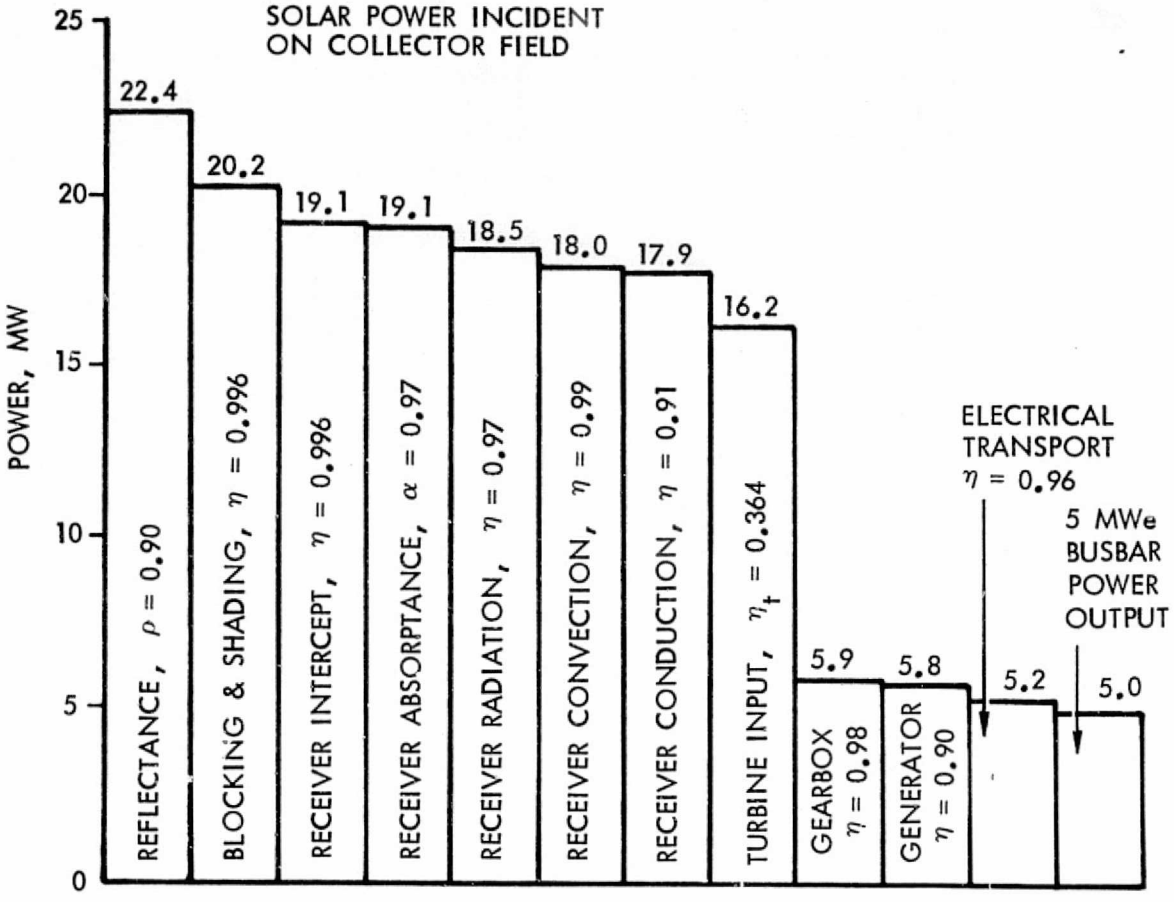


Figure 5-28. Power Flow for Point Focus Distributed Receiver

Table 5-12. Study Design Parameters

Concentrator	
Reflectance	0.85
Slope error	1.75 milliradians
Pointing error	0.9 milliradians
Receiver	
Fluid	Argon
Insulation thickness	5 cm
Aperture	20 cm
Engine	
Fluid	Argon
$\dot{m}$	0.35 kg s^{-1} (0.75 lbm s^{-1})
Temperature	815°C (1500°F)
Pressure	500 kPa (72 psi)
RPM	52,000
Alternator	
RPM	3600
Hz	60

where

$\dot{Q}_S$ = available solar power at the receiver, per dish, W

$\dot{Q}_R$ = thermal radiative loss from the receiver, W

$\dot{Q}_C$ = thermal conductive loss from receiver, W

$$\dot{Q}_S = I_B \, \eta_{opt} \, A_D$$

where

I_B = direct (beam) normal insolation, W/m^2 (nominal design value)

η_{opt} = optical efficiency, including structural blocking and shading (0.95), reflectance from receiver interior (0.95), and spillage (0.996)

A_D = dish area, reduced by a 1 m diameter nonreflective area at the center, m^2

$$\dot{Q}_S = (800)\ (0.77) \left[\frac{\pi (11)^2}{4} - 3.1 \right] = 5.64 \times 10^4 W$$

$$\dot{Q}_R = A\ \varepsilon\ F\ \sigma\ T^4$$

where

A = aperture area, m^2

ε = emittance of receiver interior

F = view factor of receiver interior to the ambient environment

σ = Stefan-Boltzmann constant W/m^2K

T = temperature, Kelvin (K)

$$\dot{Q}_R = \frac{\pi}{4}\ (0.20)^2\ (0.95)\ (5.67 \times 10^{-8})\ (1139)^4 = 2.85 \times 10^3 W$$

The apparent aperture emittance was conservatively taken as 0.95 in the above calculation. Also, the relevant temperature was estimated to be ∿50°C greater than the highest fluid temperature.

$$\dot{Q}_C = \frac{A\ k\ \Delta T}{tk}$$

where

A = insulation area, m^2

k = thermal conductivity of insulation, $Wcm/m^2\ °C$

ΔT = temperature difference across insulation, °C

tk = insulation thickness, cm

$$\dot{Q}_C = \frac{(2.67)\ (8.71)\ (1139 - 273)}{5} = 4 \times 10^3 W$$

The insulation was assumed to be a 5-cm thick material such as "Fiberfrax" whose conductivity (at the average insulation temperature of 706 K) is used in the above equation.

Thus the thermal power available to heat the fluid is:

$$\begin{aligned}\dot{Q}_T &= \dot{Q}_S - \dot{Q}_R - \dot{Q}_C \\ &= (5.64 - 0.29 - 0.40) \times 10^4 W \\ &= 49.5\ kWth\end{aligned}$$

and the thermal efficiency of the receiver is

$$\frac{49.5}{56.4} = 0.88$$

The power produced is

$$P = \dot{Q}_T \, \eta_t \, \eta_G \, \eta_g$$

where

P = power, kWe

η_t = recuperated, closed-cycle overall Brayton engine efficiency

η_G = gearbox efficiency

η_g = generator efficiency

$$P = (49.5)\ (0.32)\ (0.98)\ (0.9) = 14 \text{ kWe}$$

5) Economics. The costs of the major collector items, used as inputs to the JPL Solar Energy Simulation program, are as follows:

Heliostat	\$90 to 150/m^2 reflector
Receiver	\$10/m^2 reflector
Power plant	\$161/kWe rated
Electrical energy storage	\$32/kWe-hr
Land	\$1.25/m^2 land

6) Results. The performance of the parabolic collector, with inputs into program SES as described above, is shown on Figure 5-29. A range of collector costs and load factors illustrates the influence of these parameters on the levelized bus bar energy cost, $\overline{BBEC}$, (in 1978 dollars).

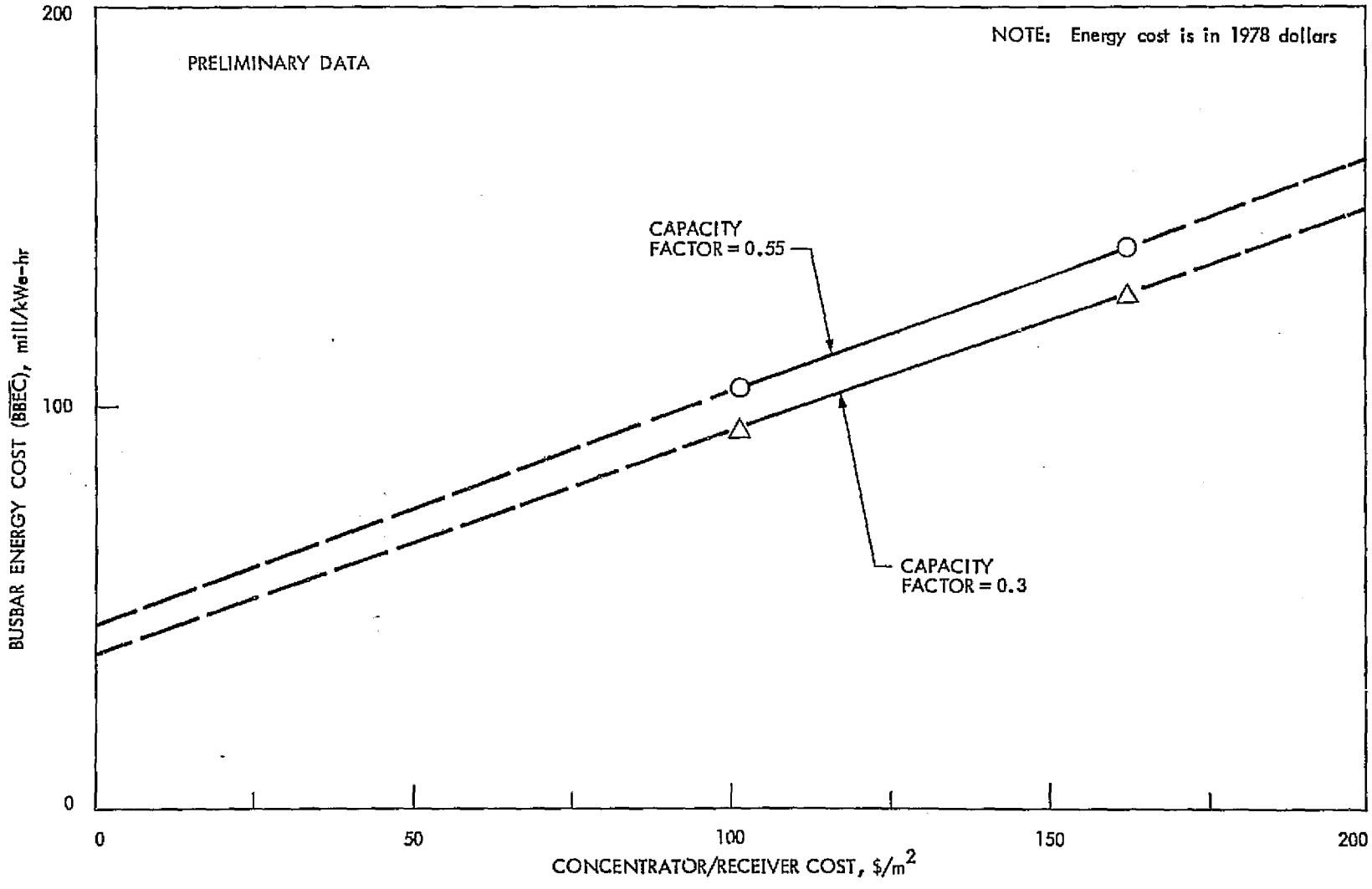


Figure 5-29. $\overline{BBEC}$ versus Collector/Receiver Costs, $/m^2

3. Engineering Experiment No. 1

a. Background. Engineering Experiment No. 1 (EE No. 1) is the first of several experimental solar thermal power plants that are planned by the SPSA project. The objectives of EE No. 1 include the following:

(1) To demonstrate the feasibility of near-term small power system technology in a community/utility environment,

(2) To determine economic, performance, functional, operational and institutional aspects of the selected system in a user environment,

(3) To advance the acceptance of the small power system concept by the user community, and

(4) To simulate the creation of an industrial base for small power systems.

Engineering Experiment No. 1 is a multiphased procurement with the three Phase I contractors competing for Phases II and III. The eventual selection of the Phase II contractor will be based on a set of predetermined selection criteria. The projected schedule for EE No. 1 is shown in Figure 5-30.

The RFP for Phase I was issued September 16, 1978 and the proposals received November 11, 1978. The three contractors selected as a result of the proposal evaluation are identified in Table 5-13, along with the technology category in which they are conducting their studies.

The 10-month Phase I effort will be conducted within three major tasks. In the first task the contractors will consider alternatives to the concept provided in the proposal, and perform tradeoff/optimization analyses and design studies necessary to synthesize three preferred system concepts for start-up times of 3.5 years, 4.5 years, and 6.5 years (start-up time refers to the time span from start of Phase I to the start of the one-year test and evaluation period of Phase III). Table 5-14 shows the event times to be assumed in the study for each start-up time. Each preferred concept will be designed for a plant rated power of 1.0 MWe, an annual capacity factor of 0.4 and a plant life of 30 years. The criteria to be used by the contractors in selecting the preferred system concepts are discussed in Table 5-3 (previously cited). Outputs of Task 1 will include development requirements, design descriptions, performance and reliability data, and cost data for each preferred concept.

In Task 2 the contractor will ascertain the influence of plant size and annual capacity factor (CF) on cost and performance of the

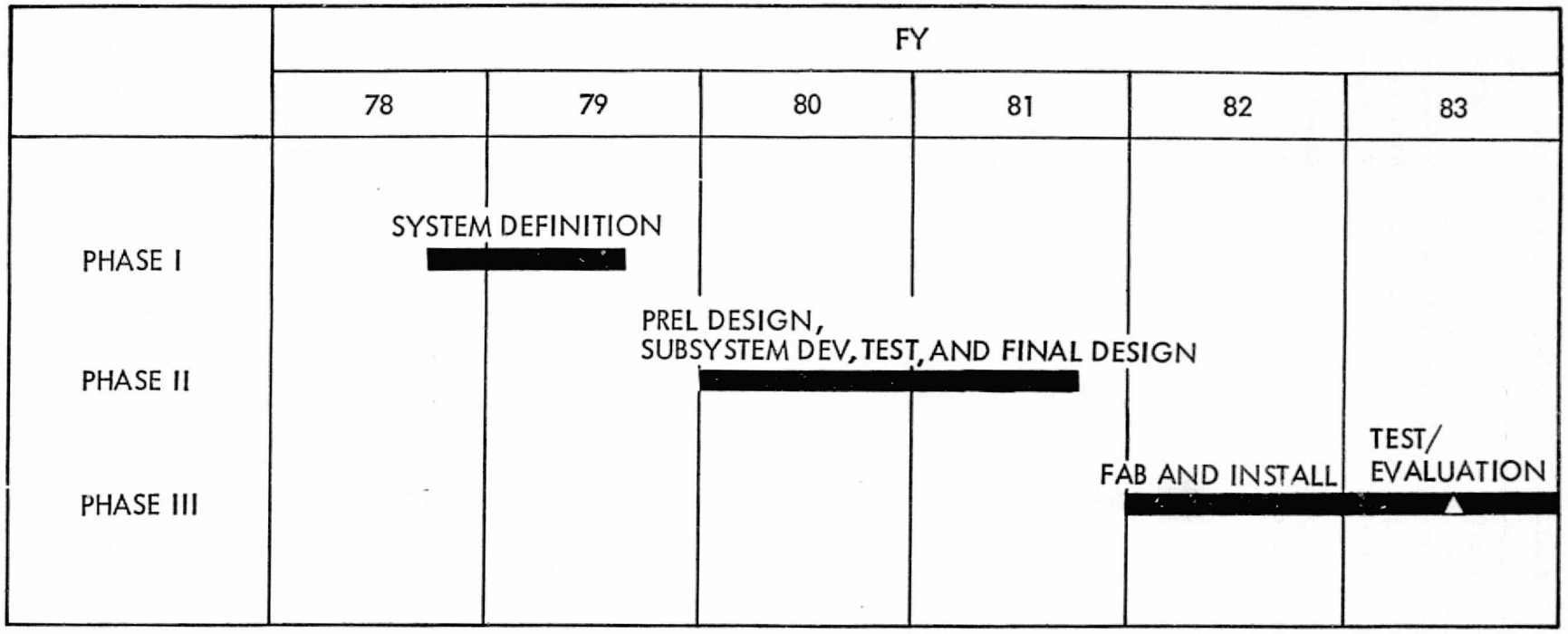


Figure 5-30. Engineering Experiment No. 1 Schedule

Table 5-13. Phase I Contractors

Category	System Technology	Contractor
A	General (To include but not be limited to central receivers and linear focusing systems)	McDonnell Douglas Astronautics, Co., Huntington Beach, CA
B	Point-Focusing, Distributed Collector, Central Energy Conversion	General Electric, Co., Schenectady, New York
C	Point Focusing, Distributed Collector, Energy Conversion at the Collector	Ford Aerospace and Communications Corp., Newport Beach, CA

Table 5-14. Assumed Program Event Times (For Planning Purposes Only)

Events	Event Times ts=3.5 yrs	ts=4.5 yrs	ts=6.5 yrs
PHASE I	10 mo	10 mo	10 mo
Time between PHASE I and PHASE II	1 mo	1 mo	1 mo
PHASE II, including • Design • Subsystem Development • Subsystem and System Level Verification Test	8 mo	18 mo	42 mo
Time between PHASE II and PHASE III	1 mo	1 mo	1 mo
PHASE III, including • Detail Design • Fabrication • Installation and Checkout	22 mo	24 mo	24 mo
• Test and Evaluation	12 mo	12 mo	12 mo
TOTAL ELAPSED TIME	4.5 yrs	5.5 yrs	7.5 yrs

Start-Up Time (ts)

preferred system concepts. Parametric values of 0.5 MWe and 10.0 MWe will be used for plant rated power. For annual capacity factor the zero storage case and CF = 0.7 will be used. In Task 3 the contractors will develop the Phase II Program Plans for each of the preferred systems selected in Task 1 and recommend which system should be undertaken in Phase II.

The schedule for Phases II and III shown in Figure 5-30 was projected assuming the 4.5-year start-up event times in Table 5-14. EE No. 1 may go on line as early as fiscal year 1982. The site for EE No. 1 will be chosen as a result of a separate procurement by DOE with JPL support.

b. Design Requirements. The plant design requirements used in the Phase I effort are tabulated in Table 5-15.

c. Systems Descriptions. Summary descriptions of the system concepts proposed by the Phase I contractors in response to the RFP are presented below.

(1) Category A (McDonnell Douglas Astronautics Company). The initial system concept proposed by McDonnell Douglas Astronautics Company (MDAC) is a small central receiver concept employing Hitec as both the receiver coolant and thermal storage fluid, and steam Rankine cycle power generation which uses an advanced high-performance radial turbine. A thermocline thermal storage approach was selected with the storage tank itself being filled with a sand/rock mixture which occupies approximately 75 percent of the tank volume. Figure 5-31 is a system schematic which identifies the four principal subsystems of the plant. Figure 5-32 is an artist's concept of the power plant layout.

The collector subsystem consists of a concentrator and a receiver. The concentrator is comprised of a field of 162 two-axis tracking reflectors (heliostats) which direct incident solar radiation to a tower-mounted receiver. The heliostat field is based on the design being developed by MDAC for the DOE 10 MWe Central Receiver Power Plant. Each heliostat is mounted on a pedestal with azimuth and elevation drives. The reflecting surface consists of rectangular mirrors mounted on either side of the pedestal as shown in Figure 5-33, for a total of 38 square meters of reflecting area per heliostat. The heliostat field utilizes an open loop control system to track the sun, with each heliostat controlled by the central control unit. The receiver is mounted on a 46 meter high, open frame steel tower supported by guy wires. Solar radiation concentrated by the heliostat field is absorbed by two series of exposed pipes within the receiver, heating the Hitec fluid used in the energy transport subsystem.

Table 5-15. Design Specifications for Phase I Study

System Rated Power	Nominal: 1.0 MWe; Range: 0.5 - 10 MWe
Annual Capacity Factor	Nominal: 0.4; Range: Max. 0.7
Plant Lifetime	30 years
Insolation	Barstow 1976
Electrical Output	Compatible with utility
Design Point (Zero Storage)	Rated power delivered to utility grid interface when direct normal insolation is 800 watts/m^2 at solar noon at equinox at the reference plant location.

The energy transport subsystem utilizes the Hitec fluid - a low melting temperature mixture of salts - to transport thermal energy from the receiver to the power conversion subsystem. The hot Hitec, at 510°C (950°F), is pumped to either the energy storage unit for use later, or to the steam generator unit to produce steam. Cold Hitec, at 288°C (550°F), is pumped back to the receiver.

Steam at 482°C (900°F) from the steam generator drives the Rankine radial turbine which in turn drives a gear box and electrical generator to produce electricity. Waste heat from the turbine is rejected by a wet cooling tower. The nominal output of the power conversion unit is 1.1 MWe of which 0.1 MWe powers parasitic loads, such as pumps and controls. The net output is therefore 1 MWe.

The energy storage unit acts as an accumulator, storing thermal energy produced in excess of the energy needed by the power conversion subsystem. When the power conversion subsystem requires more energy than the receiver can deliver, the stored energy is used to make up this deficit. The sensible heat of the rock/sand mixture stores the thermal energy as the hot Hitec mixture is pumped through the storage tank. The tank for the proposed system is large enough to hold 9 MW-hr of thermal energy which can run the solar plant for 3 hours.

2) Category B (General Electric Company). The initial system concept proposed by General Electric (GE) is comprised of a collector field of 150 two-axis tracking parabolic dish reflecting concentrators. Each concentrator is enclosed within an air-supported transparent enclosure to reduce wind loading and weather-induced mirror degradation on the concentrator. Each dish concentrates incident solar radiation on a ball shaped integral receiver/boiler fixed at the focal point of the concentrator. Steam from the 150 receiver/boilers is transported

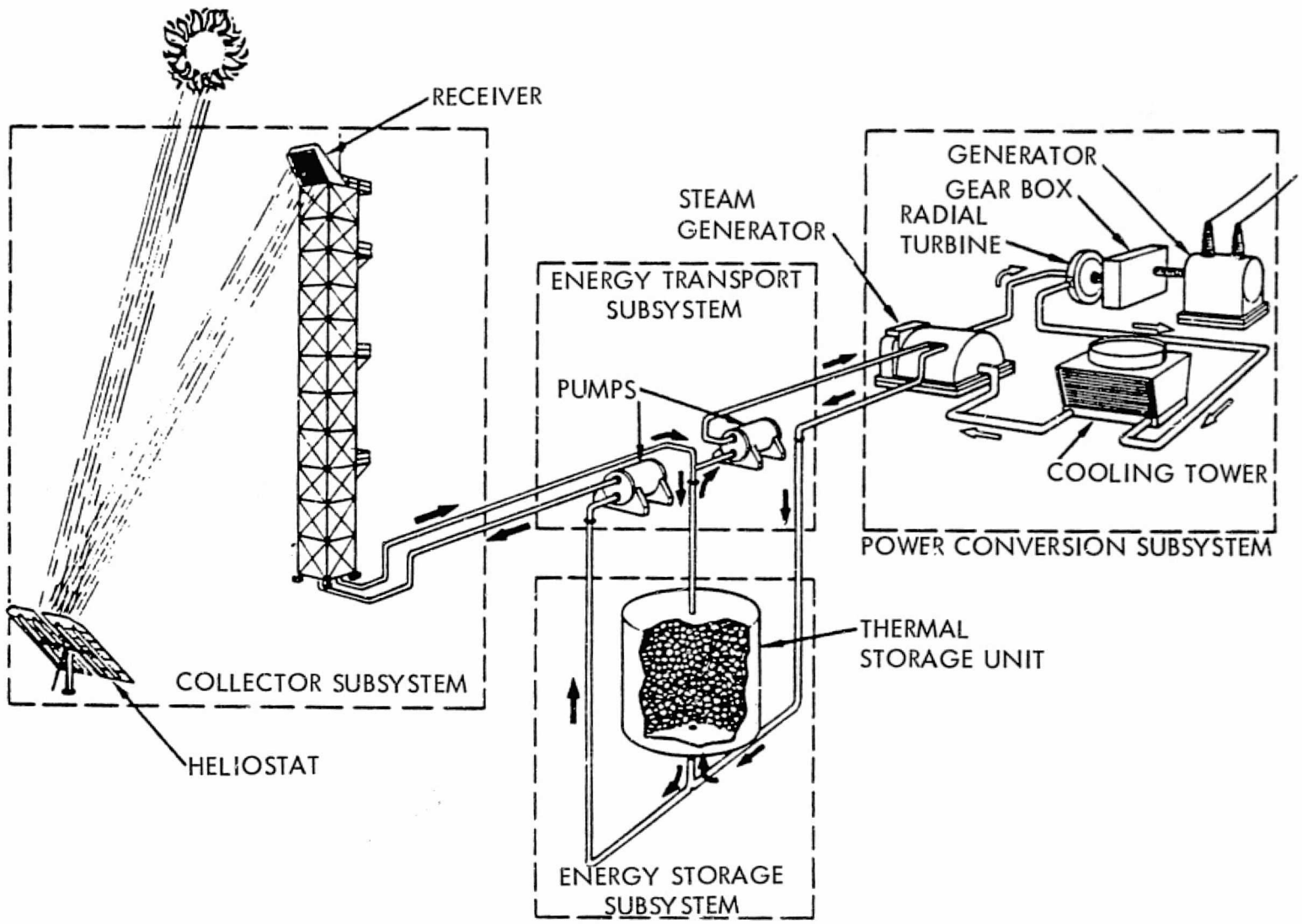


Figure 5-31. System Schematic Identifying Four Principal Subsystems of McDonnell Douglas Concept

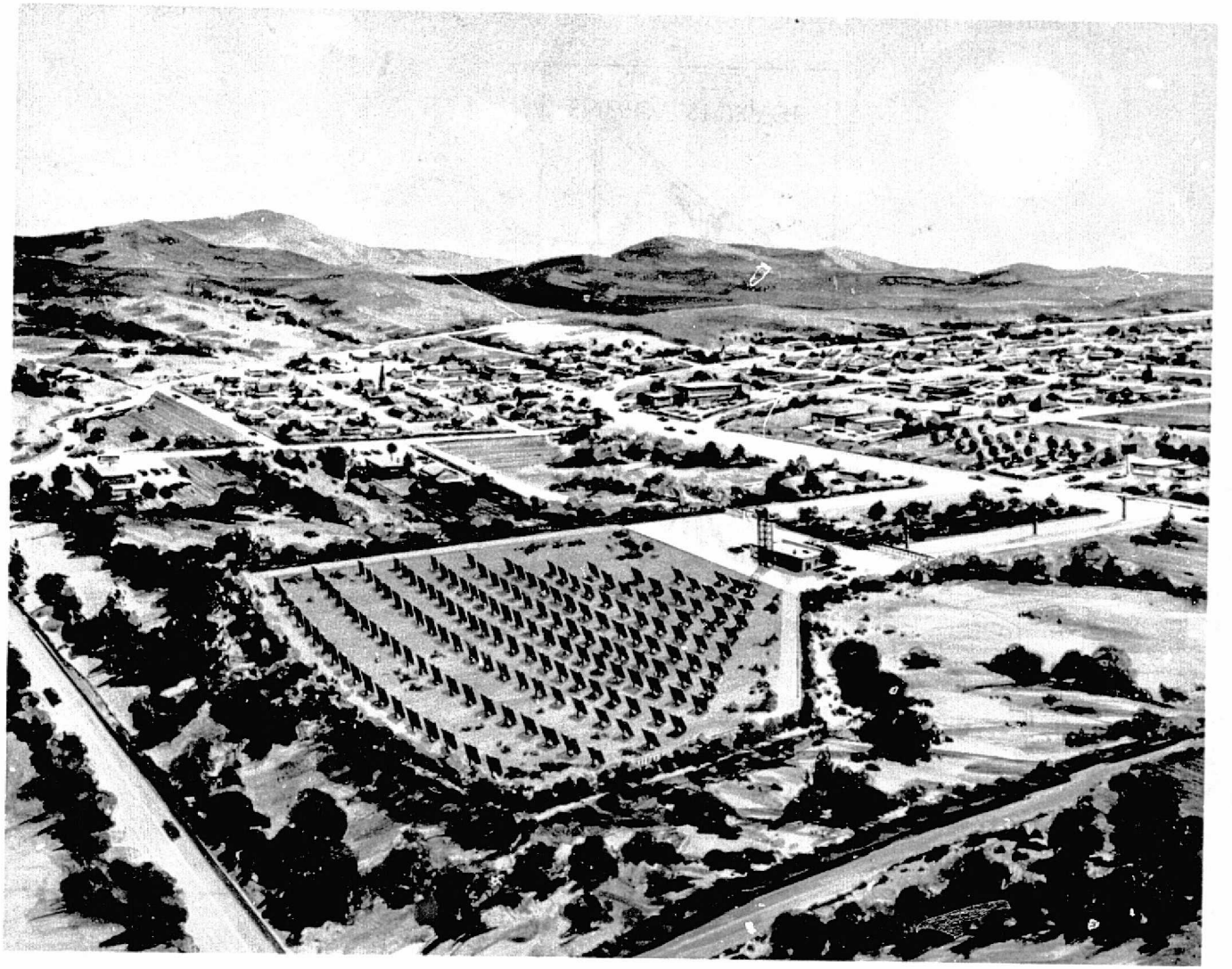


Figure 5-32. Artist's Concept of McDonnell Douglas Power Plant Layout

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

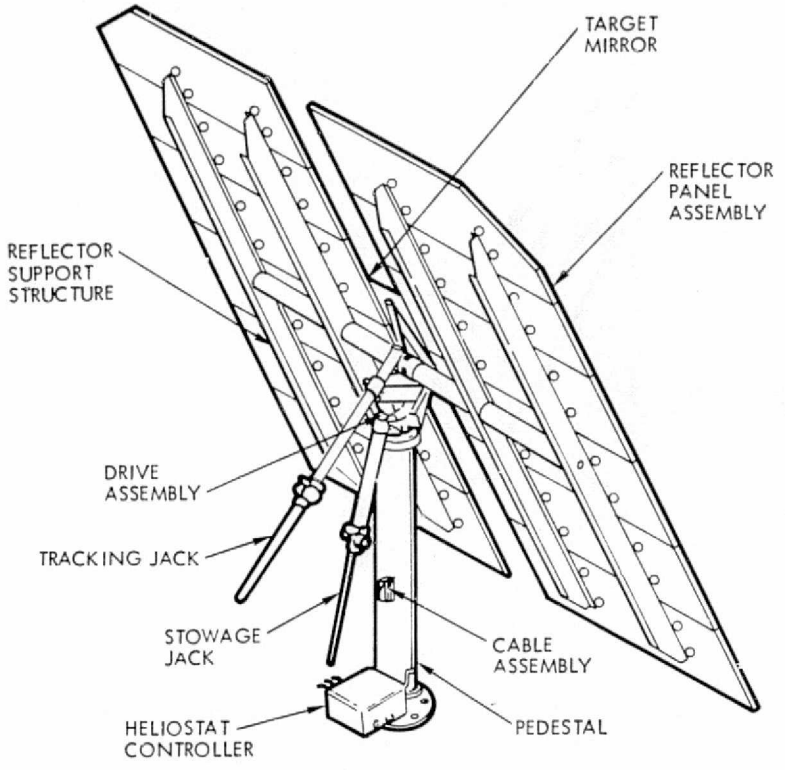


Figure 5-33. Heliostat Assembly with Rectangular Mirrors

to the central power conversion unit through vacuum insulated pipes. The General Electric system attempts to minimize field construction costs by reducing the field installation time to 120 days for the entire 1 MWe system. Figure 5-34 is an artist's concept of GE's plant layout.

Each concentrator is mounted on a single pipe pedestal mount at 40 foot intervals and is pivoted through its center of gravity located at its focal point. Figure 5-35 shows the plant layout of concentrators. Figure 5-36 shows the construction of a dish. Twenty-eight parabolic segments are mounted on a ring support structure to form a 7.9 meter diameter dish. A segment is fabricated from a 3/4 inch aluminum honeycomb sandwich core with a reflecting mylar surface. The total concentrator weight is estimated to be 500 lbs. Coarse tracking is controlled by a central computer with a closed loop sun sensor for precision tracking of the sun.

The concentrator is protected from wind and weather by a transparent enclosure. The enclosure is constructed of a flexible transparent plastic hemisphere supported by internal air pressure from a small blower. Three tubular step frames provide lightning protection and support during air-system-off periods. Although GE estimates that

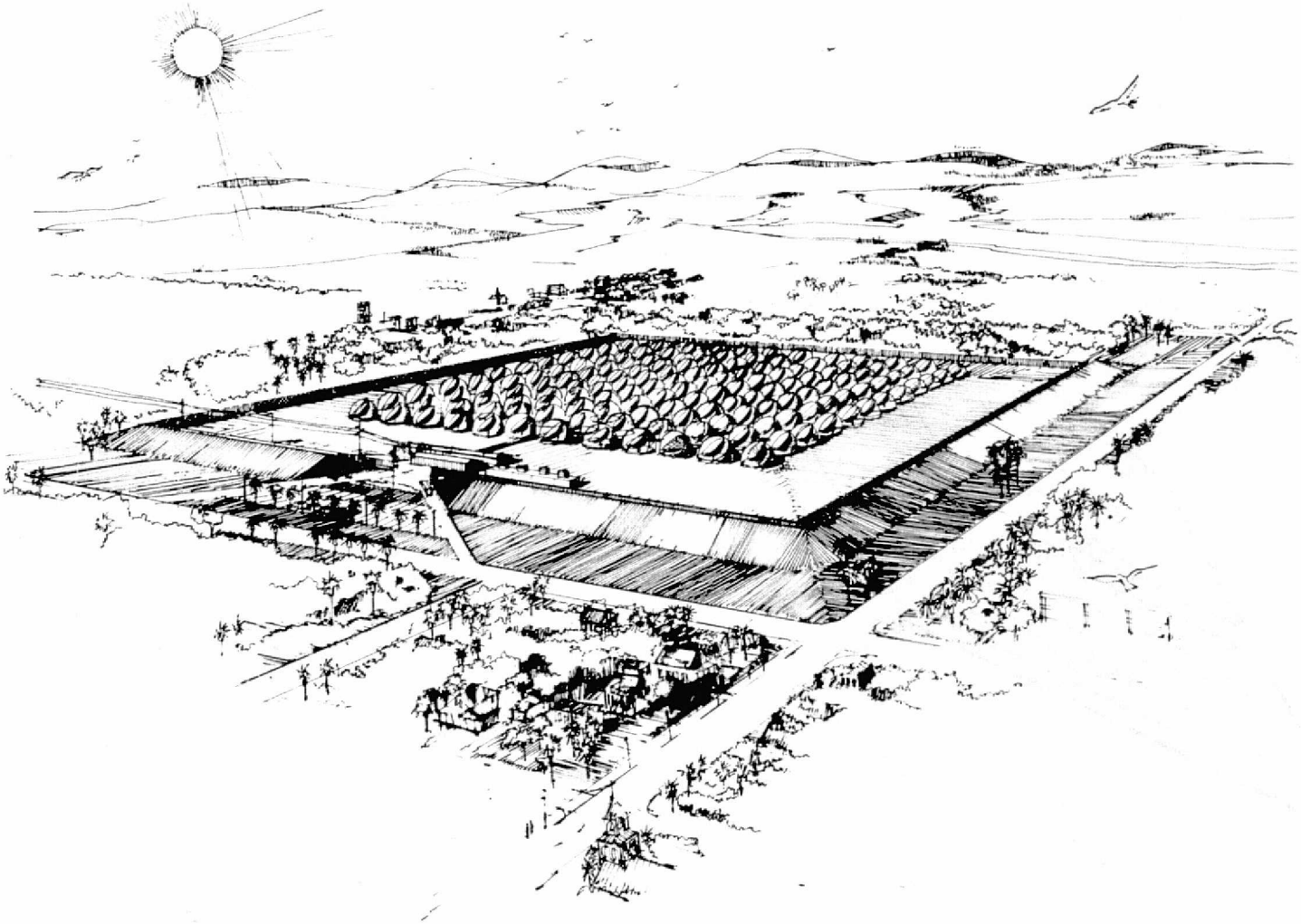


Figure 5-34. Artist's Concept of GE Plant Layout

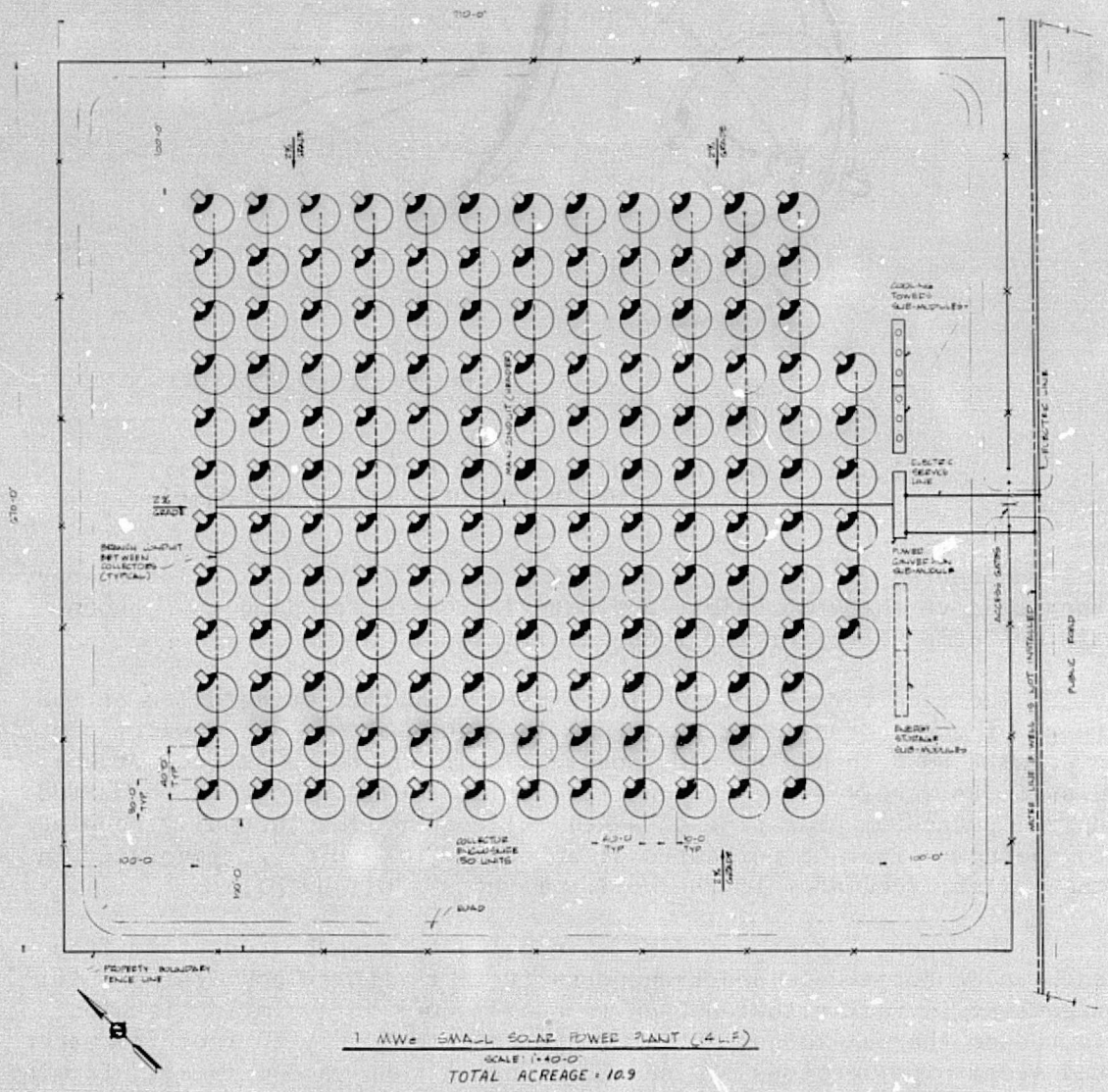


Figure 5-35. GE Plant Concentrator Layout

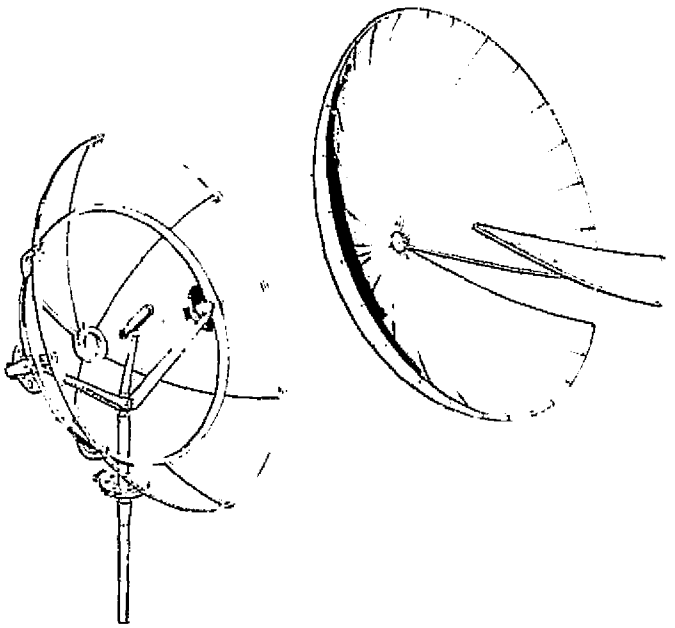


Figure 5-36. General Electric Proposed Collector, Receiver/Boiler Assembly Construction

the enclosures will transmit only 86 percent of incident solar energy, they believe that the weight and material costs saved on the concentrators compensate for the reduced efficiency.

The receiver is mounted in a fixed elevation orientation at the focus of the concentrator, as shown in Figure 5-36. A potassium heat pipe with an 8 inch diameter spherical heat absorbing surface at the dish focus receives the concentrated solar energy. Heat is conducted up the potassium heat pipe to a helical coil boiler thermally coupled to the heat pipe. Superheated steam at 510°C (950°F) is generated in the boiler; feedwater to the boiler is at 204°C (400°F).

The energy transport subsystem collects superheated steam from each collector module and transports it to the power conversion unit; feedwater is redistributed back to each module in a similar fashion. To reduce thermal losses on the long runs of piping, 20 feet feedwater and steam pipe sections are sealed within a long vacuum jacket, forming a reflective Dewar-type flash. Figure 5-37 shows the vacuum piping concept.

The power conversion unit consists of a 1235 kW marine-type steam turbine, an electrical generator coupled to the turbine through a speed reducing gear box and all of the supporting components and subsystems. The steam at the turbine inlet is 482°C (900°F) and 1200 psi. Electrical output is rated at 1139 kWe; 135 kWe of parasitic loads give a net output of 1 MWe. Waste heat is rejected by a dry cooling tower. The power conversion unit is integrated as a complete submodule as shown in Figure 5-38 and is rail transportable and skid mounted for quick installation.

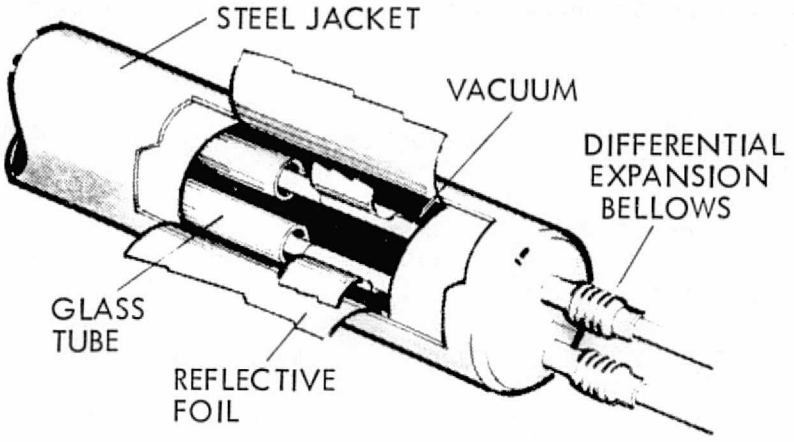


Figure 5-37. Vacuum Piping Concept Applied to Pedestals, Headers, Laterials, and Expansion Joints

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

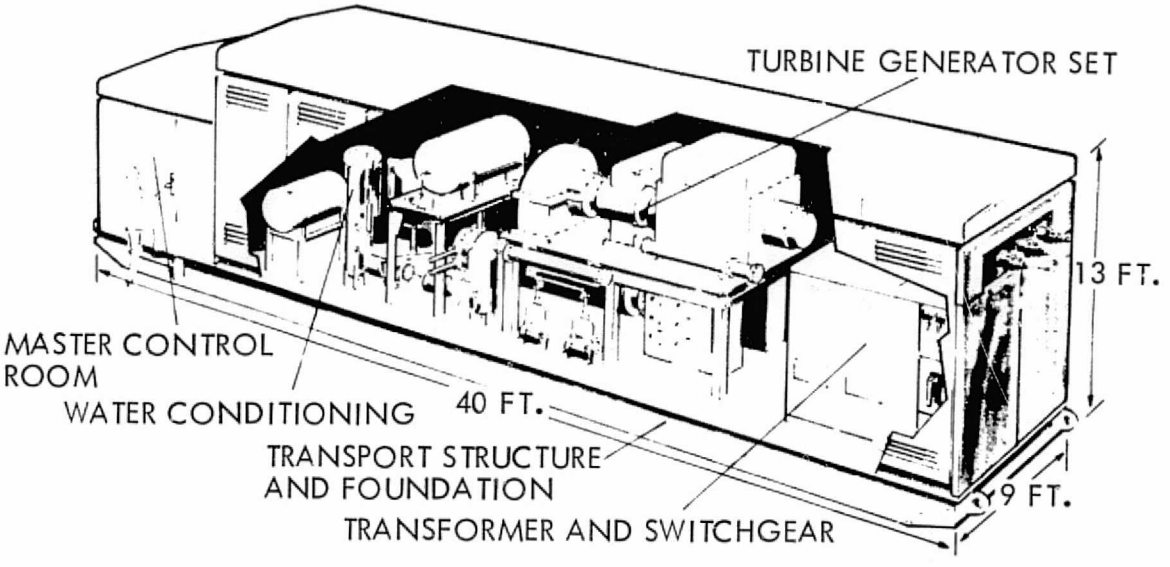


Figure 5-38. General Electric's Complete Power Conversion Submodule for the 1 MW Plant

A steam accumulator is used to maintain turbine speed at no-load conditions during intermittent cloud blockages. A battery storage system could be used to supply 6.8 hours of storage to reach a 0.7 capacity factor.

3) Category C (Ford Aerospace and Communications Corp). The initial system concept proposed by Ford is comprised of a collector field of 23 parabolic dish concentrator modules with a receiver power conversion unit mounted on each dish near the focus on a quadripod structure. Figure 5-39 is an artist's concept of Ford's plant layout. Electricity generated at each collector is transported to the station power conditioning unit providing connection to the utility grid. Figure 5-40 is a schematic showing the elements of the system.

Each concentrator module is 16 meters in diameter and similar in construction to parabolic dish radio antennas. The reflecting surface is an aluminum substrate covered with metalized acrylic tape. The concentrator is mounted on a circular wheeled track for azimuth tracking. A ball and screw jack provides elevation tracking. A sun sensor provides closed-loop tracking control. Each module is located in the collector field to minimize sun blocking by other collectors. Figure 5-41 is an artist's concept of one module. Figure 5-42 shows the plan view of the collectors.

The receiver is a cylindrical cavity which utilizes sodium as the heat transfer medium at an operating temperature of 750°C (1382°F). Figure 5-43 shows the arrangement of the receiver/power conversion unit. The power conversion unit consists of a reciprocating Stirling cycle heat engine with gear box and alternator to produce electricity. The heat engine is a P-75 Stirling cycle engine produced by United Stirling of Sweden (USS) modified for a sodium heat source and using helium as the working gas. Waste heat is conducted down the quadripod to a conventional water/ethylene glycol heat exchanger mounted behind the concentrator reflecting surface. The engine operating efficiency is 39 percent with a shaft output of 58.5 kWe at 1800 RPM. The alternator is driven by the engine through a 2:1 geared speed increaser. The electrical output is 52.7 kWe per module. Accounting for parasitic losses and electrical collection and transportation losses, the net output to the utility grid is 50 kWe per module.

Twenty modules are required to achieve the rated plant power of 1 MWe at a capacity factor of 0.37. A lead-acid battery storage subsystem and two more modules are required to achieve a 0.4 plant capacity factor. AC-DC convertors are used to connect the batteries to the utility grid.

d. Selection Criteria. The selection criteria to be used by the contractors in selecting system concepts are detailed in the following paragraphs.

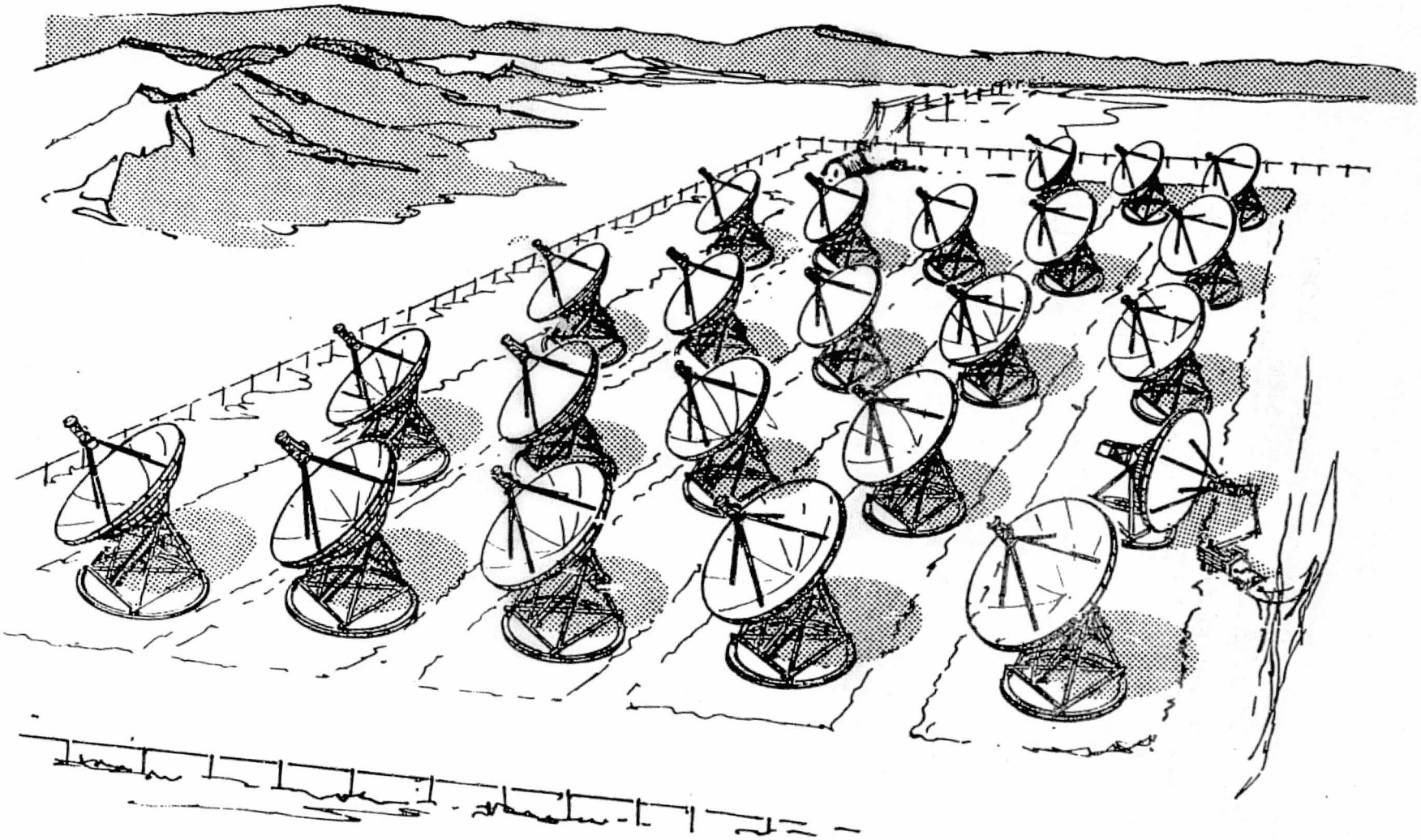


Figure 5-39. Artist's Concept of Ford Plant Layout

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

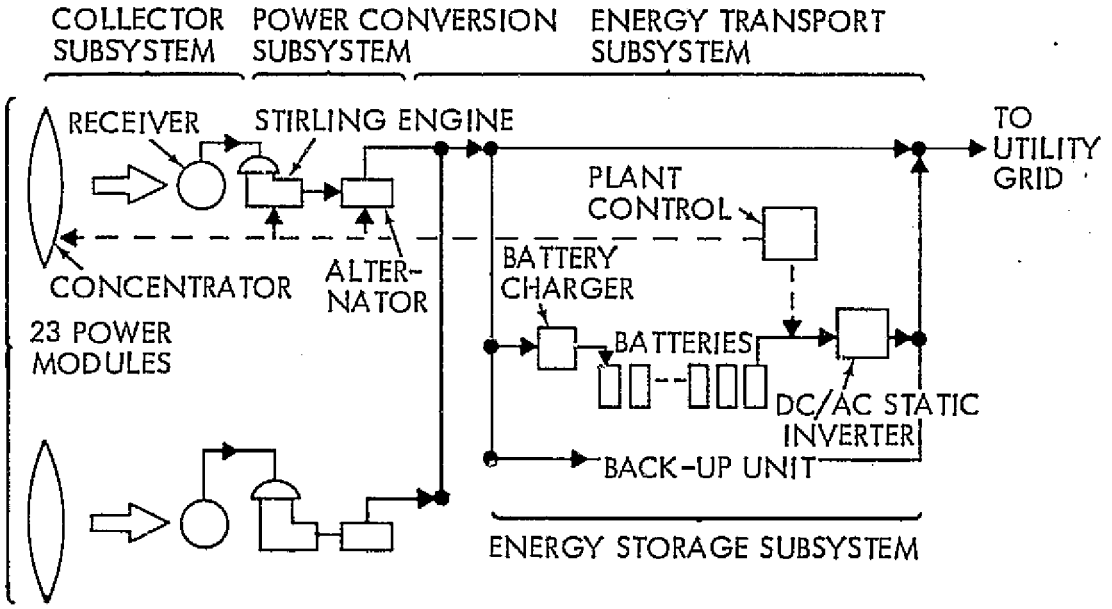
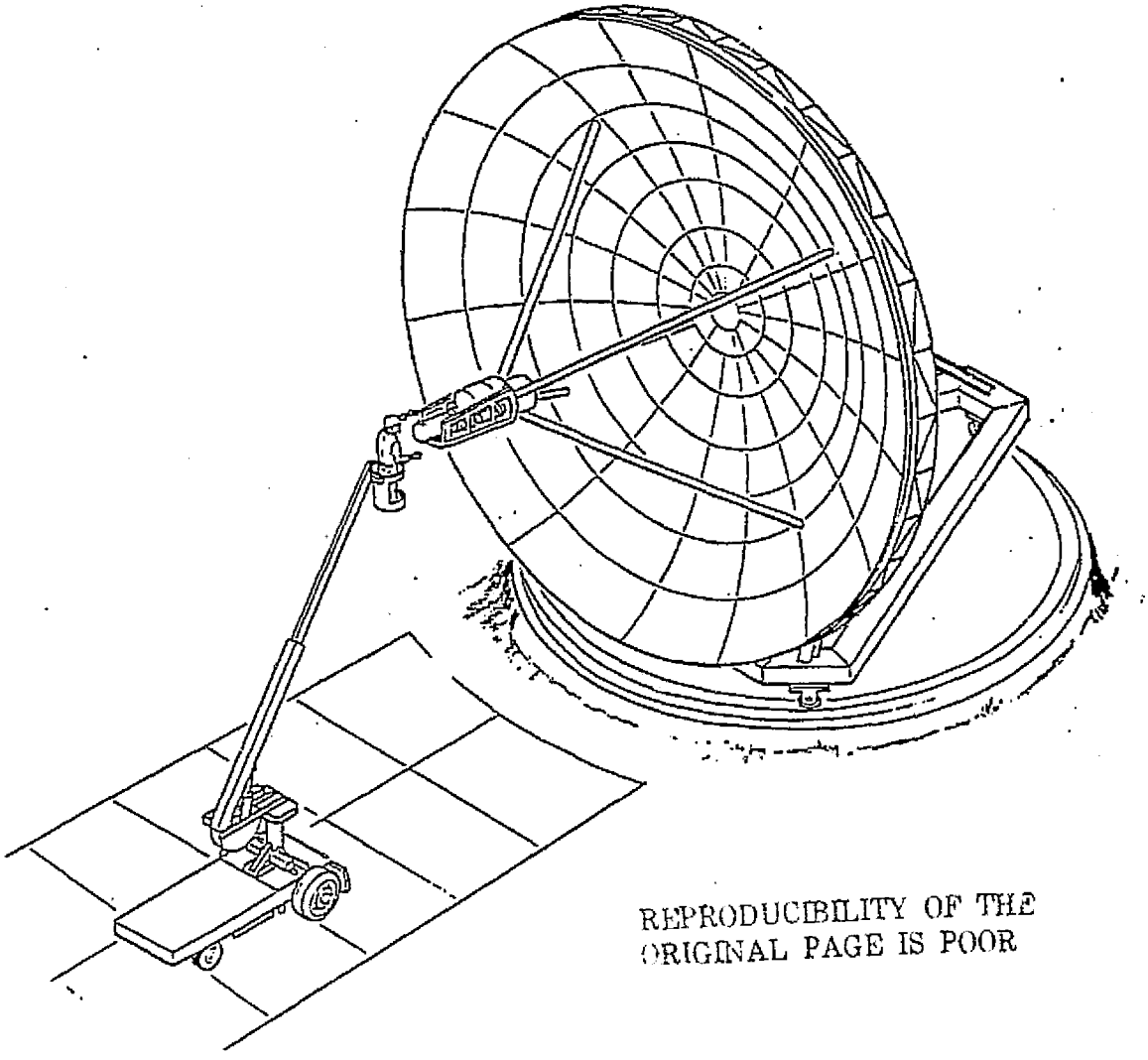


Figure 5-40. System Schematic of Ford Design

1) High Operational Reliability. High operational reliability is defined as follows: The system concept should lead to a small power system with an ultimate reliability approaching that of a commercial power plant.

This criterion is applicable to both the ultimate commercial plant and Engineering Experiment No. 1. Engineering Experiment No. 1 is the first small power system in the Solar Thermal Program to be used in a utility. Therefore, it will have a high visibility to users and to persons in position of responsibility for solar programs. Thus, it is important, that the Phase I concept selected for development during Phases II and III lead to a highly reliable experiment; i.e., one which will start satisfactorily and operate with a degree of reliability. For EE No. 1, the plant should operate reliably for at least two years after start-up with minimum forced outages attributable to system design deficiencies and hardware failures. The ultimate commercial plant must have a high reliability during its lifetime, typically thirty years.

The application of this criterion will include considering the enhancement of reliability through redundancy associated with modular design, where modularity refers to the design of the system being such that the power plant can operate in incremental power levels within an applicable power range (0.5 - 10 MWe) with minimum effect on system design and efficiency.



REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Figure 5-41. Artist's Concept of Ford Solar Thermal Power Module

2) Minimum Risk of Failure. Minimum risk of failure is described as follows: The system concept should be selected in such a way that it lends itself to subsystem development which is achievable within the Phase II time (8 months, 18 months, or 42 months) and minimize the risk of failure of the small power system being brought on line at the selected start-up time (3.5 years, 4.5 years, or 6.5 years).

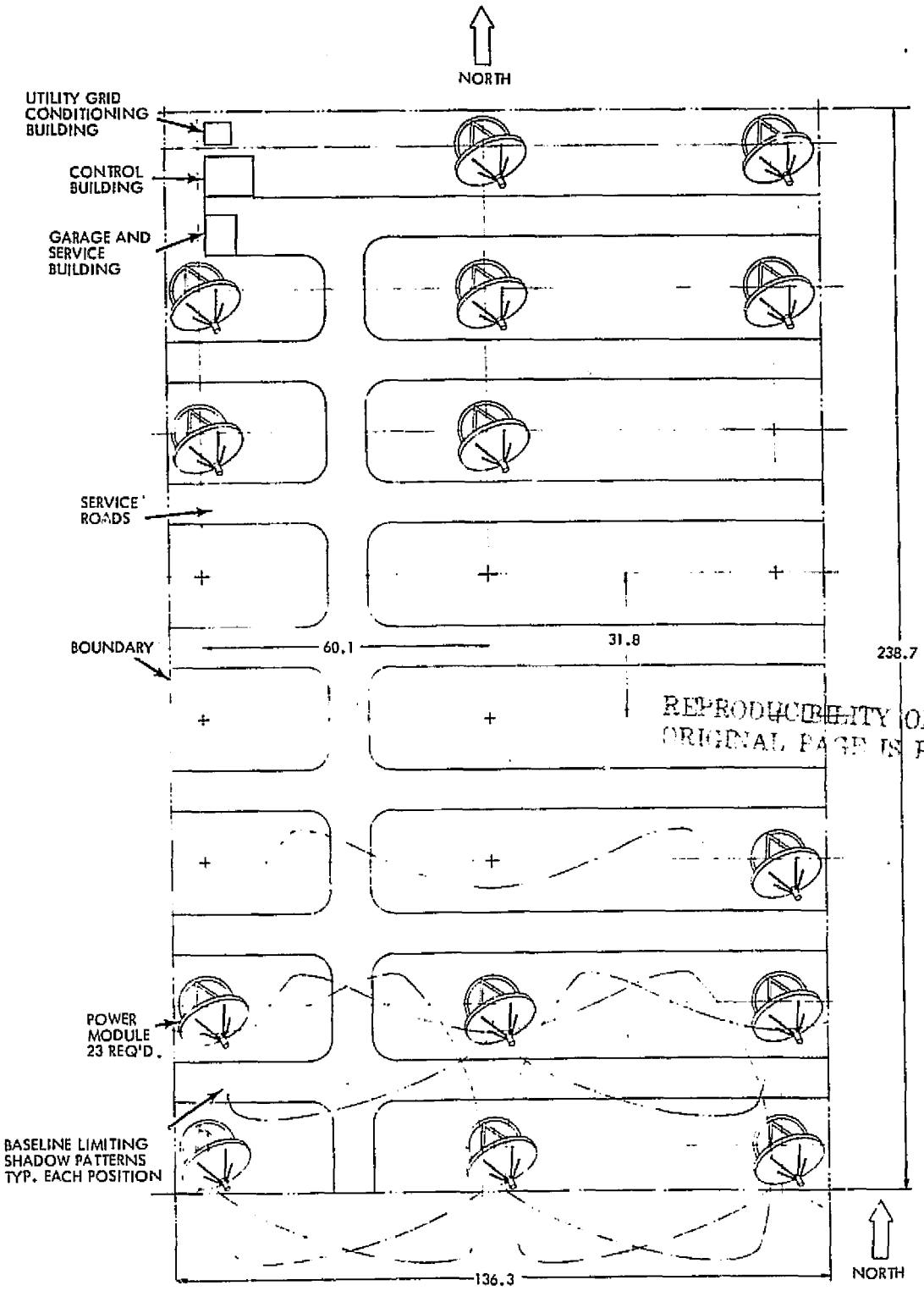
The thrust of this criterion is to assure a minimum development risk, and thereby provide a high degree of confidence that the start-up time will be met with the system selected. Considerations ensuring maximum schedule success include selecting concepts that have hardware available with proven performance so that new hardware development during Phase II can be minimized.

3) Commercialization Potential. This criterion refers to the proposed system when fully developed. The specific subsystems used for EE No. 1 need not have ultimate commercialization value, but it is essential that the proposed system concept can be upgraded to a commercially viable power plant.

Numerous factors are considered important in evaluating system concepts against this criterion. Compatibility with small community and utility applications requirements (e.g., utility interface, environmental and resource impacts, safety, aesthetics, etc) is one such factor. Another factor is the adaptability of the selected concept to applications other than utility applications. For both these cases modularity of design would be a consideration. Finally, the selected concept, when fully upgraded (developed), should lead to both low capital and low energy costs for mass-produced plants. To achieve the low energy costs suggests a system designed to have a relatively simple operation in order to minimize or eliminate the need for skilled plant operators, and minimize operations and maintenance costs.

4) Low Program Cost. Low program cost is described as follows: The system concept should be selected to minimize the estimated total costs of Phase II and Phase III.

The thrust of this criterion is to minimize Engineering Experiment No. 1 development and capital costs. To this end, consideration should be given to selecting concepts which have hardware available with proven performance so that development costs associated with Phase II can be minimized. In addition, the projected plant performance (i.e., overall efficiency and individual component costs) of the selected concepts should be such that the required capital investment for actual hardware for Engineering Experiment No. 1 can be minimized.



REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

Figure 5-42. 1 MWe Solar Power Facility, Plan View

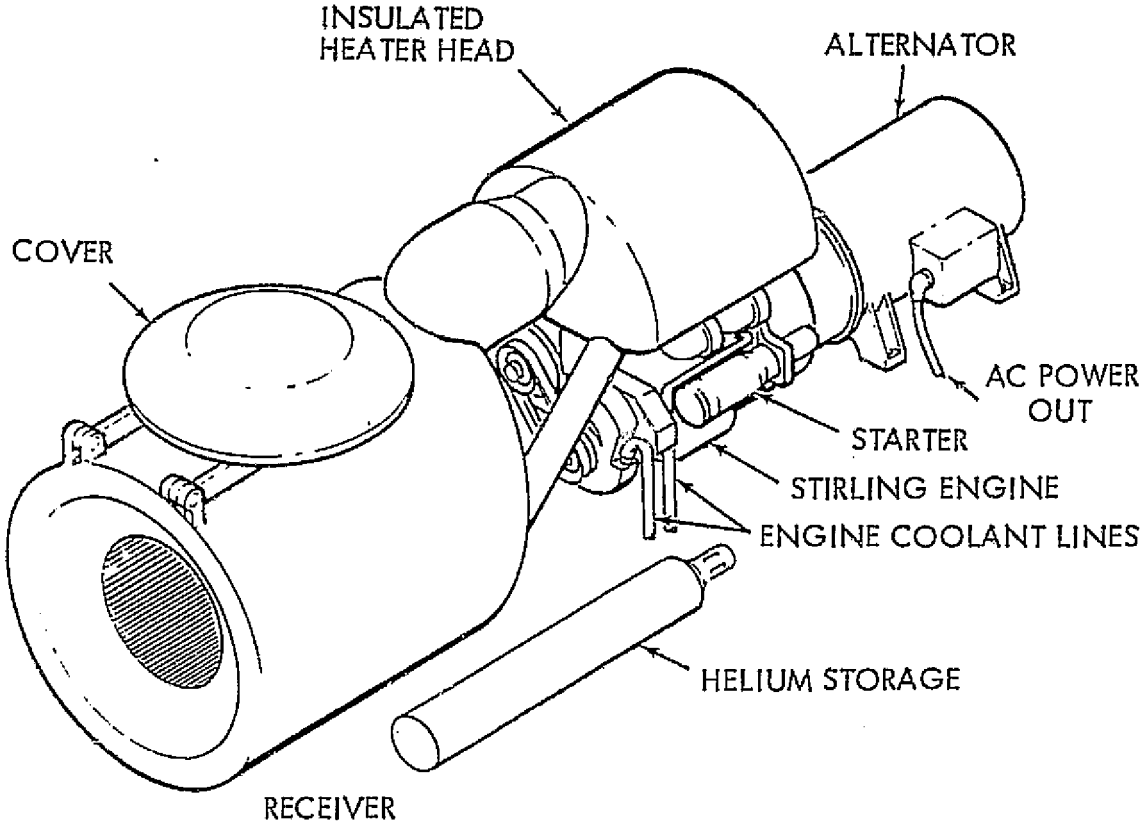


Figure 5-43. Receiver Power Conversion Unit

REFERENCES

5-1 Teagan, W.P., and Cunningham, D.R., "Conceptual Design and Analysis of a Compound Parabolic Concentrator Array," Arthur D. Little, Inc., Contract No. 31-109-38-3855, August, 1977.

5-2 R. Cole A.N.L. Private Communication, Feb 2, 1978.

5-3 Argonne National Laboratory, "Compound Parabolic Collector Field and Receiver Simulation," supplied by R.L. Cole, July 25, 1978.

5-4 Turner, R., "Economic Optimization of Energy Transport Component of a Large Distributed Collector Solar Power Plant" 11th IECEC Conference, State Line, Nev. Sept 12-17, 1976.

5-5 Honeywell Systems and Research Center, "Dynamic Conversion of Solar Generated Heat to Electricity," Monthly Technical Progress Narrative No. 3, 15 December 1973, NASA Contract NAS3-18014.

5-6 Roschke, E.J., "Compilation of Performance Data for Candidate Energy Conversion Systems," Jet Propulsion Laboratory, California Institute of Technology, J.P.L. Memorandum I.O.M. 346-479, J.R., November 17, 1977.

5-7 "Small Engine Performance Envelopes," Lewis Research Laboratory, Private Communication with the Jet Propulsion Laboratory, California Institute of Technology, 1977.

5-8 Barber, R.E., "Current Costs of Solar Powered Organic Rankine Cycle Engines," Solar Energy Volume 20, pages 1-6, Pergamon Press, 1978.

5-9 Manvi, R., and Fujita, T., "Economics of Internal and External Energy Storage in Solar Power Plant Operation," Jet Propulsion Laboratory, California Institute of Technology, (to be published in the 12th IECEC Proceedings).

5-10 Turner, R.H., "Thermal Energy Storage for Solar Power Plants," Jet Propulsion Laboratory, California Institute of Technology, JPL Internal Document 900-754, July 1976.

5-11 Semiannual Review, Solar Thermal Electric Central Receiver Research Study, FMC Corporation, Santa Clara, CA, December 1976.

5-12 Interim Report, Solar Thermal Electric Central Receiver Research Study, Document R-3617, FMC Corporation, February 1977.

5-13 Monthly Technical Progress Report Number 10, Central Receiver Research Study, Document R-3630, FMC Corporation, March 1977.

5-14 An Evaluation of the FMC Line Cavity Central Receiver Concept, Aerospace Report No. ATR-77(7523-21)-1, The Aerospace Corp., El Segundo, CA, April 1977.

5-15 Interim Report, Solar Thermal Electric Central Receiver Research Study, FMC Corp., August 1977.

5-16 Duvall, G.R., "Operational Evaluation of a Closed Cycle Laboratory Engine," Proc. 11th Intersociety Energy Conversion Energy Conf. (IECEC), 1971, 1976.

5-17 Fayrweather, D.J., et al., "Advanced Marine Closed Cycle Engines," Proc. 11th IECEC, 177, 1976.

5-18 Blake, C., "Solar/Brayton Receiver," JPL Interoffice Memo CS:78:143, July 31, 1978.

5-19 Jarvinen, P.O., "Solar-Heated-Air Receivers," Solar Energy 19, 139, 1977.

5-20 Giovan, M., Private Communication, JPL, July 31, 1978.

5-21 Selcuk, M.K., et al., "Preliminary Evaluation of a Parabolic Dish - Small Heat Engine Central Solar Plant," JPL Internal Document 900-749, July 1976.

SECTION VI

PROJECT ANALYSIS AND INTEGRATION

A. INTRODUCTION

The purpose of the Project Analysis and Integration (PA&I) task is to facilitate successful industrialization and commercialization of small solar thermal power systems. Using the results of the engineering experiments and supporting analyses, the PA&I task is directed at accomplishing SPSA commercial adoption goals, namely, achieving initial market penetrations in selected markets by 1985 and widespread adoption in the post-1990 time frame. Accordingly, the following specific objectives were established:

(1) To assess and then maximize economic and institutional feasibility.

(2) To plan and implement the accelerated transfer of small solar thermal power systems technology to the industrial and commercial sectors.

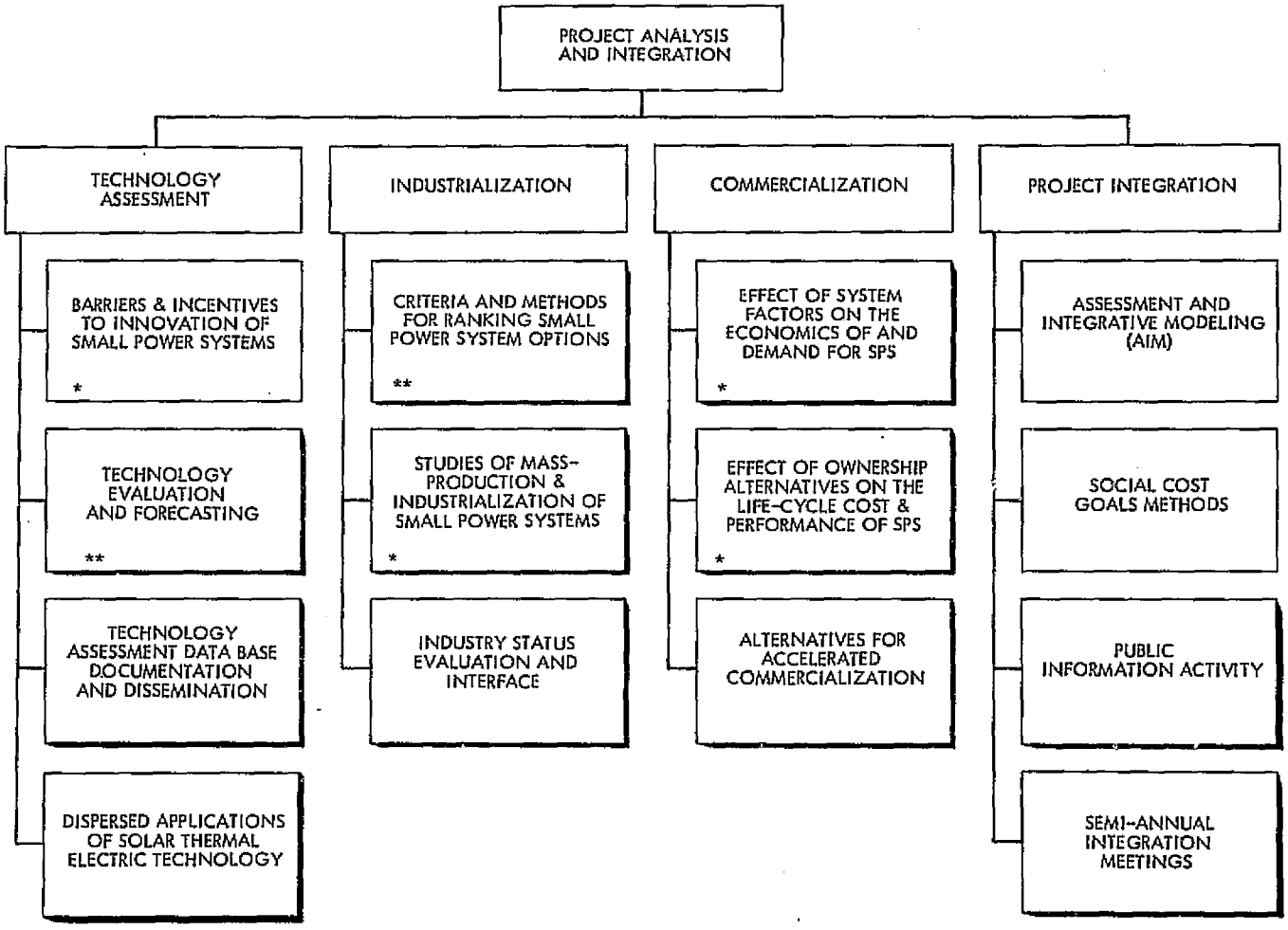
(3) To integrate SPSA activities and promote internal consistency of results.

(4) To evaluate and forecast progress in technological and industrial development and facilitate communication between industry, users, and the SPSA Project.

These objectives reflect the actions and the knowledge required to successfully introduce SPSA technology into the private sector over the next decade. Recent history of Federal RD&D efforts clearly indicates that a deliberate and well planned effort is required to stimulate the transfer and adoption of new energy technology within the private sector. The PA&I task represents a deliberate effort to conduct the Federal RD&D process in such a way that it will maximize the potential for successful commercialization of small solar thermal power systems.

B. TASK AREA ORGANIZATION

Four sub-task areas were organized to address the PA&I objectives. These are: technology assessment, industrialization, commercialization, and project integration. Sub-tasks within each of these areas are shown in Figure 6-1.



KEY:

* MAJOR SUBCONTRACTS (COMPETITIVE)

** CONSULTING AND SUPPORT SERVICES (NON-COMPETITIVE)

Figure 6-1. Project Analysis and Integration Work Breakdown Structure

C. TECHNICAL APPROACH

In order to meet its objectives and support key project decisions and other task areas, PA&I has adopted a multi-faceted approach incorporating a mix of analytic studies, program planning, information dissemination and direct interaction (with the SPSA supplier/user community.

To lay the groundwork for subsequent economic and policy analysis and concurrent program planning, PA&I initiated a study of the innovation process in general and the barriers/incentives impacting the development of small power systems in particular. This study has contributed to the identification of the key factors involved in the desired commercialization of SPSA technology.

As a means of assessing the current status of SPSA technology and the associated industry, PA&I conducted a series of interviews with selected firms. Discussions focused on both hardware and the requirements, in the opinion of industry, for the successful industrialization of SPSA technology. These interviews also served as a vehicle for disseminating information on the SPSA project and getting industry feedback.

To provide an analytic base for the development of strategies related to SPSA industrialization and market development, and to assess economic, financial and institutional feasibility, PA&I initiated a series of procurements in FY 1978 for studies of both supply and demand. The supply analysis is designed primarily to assess the potential for system cost reduction via mass production, a critical element of overall economic feasibility. The demand analysis is to estimate rates of penetration into selected markets and suggest strategies for enhancing these rates.

Potential users lack a financial model to evaluate their utilization of SPSA technology. To mitigate this problem PA&I has contracted for the development of an interactive Small Power Systems Financial Analysis (SPSFA) model. This tool will be available in FY 1979. PA&I will also use the model to perform financial analyses of small power systems applications.

To assist project management in its future selections of technical options, PA&I assisted in the development of criteria and methods for ranking small power systems options. This planning tool will be ready for use in FY 1979.

In terms of actually developing markets for SPSA technology, PA&I is actively involved in the planning of a joint DOD/DOE program (AMPS-Advanced Military Power Systems). PA&I is also exploring possibilities in foreign markets for future experiments and demonstrations.

For information dissemination, PA&I is preparing a series of brochures on the SPSA project. PA&I is also maintaining close liaison with potential suppliers and users, appropriate government departments and agencies, and SPSA supporters. PA&I supplied material for the President's Domestic Policy Review of Solar Energy.

To begin the identification and assessment of initiatives to accelerate the commercialization of SPSA technology, PA&I convened a working group in FY 1978 to develop a planning framework. Some potential initiatives and strategic plans have been identified and are being evaluated.

Finally, in order to synthesize the results of PA&I activites and generate guidelines for RD&D management, a draft comprehensive report was prepared. This planning document will be revised on a regular basis in the future. It and other documents resulting from PA&I activities will support key project decisions as shown in Figure 6-2.

D. TECHNICAL ACTIVITIES IN FY 1978

1. Barriers and Incentives Study

a. Introduction. Private industry has long been the primary source of technological innovation and commercialization. Historically, extensive federal R&D has been focused on military and aerospace efforts in cooperation with private sector technology and industrial development. A fundamental change in this relationship occurred in 1973 with the oil embargo. Faced with an energy shortage, a national endeavor was undertaken to accelerate the development and commercialization of new energy technologies. The Energy Research and Development Administration (now Department of Energy) was formed to administer this accelerated plan.

Two issues arise from this change in the federal/industrial relationship which impact the orderly development of new energy technologies. First, acceleration of normal time frames for development of new energy technologies creates discontinuities and conflicts. New as well as anticipated barriers to technology innovation are created, e.g., allocation of R&D resources between technologies, proprietary rights to inventions, patent waivers, stability and continuity of projects, etc. Secondly, technology development and commercialization traditionally have both occurred in the private sector. Industry R&D developed products for consumption in the private sector while government R&D was largely pursued for its own use. With new energy technologies, however, a large portion of the technology development is sponsored by the federal government while the marketing and adoption of that technology occurs in the private sector. A certain number of barriers emerge

PA&I SUB TASKS / PROJECT DECISIONS	SELECT BEST ACCELERATED PROGRAM OPTION	DETERMINE COMMERCIALIZATION STRATEGY	SELECT APPLICATIONS	SELECT TECHNOLOGIES	TEST APPLICATIONS & TECHNOLOGIES	DETERMINE IF DEMO REQUIRED	COMMERCIAL DEMO (S)
4.1 TECHNOLOGY ASSESSMENT							
4.1.1 BARRIERS & INCENTIVES	X	X				X	
4.1.2 TECHNOLOGY EVALUATION				X	X	X	
4.2 INDUSTRIALIZATION							
4.2.1 CRITERIA & METHODS				X	X	X	
4.2.2 MASS-PRODUCTION-INDUST				X	X	X	X
4.3 COMMERCIALIZATION							
4.3.1 EFFECTS OF SYSTEM FACTORS		X	X	X		X	X
4.3.2 EFFECTS OF OWNERSHIP		X	X	X		X	
4.3.3 ACCELERATED OPTIONS	X	X				X	
4.4 PROJECT INTEGRATION							
4.4.1 ASSESSMENT & INTEG. MODELING	X	X	X	X	X		X
4.4.2 SOCIAL COST GOALS			X				

Figure 6-2. Key Decision Support Matrix

because of the perceptions that the technology development is being pushed without a good assessment of whether there will even be a viable market for the technology in the time frames considered.

Anticipating and assessing for barriers and incentives is an on-going effort in the SPSA project. By understanding the barriers that exist, SPSA management can better insure that the program will reflect those actions required to maximize the probability of successful development and commercialization of small power systems. Efforts presently underway consist of a contract with Resource Planning Associates, Inc. to furnish an overview of the major requirements and problem areas in the assessment, industrialization, and commercialization of small power systems (see Figure 6-3). In addition, interviews with users, manufacturers, and a utility workshop have been conducted by JPL t provide additional insights.

b. Activities to Date. The barriers and incentives study to date has focused on 1) introducing potential users and suppliers to the concept and program for small power systems, 2) obtaining feedback and reactions to the concept of small power systems and the DOE Program for the development of the technology, 3) identifying those issues which could produce barriers and incentives to the successful adoption of the technology, and 4) establishing channels of communication with potential participants in the development of small power systems.

The decision to manufacture, purchase, operate and install small power systems will occur in the private sector. To provide input into SPSA management, interviews were focused on the government/industry interface and actions to facilitate the successful manufacture and adoption of small power systems.

1) Interviews with Manufacturing Industries. Industry response to our interviews was overwhelmingly positive. Few people before had asked industry its thoughts on the program management of government funded technology development and commercialization programs. The key factors emerging from the interviews were: a) high uncertainty and risk associated with the energy environment; b) poor government/industry interactions; and c) lack of defined markets for small power systems. While most of these issues are pertinent to any new energy technology, they are the framework and environment in which small power systems are being viewed.

A major uncertainty in industry's planning process is created by the lack of the National Energy Plan. The energy market operates predominantly in the private sector. Energy decisions (including R&D allocations) are based on the economics of competition. However, the government through legislative and regulatory policy can substantially impact the conditions for competition. Although the NEP is a short-term issue, it is one which will greatly delay consideration of new R&D programs for new energy technologies until NEP

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

	Economic Incentives: Lowering Small Solar Power Systems Cost								Economic Incentives: Raising Alternate Sources Costs				Technical Incentives		Institutional Incentives: Informational		Institutional Incentives: Market Development		Institutional Incentives: Legal/Regulatory		
	Direct Cash Subsidies	Credit Subsidies	Tax Credits	Accelerated Depreciation	Tax-Free Bonding	Extended Loss Carry Forward	Deregulation of Fossil Fuel Prices	Tax Policies	Marginal Cost Electricity Prices	Incorporate Social Costs	Removal of Preferential Treatments Fossil Fuels and Nuclear	Hybrid Funding/Refinancing	Utility Capacity Expansion Models	Demonstration Programs	Component Testing Facilities	Market Studies	Increased Manufacturer Role in Component Development	Federal Power Agency Purchases	Military Purchases	Back-Ground Patents Protection	New Patents Protection	Environmental Standards
Barriers to Use in all Market Sectors No proof of economic performance													▲				▲	●			
No proof of technical performance													▲	●			▲	▲			
Not considered near-term technology													▲		●		▲	▲			
Barriers to Use by Electric Utilities More expensive than competing systems	▲	▲	▲	●	●		●	●		●	●	●	▲								●
Too much land required												●									
Inappropriate size													▲	●			●				
Inability of planning models to handle these systems												●	▲	●			●				
Problems of siting dispersed systems														●			●				
Citizen opposition to unsightly collectors														●			●				
Barriers to Use in Industry Short payback required	▲	▲	▲	●	●			●	●	●		●		●							●
Unfavorable rates for utility back-up and buy-back	●	●	●							●		▲									
Lack of available land	●	●										●									
Continuous power required												▲									
Stringent health and safety regulations	●	●												●							
Barriers to Use in Farming Cost of systems too high	▲	▲	▲	●			●	●	▲	●	●	●									
Under utilization of the system	▲	▲	▲	●																	
Continuous power required												▲									
Farmer attitudes about land use	●	●																			
Barriers to Use by the Military Continuous power required												▲									
Military purchasing practices									●	●								▲			
Military budgeting practices																		▲			
Manpower ceilings																		▲			
Barriers to Use in Developing Countries Balance-of-payment problems	▲	▲																			
Limited funds available	▲	▲																			
Evening demand for village power												▲		●							
Insolation data unavailable														●							
International banks favor grid electricity	▲												▲	▲							
Skilled manpower shortage																					
Barriers to All Manufacturers Short payback required	▲	▲	▲	●	●	●								●		●		●	●		
Inadequate patent policies																				▲	▲
Federal research preempting private research															●		▲				
Barriers to Small Manufacturers High proposal costs																	▲				
Lack of credibility in federal contracting																	▲				

SOURCE: Resource Planning Associates, Inc

▲ Major impact
● Minor or indirect impact

Figure 6-3. Summary of SPSA Barriers and Incentives

is passed. Private as well as a federally funded R&D will be required for successful commercialization of small power systems. Private sector decisions to develop small power systems depend in large part on a positive assessment of defined markets - market potential, market readiness, and product fit. Once this assessment is made, then timing and allocation of resources to product development will be made. At the present time, industry perceives small power systems to be in the embryonic stage with massive market potential still 15 to 20 years away.

The government, however, is tending to push the technology development without the adequate market data. Having been its own market for R&D products for so long, the government seems to assume that a market will appear and respond instantaneously when a technically and economically viable technology is ready. In fact, the market place does not generally respond that rapidly. With a greater percentage of private innovations failing in the market place, industry is leary of allocating their scarce resources to an unproven technology for which no credible market assessment has been made (one in which industry has confidence).

Government policies can create barriers to the development of new energy technologies. Patent rights have long been an issue in federal funding of private sector R&D. With the government desire to hold patent rights, industry's incentive to innovate can be low. Industry perceives it cannot accrue the desired benefits from investment in R&D. There may be societal benefits, however, from general diffusion of information which results from government held patents. Consequently, this issue may not be a significant factor in private R&D in small power systems in the long run.

The government procurement process itself is also a barrier, reducing private industry incentive to innovate. Historically, most government procurement has been for hardware for which the government is also the consumer. Procurement proposals and specifications were often very prescriptive and tightly constrained. When these standards and methods are applied to development of the new energy technologies which are manufactured and purchased in the private sectors, little room is left for private sector innovation. Industry is concerned that the government does not know the point at which small power systems should be turned over to the private sector for further development and refinement. The government tends to overdevelop technologies. This will reduce the room industry will have to "personalize" small power technology to compete with similar technologies in the private market.

The criteria on which procurements are evaluated are often poorly related to the ultimate commercialization of the technology. Criteria for current procurements may be inappropriate for later commercial adoption. In addition, the stated criteria for evaluating proposals are perceived to be changing during the evaluation phase itself. Industry is willing to take a risk and participate in the development of new

technologies. However, it must know the ground rules under which it will operate and trust that those rules will be followed. At this time, government's credibility with private industry is not very high.

The processing time of procurements, from proposal submission to contract execution, is too long. Undue delays make it too costly for private industry to wait for government procurements. This is particularly true for small business which may not have the resources to stay afloat while waiting for the government to sign off on a contract.

2) Interviews with Potential Users. Resource Planning Associates interviewed a number of potential users of small power systems in some of the following market areas: utilities, mining, foreign countries, farming, military, industrial parks and office parks. While there are issues particular to each application, the major barriers common to all the users interviewed are:

(1) Lack of technical proof of small power systems reliability and feasibility

(2) Lack of small power systems economic competitiveness with alternatives

(3) Concern over public perceptions of "unsightliness" of large collector fields

(4) Insufficient land area availability (e.g., urban areas, expensive farmland, mining operations which don't have surface rights).

In addition, most people were unable to think concretely about small power systems. Solar energy is still generally perceived as a residential energy source. People find it difficult to realistically project the use of small power systems into the future when small power systems are still so much in their infancy today.

a) Utilities. Based on interviews with utility executives and planners, and a questionnaire distributed at a SPSA Utility Workshop, insights were provided in three areas: 1) barriers and incentives to the innovation of small power systems, 2) the utility planning process and leadtimes, and 3) the role of demonstration projects in the commercialization of advanced technology.

A major barrier to innovation is the high degree of uncertainty in the utility planning process caused by the energy environment. There is no National Energy Plan. In addition, there is a high level of uncertainty concerning fuel availability, future electricity demand, the cost and availability of capital for new power plants. It is difficult to obtain approval for new power plants. Thus, the decision-making environment is difficult enough for conventional energy sources, much less new, unproven technologies such as small power systems.

The planning process itself creates a delay in the accelerated commercialization of small power systems. The average leadtime for planning, licensing, and construction of new commercially available, non-nuclear power plants averages about 10 to 13 years. Therefore, small power systems are theoretically looking at 10 to 13 years from the time they are commercially available (technically and economically viable as well) before they can expect to come on line operationally.

Large utilities own and operate their own generation and transmission facilities. Many small utilities are just transmission and distribution operations. Small utilities will purchase power from large utilities, or if they own generating plants, it is with a consortium of other small utilities. Small utilities responding to the survey foresaw increased difficulty obtaining capital for new power plants and increased difficulty purchasing power from the large utilities. This reduced flexibility and autonomy along with the increased uncertainty in the energy future, are giving them the feeling of being "squeezed."

Land issues may be one of the more major barriers to small power systems. Utilities are concerned that citizens may oppose large fields of "unsightly" collectors. In addition, utilities are concerned about environmentalists and the "small is beautiful" contingent who generally oppose large scale or centralized energy systems. For these groups even small power systems may be perceived as "large".

b) Foreign Markets. Financing small power systems will be a major issue for the less developed countries (LDC). The bankers will, therefore, play a large role in this market than in domestic markets. In fact, banks have pushed centralized power generation and expansion of national grids in the LDC's.

The technology must be proven to the bankers (World, Inter-American, Asian, and African banks) and approved by the banks own engineering staffs before banks will finance small power system investments. The relative cost of the systems will be a major barrier. The international banks currently aim for the lowest cost plan (generation and transmission).

LDC's have severe balance of payments problems. With the many other pressing problems of food, health, and education, electrification projects may not be able to get the needed foreign exchange to buy small power systems. In addition, rural electrification can cause major sociological changes in rural villages.

The Middle East and other middle developed countries (Argentina, Brazil) appear to offer the best opportunity for small power systems. There is good insolation, the topography near the populated areas is relatively flat, and often there is land available near the populated areas (e.g. unusable desert land in Egypt). In addition, their populations and governments are better educated to deal with new technologies.

c) Agriculture. Irrigation consumes the largest amount of electrical energy. It is a good application for solar energy, since peak irrigation is generally at times of peak insolation. However, land is the primary asset for agriculture production. Therefore, the farmer will have to be convinced that permanently taking land away from crop production for mounting solar collectors is in his best interest.

d) Mining. Mining operations generally require a five-year payback. Mines generally run 24 hours a day, require absolute energy reliability, and often are only short-term (i.e. 10-20 years operations). Open-pit mining consumes a tremendous amount of land area, therefore, a land consuming technology such as solar is not viewed positively. In underground mining the surface rights are often not held by the mining operator.

e) Industrial and Office Parks. Few industrial and office parks produce on-site power. Parks tend to be speculatively built without hard commitments from potential tenants. With little idea of tenant power requirements, parks prefer to tie into the local grid and rely on the utility to meet new energy demands as the parks expand. A more detailed analysis of this m[illegible] will have to be undertaken before a good assessment can be made of [illegible] potential for small power systems. With an unknown electrical demand, the issue of system sizing will be an important factor in any determination of utilization of solar energy.

3) Incentives, Information, and Communication. Potential incentives which emerged from the survey efforts as necessary for the adoption of small power systems include:

(1) Demonstrations of commercial readiness (not technical or experimental) with three to five years of operating experience.

(2) Tax incentives for tax-paying firms.

(3) Grant incentives for publicly-owned firms and foreign markets.

(4) Appropriate and timely information and assessments.

(5) On-going communication, interaction, and information exchange between the government and private sector.

If small power systems are to be manufactured and adopted, better information and demonstrations will help mitigate the uncertainties about the technology. Technology and environmental assessments were identified as one of the more effective federal incentives. That information also needs to be disseminated in the appropriate form, to the appropriate people, and at the proper time. Demonstrations will also be required. However, the timing, size, and purpose may significantly

impact the success of the demonstrations. In all cases, the technology must be well in hand, technically and economically viable, before a commercial demonstration is undertaken. Premature or inappropriate demonstrations could kill any market for small power systems, no matter how viable the technology.

The SPSA project is undertaking a series of Engineering Experiments of small power systems to test concepts and ideas in particular applications. While these experiments must not be confused with, or in any way considered a commercial demonstration, they are a necessary prerequisite to any future successful commercial demonstration.

With marketing expertise in the private sector, it is essential that on-going and meaningful communication and interaction occur between industry and government. Industry (users and manufacturers) should help develop the criteria on which it will have to make a decision. Industry should be involved in the development of regulations and incentives under which it will have to operate, and participate in the evaluations of the technology and program approach to the technology development and commercialization.

c. Summary and Conclusions. Evaluation and development of strategies and incentives for SPSA management are just beginning. They will come from the analysis and evaluation of the issues briefly identified in the foregoing discussion. From the study of innovation processes, certain features of the traditional federal innovation process were identified which make the commercialization of small solar power systems much more difficult. These features include the lack of federal emphasis on analyzing market conditions, limited user involvement in federal innovation efforts, limited federal interaction with potential manufacturers, an emphasis on demonstrations as a measure of project success, and the tendency to prolong federal development efforts to the point where the government is competing with private innovation efforts.

Preliminary results from interviews and workshops indicate that the potential manufacturers and users of small power systems and components are ready and willing to participate in the SPSA program. And, they are willing to allocate their best resources to do so. There are, however, conditions which must be met to maximize industry's participation. One, industry must know the ground rules for government/industry interaction. It must have confidence in the validity and stability of those rules as they pertain to procurements, personal interactions, information exchange and government policies. Without that confidence government will have little credibility in the eyes of private industry. Two, industry must be involved in an integral way with the development of the technology and the programmatic planning for that development. To ask industry to make a commitment of resources to a program in which it may have no say is unreasonable.

Given the federal innovation process and the barriers and incentives to innovation in the private sector, some preliminary recommendations for the federal commercialization efforts can be made. While a major emphasis is required on the continued development of the technology and the meeting of technical and economic goals, the following recommendations will help assure that the technology will be introduced and adopted into the society with minimum difficulties.

1) Emphasize Market Analysis. The primary measure of successful innovation is the marketability of new products. Private firms must be convinced of the market potential of small power systems before they will produce and market them. If SPSA management hopes to succeed in commercializing small power systems. It is essential to undertake comprehensive market analyses. Initial evaluations of market potential should be conducted early in the innovation process. The specific applications for the technology should be identified for each potential market. In addition, it must be clearly understood how the technology will be applied in each market. Only the technology for which there is a strong present or projected market demand should then be funded for further development.

These market demand projections should be continuously revised and updated as cost and performance estimates are refined. At the stage where the technology is to be transferred to the private sector, a final analysis of market demand should be made to assure private firms that they can produce and sell small power systems profitably. Private firms are aware that more innovations fail because they lack a viable market than fail because of unresolved technical problems.

2) Build a User Community. Private firms have found that user involvement clearly identifies customer needs and desires. Once customers are involved in helping to develop a new product, they become committed to purchasing the product. Through workshops, program reviews and evaluations, SPSA can promote this user involvement and commitment to small power systems.

3) Build a Manufacturer Community. In addition to working closely with potential users, SPSA management should incorporate manufacturer/distributor communities into the small power systems R&D process. By forming a large group of potential manufacturers to take an active part in the development of small power systems, the SPSA management can more clearly identify the production and marketing conditions private firms require to produce and sell federally developed small power systems.

4) Adopt an Appropriate Demonstration Strategy. Although not the most immediate concern, SPSA management should develop an appropriate demonstration strategy by examining past demonstration efforts that resulted in successfully commercialized projects. The appropriate role of a demonstration in the federal innovation process is to reduce user, manufacturer, and distributor uncertainties about

the costs and performance of a technology. The demonstration should allow them to evaluate the technology to their own satisfaction. Joint participation and funding of demonstrations is an effective means to further the success of these demonstrations.

5) Avoid the Overdevelopment of Technologies. The federal government, in its attempt to perfect certain innovations, has refined some technologies to the point where potential manufacturers of the technology are unable to add unique features to differentiate their products from the products of competing firms. This prevents the firm from establishing its own market for the product. SPSA management must be careful, therefore, not to develop small power systems beyond the point where manufacturers are willing to adopt, refine, and market the new technology.

Small power systems are in their embryonic stage. A concentrated effort is required by SPSA management to steer the program toward the goal of successful development and commercialization of the technology. Working toward these initial guidelines and developing strategies corresponding to those guidelines, a more unified attack by industry and SPSA management can be focused on overcoming or mitigating the barriers to the accelerated utilization of small power systems.

2. Industrialization Studies

a. Introduction. The industrialization of a new technology can be defined as the process by which the technology is adopted by the manufacturing (i.e. supply) sector and developed into a marketable product. Hence, industrialization implies the development of both a product and a supply infrastructure. In addressing this duality as it applies to the SPSA Project, two key issues are being studied as part of the PA&I Task Area activities. These are:

(1) The potential for cost reduction via mass production

(2) The means by which the government can best stimulate the industrial development of SPSA technology

The first issue is a key element in the overall economic feasibility of SPSA technology. It is imperative that project management be given a valid assessment of the potential for reducing system costs via mass production. This information is critical to the formulation of project cost goals and the selection of R&D paths.

The second issue directly impacts the achievement of SPSA commercialization goals. It takes times for a supply infrastructure to evolve. Given the tight time frame in which SPSA technology is to achieve initial commercialization, the government, DOE and JPL must facilitate and stimulate industrial activity in SPSA technology development.

b. Analysis. The PA&I Task area has initiated a major analytic program addressing industrialization issues. The approach adopted includes (i) a major subcontract for a study of SPS mass production, (ii) ongoing interviews and discussions with selected firms, and (iii) other research activities.

1) Subcontract. The RFP for "A Study of Mass Production and Industrialization of Small Solar Thermal Electric Power Systems" was released June 1, 1978. Contract execution is expected in October 1978. The RFP calls for a 14 month effort and hence will conclude in late 1979.

The RFP calls for the development and costing out of scenarios for the mass production of three given systems. The first system to be analyzed will be a parabolic-dish concentrator with a Brayton cycle engine located at the focal point. The other two systems will be advanced versions of parabolic-dish distributed receiver systems using small heat engines. Although the designs will be preliminary in nature, the objective of this effort is to determine the potential for cost reduction via mass production.

The contractor is to determine the most cost-effective means of producing and installing the systems for annual volume in the range of 100-10,000 MWe. This effort will include consideration of manufacturing processes, factory layouts, and supply industry infrastructure. Particular attention will be paid to the identification and assessment of measures that could lead to system cost reduction.

A computer cost model will be developed so that extensive parametric and sensitivity analyses can be performed. This model will serve as a standard tool for costing out SPSA designs.

2) Interaction with Industry. Site visits were made to twelve firms over the past year as part of an information gathering effort in support of PA&I research activities, particularly in the areas of technology assessment, barriers and incentives analysis, and industrialization analysis.

The discussions on industrialization pointed to a number of key factors that are b ing studied further, for example:

(1) Market uncertainty appears to be the primary impediment to private sector development of SPSA technology.

(2) Contributing disincentives are uncertain government policies, poor RFP's, the government's patent policy, inadequate information on government programs, and the evolutionary nature of the technology itself.

(3) Fabrication and installation procedures may be a better source of system cost reduction than mass production.

(4) Mass production may reduce collector costs by about a factor of two.

(5) Engine development would be facilitated if the SPSA engines could also be used in other applications.

(6) The prescriptive nature of the SPSA program may inhibit innovation.

A report summarizing these industry visits will be available in October 1978.

3) Other Research Activities. B. Hyman and M. Baker of the University of Washington were engaged under a consulting contract to perform a preliminary analysis of industrialization issues. They did a literature research on technology transfer, studied patent activity in the solar thermal area, and developed a questionnaire suitable for ascertaining the views and plans of the manufacturing sector regarding SPSA technology. It was concluded that use of this questionnaire would be premature at this time given the embryonic nature of the SPSA supply industry. The questionnaire will be of use at a later date as a formal survey instrument.

As part of a general PA&I effort to identify initiatives that will accelerate the commercialization of SPSA technology, consideration is being given to the implementation of a major push via a program of cost-shared demonstration projects, initiated and designed by the private sector, and aid to manufacturers as needed to generate the necessary supply industry. This initiative and others will be explored intensively in FY 1979 with a view to a selection being made in FY 1980 and implementation beginning in FY 1981.

Some historical analysis has been performed inhouse to determine the effects of mass production on analogous technologies. Significant unit cost reductions have been achieved in the production of heat pumps and gas turbines for example. The evidence, however, is inconclusive since it would require detailed study of the production history to determine the portion of this cost reduction that arose from mass production per se and not improved design. This analysis will be pursued further in the major subcontract described earlier.

c. Summary and Conclusions. In FY 1978 the primary PA&I effort in terms of industrialization analysis focused on the design and processing of a major RFP. The contract will be signed in October 1978 and will yield, among other things, comprehensive estimates of the potential for system cost reduction via mass production. As the data base improves over the life of the contract, substantive inputs to project management will be possible on matters related to the industrial development and production of SPSA technology.

3. Market Development Studies

a. Introduction. Commercialization is the process by which a new product moves from a technical feasibility status to one of marketplace acceptance, where private capital represents the primary source of financing (Ref. 6-1). The commercialization process is usually divided into four stages: Invention, Development, Introduction, and Diffusion.

The Small Power Systems Program has as its primary goal the commercialization of solar thermal electric technologies for dispersed applications (Ref. 6-2). The SPSA Project is one of three major projects being conducted within the Solar Thermal Power System Program. The other two, the Research and Development Project and the Point Focusing Distributed Receiver Technology Project, focus on the invention and development stages of the overall commercialization process. The focus of the SPSA project is on the determination of the most effective strategies and activities for the introduction and diffusion of solar thermal technology into the energy marketplace. The ultimate objective of "commercialization activities" is to match a sufficiently large number of willing buyers with willing sellers at an agreed upon price to have an impact on the future U.S. energy economy. In most market situations within the U.S. economy, this occurs between private parties with little or no direct governmental involvement. However, the depletion of low-cost fossil fuel resources and the growing dependence on foreign fossil fuel supplies are now major national issues. Thus, the government has recognized the need to intervene in the energy marketplace so as to stimulate the development and utilization of emerging energy technologies. In order to obtain the socially and nationally desired substitutions within the private sector energy marketplace, governmental intervention must be structured so as to produce a convergence between private and public sector needs and goals.

In order to achieve this required convergence within the Thermal Power System Program, all research, development, and demonstration activities must be conducted with the needs and requirements of both the buyers and sellers within the private sector clearly in focus. Industrialization analysis seeks to understand the seller's viewpoint within the private sector and was considered in the previous section. In this section, commercialization analysis is considered. The commercialization analysis seeks to provide a private sector user/consumer "demand-perspective" to the SPSA program in order that the program evince in its structure and activities a substantive understanding of the requirements and possible facilitating mechanisms for the successful introduction and diffusion of modular solar thermal SPS technology into the private sector marketplace.

The purpose of market analysis is to understand how the market penetration process for innovations occurs, and how, from the demand perspective, that process can be influenced in the most cost-effective manner. Unless SPSA activities are responsive to such considerations, the realization of private sector support and continued development of solar thermal electric technology in the near future is not probable.

b. Activities. The focus of the Market Development subtask area is the analysis of the markets for small power systems and of the market penetration process within each of those markets, the purpose being to maximize the potential for the successful introduction and widespread adoption of small solar thermal power systems. Previous governmental efforts at introducing technological innovations into the private sector have frequently failed due to a "technology push" orientation as opposed to a "demand pull" viewpoint. The private sector invests in that for which there is a definitive market demand. Thus, one goal of the SPSA project is to identify and characterize the various markets for small power systems and to understand the decision-making criteria utilized by potential investors in those markets. In this manner, the system requirements for the most promising markets can be more accurately defined, enabling RD&D activities to be evaluated with respect to the objective of ultimate commercialization. So also, governmental intervention strategies, mechanisms, and activities can be developed which will indeed stimulate private sector interest and investment. PA&I is just beginning to identify the issues, risks, and uncertainties which must be addressed and resolved in order for the SPSA program to more clearly define its role in the commercialization process for small power system technology and to identify the appropriate activities and strategies it should pursue. In-house studies have served to identify three near-term commercialization concerns:

(1) The identification of those markets for which government support of small power system technology is most apt to be successful in terms of subsequent commercialization

(2) The determination of the unique set of technical, economic, institutional, and environmental issues within each market sector which SPS technology and the SPSA program must successfully deal with and resolve in order to engender marketplace demand and to produce market penetration

(3) The appropriate role of the federal government in the commercialization process and the measurement of the costs and benefits of alternate intervention mechanisms.

In this section, the commercialization activities will be considered in addressing these concerns.

1) Market Sector Identification. Numerous studies (Refs. 6-3 and 6-4) have stressed the deleterious effect on market acceptance which an ill-conceived and inappropriate demonstration of a new technology can produce. In this context, it is imperative that program strategies and activities be evaluated with respect to the market sector to which they are directed. It also follows that market sectors for which the demand for SPS technology is greatest and in which it appears to have the greatest probability of successful inclusion need to be identified, characterized, and be the focus of near-term program activities and strategies. In this manner, government support can produce optimal results in terms of realizing near-term commercialization of the technology.

A 14-month contract is to be executed by JPL by November 15, 1978 entitled: "The Effects of System Factors on the Economics of and Demand for Small Solar Thermal Power Systems" (hereafter to be referred to as the "Market Analysis contract"). The objectives of Task 1 of this contract are to estimate the demand for and the rate of market penetration by small solar thermal power system technology in all feasible market sectors, and to select the more promising near-term market sectors for subsequent, detailed characterization and analysis. This contract will synthesize the existing information with respect to the demand for small solar thermal power systems, identifying the gaps in prior studies, and "filling in the cracks". The output of this task will provide valuable input into SPSA program planning and decision-making concerning those market sectors on which future program elements, strategies, and activities should focus.

2) Critical Market Factors. The commercialization of a new technology implies the acquisition of private sector support. This in turn requires an understanding of the workings of the private sector marketplace and of the factors which most critically impact demand and the rate of penetration in that marketplace. Historical data concerning government involvement in the introduction and diffusion phases of the innovation process point to the need for a program which utilizes the input and involvement of those people who will be the principal actors in the widespread use of the technology.

The SPSA project has initiated or is in the process of initiating studies directed toward an understanding of the energy marketplace and of those factors which have the greatest impact on marketplace acceptance, and has contacted numerous industrial and utility personnel to obtain their input and to acquaint them with the activities and objectives of the SPSA program.

Task 2 of the Market Analysis Contract calls for a sensitivity analysis of market penetration in specific market sectors to variations in solar thermal system factors such as:

(1) System Factors. Lifecycle cost, size of initial investment, performance capabilities, modularity, hybrid firing and storage capabilities, cooling requirements, etc.

(2) Ownership Options and Financial Factors. Utility, industry, cogeneration joint venture, third party; tax incentives, methods of financing, etc.

(3) Technology Diffusion and Marketing Factors. The degree to which the information requirements for decision-making by potential users are satisfied, the manner in which required information is formatted and disseminated, the nature of the marketplace: infrastructure, information delivery system, behavior and innovativeness, capital availability, legal and institutional barriers, regulatory environment and patent privilege status, etc.

This type of analysis will provide more detailed, market-sector-specific insights into the barriers and incentives associated with the commercialization of SPS technology.

The cost of small power system technology relative to that of the competition is a particularly critical issue impacting the viability of small solar thermal power systems in the marketplace. Those costs partly depend on a variety of ownership options and financial factors. The SPSA program has executed a contract with ESC Energy Corporation to develop an interactive computer program to compare the financial implications of constructing and operating alternative small power systems from the viewpoint of an industry or utility owner. This program will serve JPL as a planning tool and will be available to utility and industry representatives for use in energy and capital investment planning. Outputs of the program will include: (1) a printout of yearly cash flows for the life of the plant, (2) a net internal rate of return analysis, (3) optional capital investment analyses, including revenue requirement, net present value, and pay back period approaches, and (4) down-side risk and up-side benefit sensitivity analyses.

The data input format for the program has been drafted. Preliminary baseline cases are now being developed for internal JPL review. This computer program will be a major input to Task 2 of the Commercialization Contract.

3) Federal Strategies. Government support of the introduction and diffusion of SPS technology into the private sector marketplace is the primary focus of the SPSA project. The primary question which the SPSA project must address is: What is the optimal form and content of government support of the introduction and diffusion phases of SPS technology? The government must take the initiative, enlisting private sector support and input, and defining, in the context of SPS technology, the new roles and relationships that will enable national energy objectives to be achieved.

This role definition process will undoubtedly require an iterative approach. The total implications or value of any given role/strategy can never be predicted (Ref. 6-5). We lack substantial experience with predicting the response of the private sector to government support of the workings of the private sector. Strategies will need to be implemented on a small scale and the results carefully monitored and used to provide input to the subsequent round of programmatic decision-making. What is important in the near-term is that those market sectors which appear to be the most promising with respect to the marketplace viability of SPS technology should be identified so that they can serve as the testing ground for near-term strategies, and that strategies be formulated and evaluated based on the characteristics of those specific market sectors. To this end, Task 3 of the Commercialization contract calls for "the development of strategic measures in response to those critical factors (identified in Task 2) which most stimulate demand and accelerate

market penetration in specific market sectors; and recommendations for the most cost-effective commercialization strategy to foster and accelerate the widespread adoption of solar thermal small power systems in selected near-term market sectors" (identified in Task 1).

c. Summary and Conclusions. SPSA project activities must be closely aligned with typical private sector business activities and perspectives if the SPSA goal of long-term, sustained private sector investment in small solar thermal power systems is to be realized. This alignment process occurs through the proper integration of solar thermal technological capabilities and marketplace needs and demands. The Market Analysis subtask area provides a demand perspective to the SPSA project by identifying the potential markets for solar thermal technology, by determining the sensitivity of the rate of market penetration to various market factors in each market sector, and by characterizing the process whereby the private sector in each of those market sectors evaluates alternative energy sources. These three activities are the major focus of the Market Analysis Contract to be completed by December 1979. Such a demand perspective will enable SPSA program management to:

(1) Provide specific inputs to R&D efforts

(2) Structure appropriate, directed demonstration activities

(3) Develop effective, market-sector-specific commercialization strategies for stimulating private sector investment in solar thermal technology

4. Decision Analysis

a. Introduction. The development of a suitable ranking methodology in support of the Technical Comparison Studies (see Section V) was assigned to the PA&I Task Area. The methodology, as it is developed, will be supplied to Pacific Northwest Laboratories and the Solar Energy Research Institute for use by them in their studies.

During the 1978 fiscal year, the decision analysis effort has concentrated on developing criteria, attributes and a practical methodology for evaluating and ranking the technology alternatives for small solar thermal power systems applications. Among the technology alternatives to be ranked are point focusing distributed receiver systems, point focusing central receiver systems, and others as described fully in Section V of this report.

The main purpose of the decision analysis effort is to rank order technology alternatives for small solar thermal electric power systems in order to help narrow the field of alternatives to those which show the greatest potential for successful commercial development. With the basic methodology developed for ranking, appropriate changes in the criteria and attributes would enable the methodology to be adapted to assist with other small solar thermal power systems decision activities such as selecting:

(1) Appropriate technology alternatives for construction of experimental systems

(2) The optimal technology alternative for a specific application and/or site

(3) Applications and sites

A flow chart of the implementation process for the ranking methodology is given in Figure 6-4. During the next fiscal year, the decision analysis effort will be concerned with applying the methodology. The technical information needed to carry out this effort will be supplied by the systems definition task. Coordination between the decision analysis and systems definition efforts will have to be close.

The attributes for evaluating the technology alternatives are grouped into the five major criteria of cost, finance, performance, impacts, and industrial and commercial potential. Meetings and discussions involving decision analysis and systems definition representatives of Jet Propulsion Laboratory, Pacific Northwest Laboratories, and the Solar Energy Research Institute, were held to discuss the criteria and attributes to be used in the ranking effort. Out of 25 proposed attributes, 6 primary attributes were selected to evaluate technologies with respect to the major criteria. These attributes are discussed following this introduction.

The methodology prepared to rank the technology alternatives with respect to the attributes is derived from the widely respected work of Keeney and Raiffa (Ref. 6-13). Their approach is based on a special form of the decision maker's utility function. An introductory level explanation of the Keeney and Raiffa approach is given in Feinberg and Miles (Ref. 6-11). This approach has been applied to a variety of problems including ranking of proposed pumped storage sites, determination of R&D planning strategy for a private corporation, comparing underground vs. surface siting for nuclear power plants, etc. (see Thornton et al (Ref. 6-14) for a more extensive list).

The multiattribute decision making approach of Keeney and Raiffa does require that the decision maker answer a fairly large number of questions, many of which are posed as lotteries. A sample lottery question is: "Do you prefer levelized energy cost of 100 mills per kilowatt-hour for sure or a fifty-fifty chance of levelized energy cost of 70 mills or 120 mills per kilowatt-hour?"

A simplified approach based on Keeney and Raiffa's methods has been described by Miles (Ref. 6-15). This simplification preserves most of the power of the Keeney and Raiffa approach but requires only seven lottery questions when there are six attributes used in the evaluation. Both the Keeney and Raiffa approach and the Miles simplification are discussed in the methodology section.

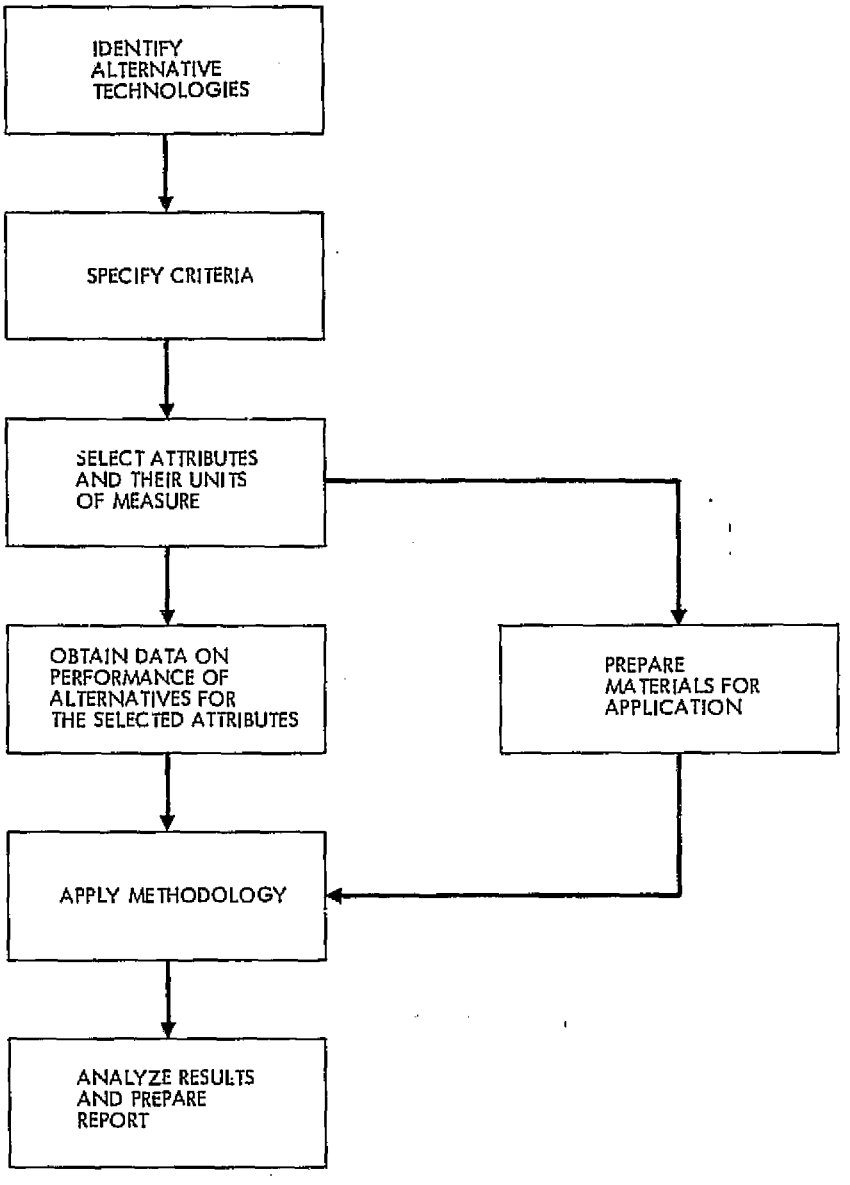


Figure 6-4. Implementation Process for Ranking Methodology

The decision analysis section is concluded with a brief summary. The summary covers progress to date and planned efforts for the next fiscal year.

b. Criteria and Attributes. It is appropriate to define the terms criteria and attributes. Here criteria are defined to be performance areas by which technology alternatives are assessed with regard to managerial objectives for Small Solar Thermal Power Systems Applications. They are attended to be broad general areas such as cost, financial requirements, impacts, plant performance, and industrial and commercial potential.

More specific than criteria are attributes which are defined to be measures of performance of alternatives with respect to criteria. Attributes must be quantifiable. Sometimes this entails a subjective scale that is assigned the range 0 to 10. For example, forced outage rate is an attribute that is an essential indicator for the criterion, plant performance. Although many attributes can measure performance for each criterion, the number of primary attributes used must be limited to about ten or less in order to make the procedure tractable for the decision maker.

The set of attributes to be employed when ranking technological alternatives must meet several standards. It must be complete enough to include all of the factors that could significantly influence the decision, yet not so large as to overwhelm the evaluator. As a general rule, attributes should be carefully selected to avoid redundancy or double counting of the system characteristics. The attributes selected should also differentiate between systems by measuring only important advantages and disadvantages inherent in the different types of technologies being considered. For instance, most of the cost factors are included by a single calculation of levelized energy cost. It would be redundant to include additional cost attributes. Rather, other attributes should measure major extra aspects such as environmental, social or institutional factors that impinge on the choice of technologies.

The criteria and attributes selected should have the following properties:

(1) Differentiation - the attributes should reflect actual differences between the alternatives technologies being considered.

(2) Importance - each attribute should represent a significant factor in the value model of the decision-makers.

(3) Familiarity - each attribute should be recognizable and understandable to the decision-maker.

(4) Measurability - the criteria or attribute can be subjectively or objectively measured with data that can be attained within the time and resources available for the decision analysis.

(5) Independence - changes within certain limits in the value of one attribute should not affect preferences or tradeoffs between other attributes.

The criteria and primary attributes developed during this year for ranking technology alternatives is depicted in Figure 6-5.

After considerable investigation and discussion, tentative scales for the primary attributes were derived based on preliminary technical reporting from the project (see criteria and attribute listing (2)). These scales consist of a unit of measure and an upper and lower bound for each attribute. These tentative scales are given in Table 6-1 which is followed by some explanatory notes.

c. Methodology for Multi-attribute Decision Analysis. The steps in Keeney and Raiffa (Ref. 6-13) multi-attribute decision analysis methodology are given next.

1) Keeney and Raiffa Approach

(1) Conduct tests for preferential independence. This involves assessing the tradeoff for each attribute in terms of the most important attribute, and ascertaining if this tradeoff varies with changes in the other attributes. For example, test to see that the tradeoff of plant performance for levelized energy cost does not vary with the value of capital cost, nor with environmental and safety effects, nor with R&D requirement, nor with applications flexibility.

(2) Conduct tests for utility independence. This entails assessing the probability within a lottery for two different values of one attribute, that would make the lottery equally preferable to a fixed value of the same attribute. In order for utility independence to hold, the probability cannot vary with charges in the other attribute values.

(3) Determine utility values for each attribute by asking a series of lottery questions for each attribute.

(4) Calculate the scaling constants by asking a lottery question for each attribute.

(5) Calculate utility values for the technology alternatives and rank them accordingly.

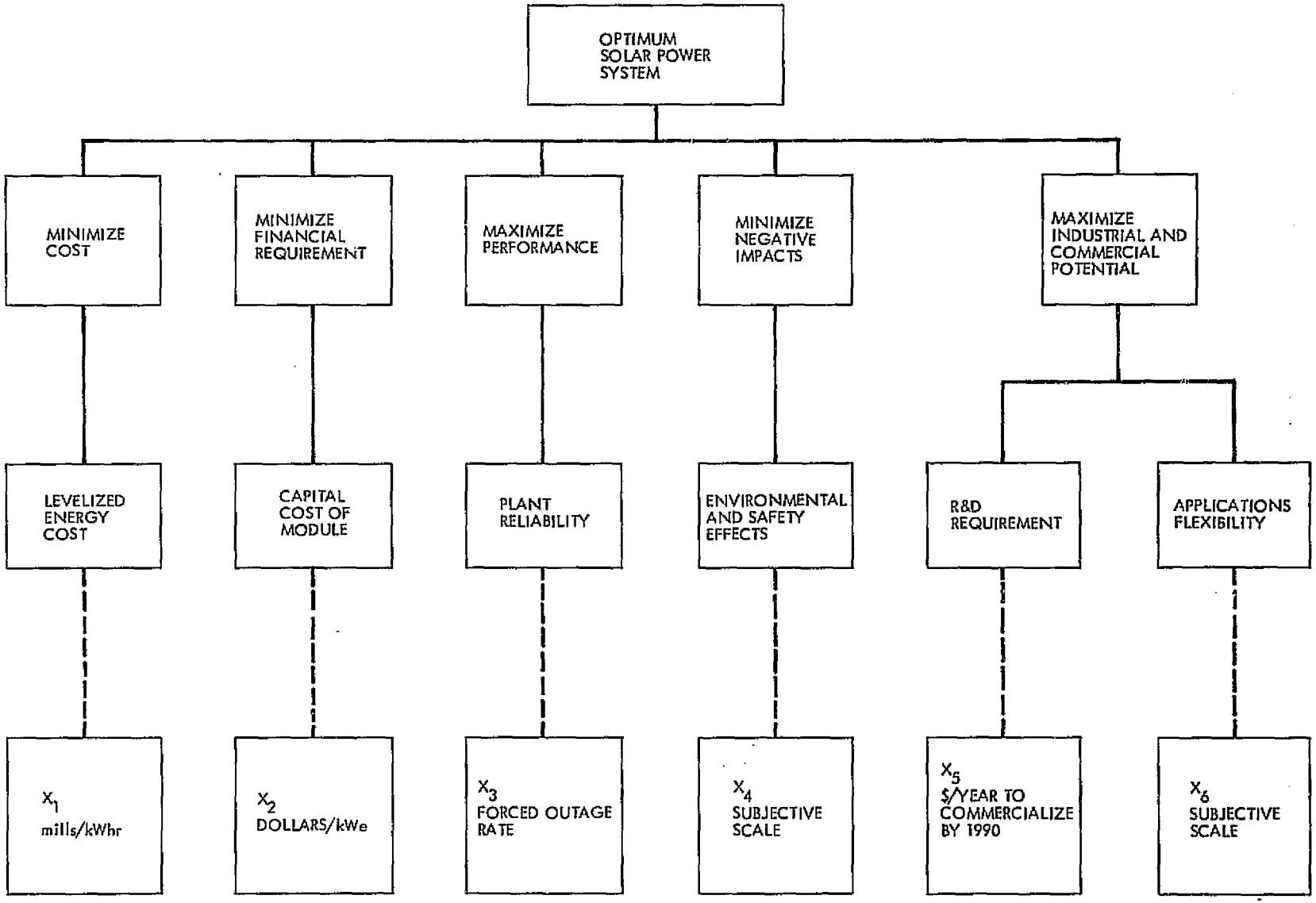


Figure 6-5. Criteria and Attributes for Ranking Solar Thermal Electric Power Systems Technology Alternatives

Table 6-1. SPSA Technology Alternatives Criteria and Attributes with Tentative Scales(1)

Criteria	Primary Attributes	Tentative Scale (a)
Cost (b)	Levelized Energy Cost	70-120 mills/kWhr in 1978 $ for 1990 Startup or 40-80 mills/kWhr in 1978 $ for 2000 Startup
Finance (c)	Capital Cost	$1800-3000/kWe in 1978 $ for 1990 Startup or $600-1800/kWe for 2000 Startup
Performance (c)	Plant Reliability	18-80% Capacity Factor (Depending on Insolation and Storage) 0-10% for Forced Outages (Due to Hardware Failures)
	Safety and Environmental Effects	0-10 Subjective Scale 0 = Effects similar to Coal Fired Steam Plant 9 = Environmentally Neutral 10 = Mildly Positive Environmental Effects
Industrial (4) and Commercial Potential	Research Development and Industrial Requirement	10-50 $ Million/Year to Commercialize by 1990 for 1 Technology
	Applications Flexibility	0-10 Subjective Scale 0 = Few Applications 10 = Wide Applicability

Notes on Attribute Scales from Table 6-1

(1) Nearly all systems ratings and therefore attribute scales are affected by hybrid systems, year of startup, and intended market penetration (utility or non-utility, intermediate or base load). Non-utility applications (e.g., military, foreign) may be important in the 1985-1990 time period.

(2) These cost ranges reflect current goals for competitive systems. These ranges are sensitive to insolation data and to the use of storage. The levelized energy cost ranges and capital cost ranges may not coincide with each other since they were independently derived. See (2) for further detail.

Table 6-1. SPSA Technology Alternatives Criteria and Attributes with Tentative Scales (Continuation 1)

(3)	This range includes allowances of 0-10% for mechanical forced outages with hybrid firing, a modular plant could theoretically go to 100%.
(4)	Research, development and industrial costs are not additive for multiple technologies. If $20 million/year is spent for one technology, then three technologies would cost less than $60 million/year due to overlap. A commercial technology would take five years of development for 5-10 plants (of 10 MW at $2000/KW, this would be $20 million per plant). For $100-200 million over 5 years, this would be $20-40 million/year. Additional similar technologies would be less, but some technologies would be more costly to develop.

Many lottery questions are involved in each of steps 2, 3, and 4. Although this procedure has been used extensively (many applications are listed in Ref. 6-14), the large number of questions overall, and numerous lottery questions in particular, makes the procedure hard to apply, especially with busy executives as the respondent decision makers.

Pursuing objectives of retaining much of the rigor of the Keeney and Raiffa methodology yet reducing the burden on the respondent decision maker, Miles (Ref. 6-15) has developed a simplified approach. The steps in Miles approach, given below, would require that the number of lottery questions be only one more than the number of attributes. With six attributes, only seven lottery questions would need to be posed.

2) Miles' Simplified Approach

(1) Assess the utility function for each attribute by asking but one lottery question for each attribute. Ascertain that these responses do not vary with the levels of the other attributes.

(2) Ask the decision maker which attribute he would most prefer to move from its least preferred to most preferred value. This would then be his most important attribute.

(3) Assess the scaling constant or tradeoff for each other attribute in terms of the most important attribute.

(4) Assess the scaling constant for the most important attribute by asking a single lottery question.

(5) Perform calculations necessary to determine the utility value for each technology alternative and rank them accordingly.

d. Summary. The accomplishments of the decision analysis effort have included consensus among three organizations on a workable set of criteria and primary attributes for evaluating the technology alternatives. Also tentative scales for the primary attributes have been obtained. A vigorous procedure for ranking multiattribute alternatives has been simplified into a more practical procedure. Toward the close of the fiscal year, the simplified procedure has been pretested and revised accordingly.

In the coming fiscal year, decision makers will be identified and asked to participate in the ranking exercise. These will include both utility and government representatives. The simplified procedure will be applied. With the decision makers' answers and final technical data on the alternatives, a ranking in order of preference will be determined and analyzed.

5. Other Activities

a. Strategies for Accelerated Commercialization. A working group was convened in June 1978 to address the problem of identifying initiatives that the SPSA Project might undertake in FY 1980 to accelerate the commercialization of SPSA technology. The group's efforts concluded with a presentation of their findings to SPSA Project management August 15, 1978. Further work will focus on the design and implementation of an "Industrial Transfer" initiative for FY 1981. The results to date will be reported in a paper to be presented at the ASME Annual Meeting in San Francisco, December 10-13, 1978.

b. The Economic Benefit of Modularity. A financial analysis of a modular solar thermal electric power system was performed to determine what savings in interest during construction would accrue from the sequential installation and startup of modules as compared with the conventional all-or-nothing plant. The analysis indicates that the modular power plant will have a power cost 4-7% less than that of its non-modular counterpart due to less interest during construction. Other advantages of modularity, such as reduced reserve capacity, will likely enhance this cost advantage. These aspects will be explored further in FY 1979.

c. Public Information. A general purpose leaflet was prepared describing the SPSA program. A technical brochure for use by potential system manufacturers and users is also in preparation. PA&I is also preparing a brochure describing the First Engineering Experiment, EE #1. The latter two documents will be available for distribution in early FY 1979.

d. Social Cost Analysis. In terms of social cost analysis, two studies were completed by PA&I in FY 1978. One study involved a broad analysis of the role of classical cost-benefit analysis in defining policy for alternative energy technologies. The other study focused on the valuation of human life and injury, a necessary quantification if one wants to do a comparative social cost analysis of the impact of alternative energy technologies on human mortality and injury rates.

e. Military Applications. The PA&I task area, in conjunction with the Systems Requirements task area, succeeded in initiating the development of a joint DOE/DOD Advanced Military Power Systems (AMPS) program. The structure of the program is currently being defined, as are the sources and level of funding for FY 1979.

REFERENCES

6-1 Resource Planning Associates, Inc., Barriers and Incentives to Small Solar Thermal Power Systems: Working Paper, Interim Report #1 prepared for the Jet Propulsion Laboratory, June 1978.

6-2 Resource Planning Associates, Inc., Private and Federal Innovation: Working Papers, Interim Report #2 prepared for the Jet Propulsion Laboratory, September 1978.

6-3 Federal Energy Administration, Task Force on Solar Energy Commercialization, DOD Photovoltaic Energy Conversion Systems: Market Inventory and Analysis, June 1977.

6-4 SPSA Annual Operating Plan, 1979, p. 12.

6-5 U.S. Department of Energy, The Demonstration Project as a Procedure for Accelerating the Application of New Technology, (Charpie Task Force Report), DOE/RA-0003/1&2, February 1978.

6-6 Office of Technology Assessment, The Role of Demonstrations in Federal R&D Policy, July 1978.

6-7 Tolley, George S., Methodology of Evaluating Research and Development Projects, Energy Research and Development Administration, COO/4128-1, September 1977.

6-8 Bezdek, Roger, et al., Analysis of Policy Options for Accelerating Commercialization of Solar Heating and Cooling Systems, The George Washington University, April 1977.

6-9 U.S. Department of Energy, Psycho-Economic Factors Affecting the Decision-Making of Consumers and the Technology Delivery System, HCP/M 2534-01, January 1978.

6-10 Office of Technology Assessment, Applications of R&D in the Civil Sector, (Library of Congress Catalog Card Number 78-600062), June 1978.

6-11 Feinberg, A., and R. F. Miles, Jr., "A Brief Introduction to Multi-attribute Decision Analysis," JPL Internal Document 5030-222, Jet Propulsion Laboratory, Pasadena, California, June 1978.

6-12 Ferber, R. R., A. T. Marriott, and V. C. Truscello, "Dispersed Solar Electric Power: A Small Power System Program," Proceedings of the ISES Conference, Denver, Colorado, August 1978.

6-13 Keeney, R., and H. Raiffa, Decisions with Multiple Objectives, John Wiley and Sons, New York, 1976.

6-14 Thornton, John P., Charles J. Bishop, Kenneth C. Brown, and Alan L. Edgecombe, "Small Power Systems Study, Quarterly Report No. 1," SERI-36, Solar Energy Research Institute, Golden, Colorado, July 1, 1978.

6-15 Miles, Jr., R. F., "Simplifying the SPSA Decision Analysis Interviews," JPL Interoffice Memorandum 311.2-544, Jet Propulsion Laboratory, Pasadena, California, 16 August 1978.

SECTION VII

FIELD TEST INTEGRATION

A. INTRODUCTION

The goal of the SPSA project is commercialization of solar thermal electric power systems for a variety of applications in the one to ten megawatt power range. To achieve this goal a major project objective is the development of experimental power plants to demonstrate the feasibility of utilizing small power systems. The first Engineering Experiment (EE#1) with a small community application is scheduled to be on-line at the end of 1982.

The objective of the Field Test Integration task area is the successful implementation of these experimental power plants following research of other SPSA tasks in requirements and systems definition. The specific tasks which will achieve this objective are: the development of site requirements and evaluation factors, technical management of the power plant site development contracts, and the integration of site and system efforts from inception through experimental operation.

B. TASK AREA ORGANIZATION

The Field Test Integration task efforts, identified in the task work breakdown structure, Figure 7-1, are organized into four major subtask categories.

1. Site Selection

Responsibilities include development of the siting approach, preparation of proposal requests (PRDA), proposal evaluation criteria and procedures and technical management of the resulting DOE site participation agreements.

2. Site Integration

Site activities must be integrated with the power plant system efforts. The system contractor will accomplish the design, fabrication, construction, installation, and testing of the power plant; the site participants will acquire the site and permits, provide services, and incorporate the plant into the utility grid.

3. Experiment Implementation

The Field Test Integration task area is responsible for technical management of experimental power plant construction contracts following

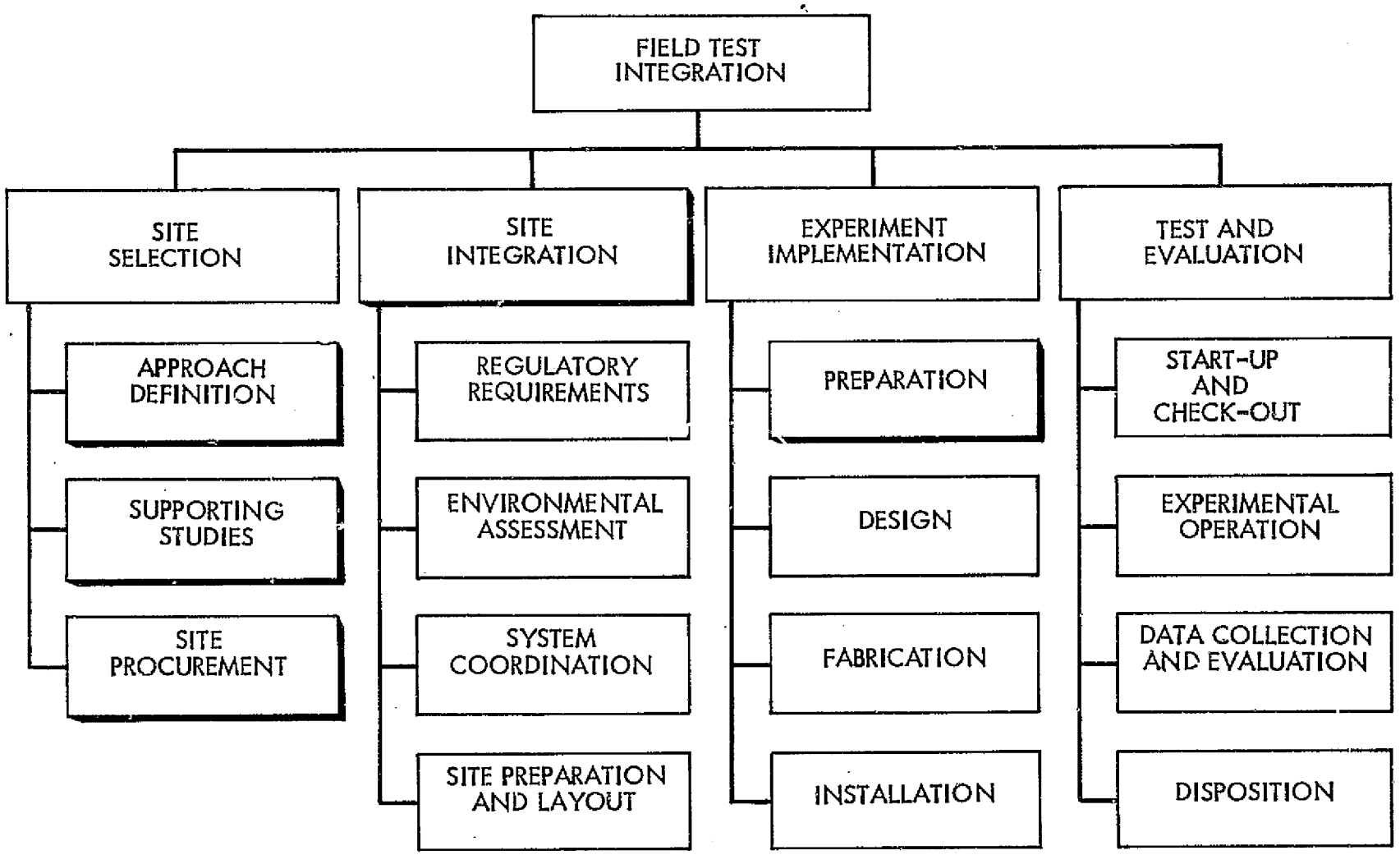


Figure 7-1. Field Test Integration Work Breakdown Structure

system definition. This includes final design, fabrication, construction, and installation.

Preparation for these construction activities is accomplished by participation in system definition and design and the accomplishment of ad hoc study efforts.

4. Test and Evaluation

Technical management of the power plant system contract also extends through test and experimental operation. This will involve the coordination of data collection and evaluation relative to plant performance.

C. TECHNICAL APPROACH

In this section the task approach is described for the first Engineering Experiment (EE#1) which is defined as a small community/utility application. This approach will be modified in future experiments to fit alternate applications.

1. Development of Siting Plan

Workshop inputs from utility representatives were considered in conjunction with experiment system requirements and programmatic direction from DOE in the development of the siting plan and procedures. For the first engineering experiment site proposals will be solicited by a Program Research and Development Announcement (PRDA). To minimize costs, the PRDA will contain a set of advisory qualification standards which will enable proposers to estimate the adequacy of their sites prior to proposal submission. Additionally, the information requested by the PRDA will be simple and easily accessable to community/utility proposers.

2. Siting Issues Study

Following development of the siting plan a study was conducted that defined the important siting issues. The results of this study were published in the report, "Siting Issues for Solar Thermal Power Plants with Small Community Applications."

3. Site Evaluation

Results of the siting issues study provide the basis for defining evaluation factors for site screening and selection.

Screening proposal requirements and evaluation factors have been proposed for DOE who will issue the proposal solicitation. Consulting support will be provided to a DOE screening evaluation board.

Similarly, the PRDA for site selection will be prepared for DOE release, and consulting support will also be provided to the DOE evaluation board.

4. Site Integration

Technical management will be provided for the DOE site participation agreement. These activities will be integrated with the power plant construction.

5. Experiment Implementation

Technical management of the power plant system contracts will be provided from final design through construction, installation, test and experimental operation.

D. 1978 TECHNICAL ACTIVITIES

1. Development of Siting Approach for EE #1

a. Small Power Systems Solar Electric Workshop.

1) Workshop Description. The Small Power Systems Solar Electric Workshop was conducted on October 10-12, 1977, to gain input from the utility community in identifying the important issues and requirements involved in the adoption of solar thermal power technology. One of the workshop topics was "Sites for Experimental Solar Thermal Systems." The purpose of this session was to obtain input and feedback from potential users of solar thermal electric experimental power systems. Opening remarks provided an introduction to interactive small group discussions. The participants of this workshop represented a cross-section of utility types and sizes; discussion inputs provided valuable project planning information to the Small Power Systems Applications Project relative to site activities and reasonable requirements for site proposer responsibilities.

2) Questionnaire Results. A questionnaire relative to siting issues and responsibilities was distributed to participants prior to the workshop session. (Tables 7-1 and 7-2.) The results provided a background for small group discussions in which participants were grouped by utility category and size.

Representatives from the utilities tended to opt for greater site participation. However, in most areas there was a general response similarity.

Table 7-1. Site Integration Issues for Experimental Solar Thermal Power Systems

Utility Category_____ Size_____ Generation_____
(Inv, Mun, REA, other) (Peak MWe) (Approx. percent)

Please check the following list of user/power plant system integration issues for which you think the site/user organization should have responsibility. Indicate P for primary, S for support and blank for no responsibility. Also check those items you consider to be important with an A for top priority, B for second priority or blank for low priority. Feel free to add items to this list.

PRIORITY (A,B)	ITEM	USER RESP. (P,S)	COMMENTS
	Power plant system design		
	Subsystem specifications		
	Plant/site layout		
	Site preparation/construction		
	Construction schedules		
	Power plant installation		
	Plant operation start-up		
	Experimental operation		
	Power production scheduling		
	Plant safety/security		

Table 7-2. Items To Be Furnished By Site/User Organization

Utility Category_____ Size _____ Generation _____
(Inv, Mun, REA, other) (Peak MWe) (Percent)

Please check those items you feel a site/user organization would be willing to provide to obtain an experimental solar thermal power plant. Use an X for fully furnished items and approximate percentage for partially furnished items. No commitment is implied. Also indicate by A or B those items you feel are major or minor problem areas. Feel free to add items to the list.

PROVIDE (X, %)	ITEM	PROB. (A,B)	COMMENTS
	Site (approx. 10 A.)		
	Site preparation		
	Non-solar portion of plant		
	Access roads		
	Utility services		
	Plant cooling water		
	Environmental impact statement		
	Site approvals and licenses		
	Visitor center		
	Funding of site costs		
	Insolation/environmental data		
	Community/government relations		
	Plant security/maintenance		
	Experimental operation		

It was generally agreed that the site participant should provide:

(1) A suitable site
(2) Local permits
(3) Utility services and access roads
(4) Tie-in to the utility grid
(5) Participation in site layout and preparation
(6) Plant security and general maintenance
(7) Local government/community relations

It was generally expected that the government system contractor should provide:

(1) The power plant (including generation)
(2) Construction and installation (including construction roads)
(3) Cooling (water) provisions
(4) Federal/state approvals
(5) Environmental data
(6) Power system maintenance
(7) Initial experimental operation

The larger generating utilities expected to provide more operational, licensing, and construction support and wanted a larger role in plant design, operation, and integration than small generating utilities and non-generating utilities.

3) Discussion Results. Questionnaire results were described in small group discussions after which each group reported in a general discussion period. Discussion remarks expanded on the relative responsibilities of the government and the site participants as well as site selection factors and site proposer concerns. Some key selection factors were considered to be insolation, utility demand and need, cooling water, community support, and site proposer capability (financial and technical).

The major concerns expressed from a potential site participation viewpoint were: power plant definition, provisions for disposal, coordination of experimental and power production objectives, maintenance, site participation funding, and environmental impact requirements.

4) Workshop Summary Comments. Utility representatives at the workshop were sensitive to any site limitations based on insolation and felt that requirements should be specific in this regard so that proposers are not mislead. For purposes of EE#1 siting, it was considered desirable to use a standard geographic insolation chart to standardize the site comparisons.

A wide range of comments were made with regard to utility capability. It was felt that there should be a balance between requirements for utilities with strong capabilities and incentives for smaller utilities.

Utility representatives at the workshop were especially concerned that the siting PRDA be very specific with respect to what a site proposer should be expected to furnish and what the government or system contractor will provide. A loose definition was expected to result in a bidding war where only the largest utilities could compete. This issue was addressed in both the questionnaire and a discussion group session at the workshop. The response indicated that the EE#1 site proposers should not be expected to offer as much as was indicated in the Program Opportunity Notice (PON) for the Central Receiver Solar Power 10 MWe Pilot Plant, especially if smaller utility bids were expected.

A number of comments at the workshop indicated concern with the high cost of proposal preparation, particularly for the smaller utilities. Specific definition of requirements as discussed in the previous section would help to reduce the number of noncompetitive proposals. The major potential approach for proposal cost mitigation was: the use of pre-qualification letters or simple proposal requirements for a preliminary screening with final, more detailed proposals submitted only by those surviving the screening.

Partial government funding of detailed engineering studies used in the final selection process was also suggested.

b. Proposal Requirements for EE#1 Siting. After review of results from the Small Power Systems Solar Electric Workshop, the following considerations were identified for refinement in the development of EE#1 siting plans.

(1) Delay of site selection until the power system technology approach is defined.

(2) Geographic site restrictions based on minimum insolation requirements.

(3) Proposal restrictions based on utility capability for experimental operation and/or type of system load application.

(4) Specific definition of items and services to be furnished by the successful utility/site proposer and definition of government support.

(5) Mitigation of potentially high site proposal costs.

c. Site Procurement Approach. Following discussion and review at JPL, the key issues were reviewed with DOE. This resulted in the following approach.

(1) Site restrictions should be minimized except for those which define the small community application. Rather, siting factors should be accounted for in an evaluation with a strong technical basis.

(2) The application must be in a definitive, small community with a load demand less than 100 MWe. The community character may be primarily residential, agricultural or commercial served by a utility or cooperative.

(3) A site selection process should be used that would minimize proposal costs for a large number of potential participants.

(4) Site participation requirements should consider the limited resources of small community participants. Requirements should include:

(a) Acquisition of site and permits
(b) Normal access roads and utility services
(c) Tie-in to a utility grid
(d) General maintenance
(e) Post-experiment operation

(5) The Government should provide:

(a) The solar thermal power plant
(b) Construction and installation
(c) Maintenance of solar thermal equipment
(d) Experimental operation

(6) DOE will:

(a) Issue the siting PRDA.
(b) Set up the evaluation board for site selection.
(c) Make the site selection.
(d) Issue the site participation agreement.

(7) JPL will:

(a) Prepare the siting PRDA for DOE approval and release.

(b) Develop evaluation factors and procedures for selection, subject to DOE approval.

(c) Participate in the DOE site evaluation board.

(d) Provide technical management of the site participation agreement for DOE.

2. Siting Issues Study

a. Background. Technologies for solar thermal power plants are being developed on an accelerated basis to provide alternatives for future energy needs. Besides technology development, solar thermal power systems will require sites. However, there are certain constraints. As industry and population expand, solar technology increasingly will be in competition with other potential land uses for optimal sites. Also, there is an increasing public and governmental awareness of land use planning and its environmental impact.

Solar thermal power plants have many siting constraints in common with siting constraints of conventional electricity generating facilities. Solar power systems minimize some constraints while introducing additional ones specific to solar thermal electric plants. Also, the early experimental plants will have special siting requirements which satisfy experimental objectives.

b. Approach. The primary objectives of the siting study were to identify and discuss the issues which will both enhance and inhibit the construction and operation of solar thermal power plants with small community applications with regard to siting. Because this study effort is a part of the siting activity for an experimental 1-MWe power plant, specfic examples in the report are based on siting requirements for this experiment. However, many issues are expected to have a more general application.

Siting issues were identified by first analyzing the siting requirements of conventional power plants. Significant issues were then evaluated in conjunction with the requirements and impacts of solar thermal electric technology. The resulting siting issues are similar to those for conventional generation facilities, with the exception of their emphasis or relative significance.

The siting issues identified were grouped into categories. Effects of the site on the plant were discussed by identifying the resources required for plant development and operation, physical site characteristics, and social-institutional characteristics desirable for construction, operation, and maintenance. The effects of the plant on the site were discussed by identifying the impacts plants may have on their sites, and how these site impacts may result in construction delays and even development termination. The study describes these relationships and delineates the information that should be assembled during site selection in order to make informed siting decisions. The siting issues identified by the study are summarized in Table 7-3; the most important issues are asterisked.

In the following paragraphs the siting issues identified by the study will be discussed in four categories, preceded by a brief description of the solar technology under consideration. Because solar thermal power technology is described in Section V, the description included here provides only a background for the discussion of siting issues.

C-3

Table 7-3. Siting Issue Summary

SYSTEM RESOURCES	
*Insolation	Intensity and occurrence/time of direct component Measurement capability and/or data availability
*Water	Quantity available Quality
Construction Materials and Manpower	Local availability
*Land	Adjacent land uses Stability Slope Site preparation
PHYSICAL ENVIRONMENT	
*Wind	Velocity and occurrence/time Particulate content Averages and extremes
Precipitation	Types Averages and extremes Erosion and flood occurrence
Temperature and Air Quality	Averages and extremes Degree change/time
SOCIAL/INSTITUTIONAL ENVIRONMENT	
*Legal-Regulatory	Regulation complexity Regulatory impediments Capability of local regulatory agencies Proposal team/regulatory agency rapport
*Community/Regional Support	Public opinion Publicity Access Resources Stability Experience and innovation

(Continued)

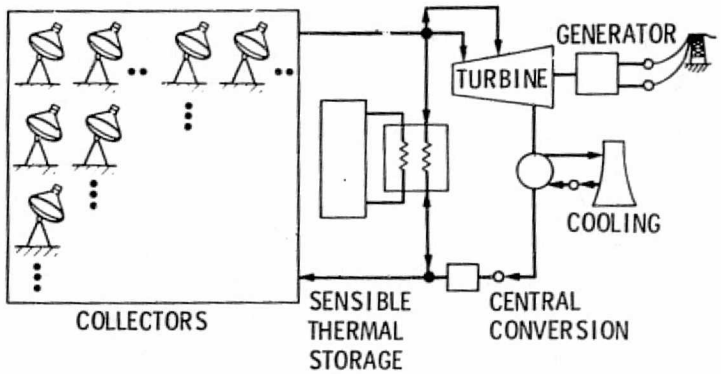
Table 7-3. Siting Issue Summary (Continuation 1)

SOCIAL/INSTITUTIONAL ENVIRONMENT (Cont)	
*Utility Interface	Grid flexibility Convenient transmission line tie-in
SOLAR THERMAL POWER PLANT IMPACT	
Microclimate	Albedo changes Meteorological change
*Water Use	Compatibility Depletion Other users
*Land Use	Compatibility Zoning Right-of-way
Ecology	Endangered species Exotic species intrusion Critical link
Community	City services strained Nuisance Aesthetic
Safety	Malfunctioning tracking mechanisms Nuisance Glare hazard Toxic High-temperature pipelines

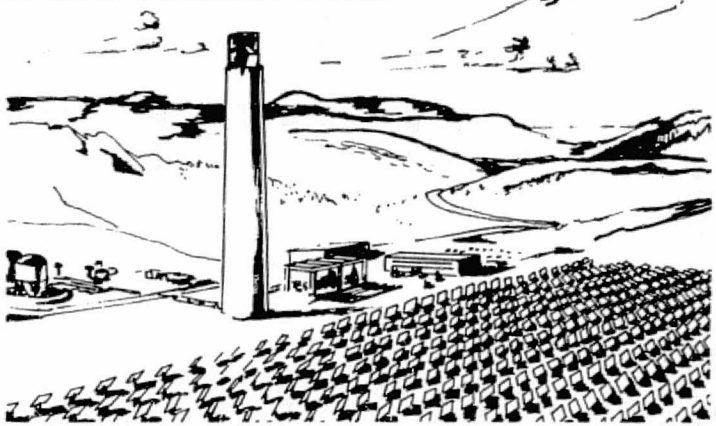
c. Solar Thermal Technology Overview. There are a variety of ways to utilize solar energy (insolation). Solar thermal electric systems concentrate insolation on a receiver in which a working fluid is raised to a high temperature. This fluid is then transported to a heat engine or to storage as shown in Figure 7-2. Only the direct component of insolation is used because diffuse radiation cannot be effectively concentrated.

The collectors of both central receiver plants (heliostats) and distributed receiver plants (parabolic dishes) are large, relatively unprotected structures. (See Figure 7-2). Their designs trade structural integrity for lightweight, low-cost construction. Each dish or heliostat must accurately track the sun for efficient, high temperature operation. These tracking requirements are more critical for central receiver plants because of the length of the focal distance.

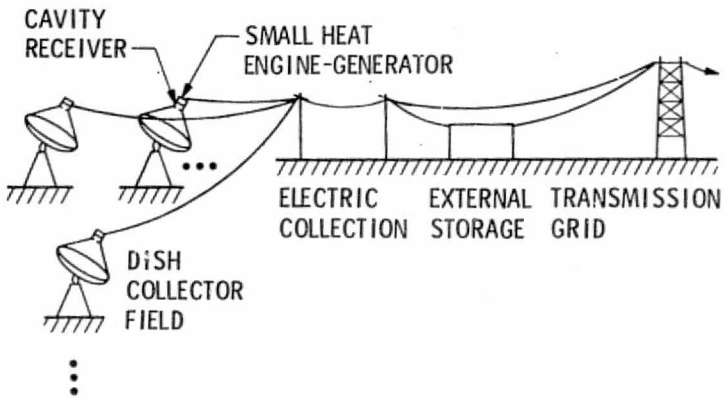
(a) WITH CENTRAL CONVERSION



(a) ARTIST'S RENDERING OF FIELD



(b) WITH DISTRIBUTED CONVERSION



(b) SCHEMATIC OF CENTRAL RECEIVER SYSTEM

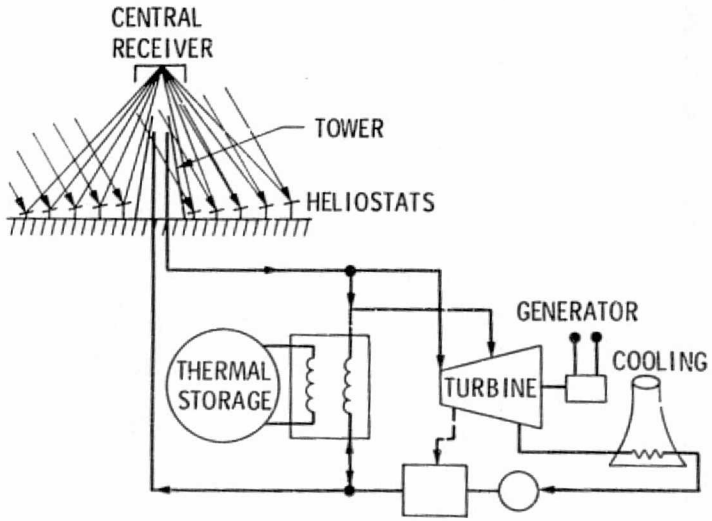


Figure 7-2. Schematics of Solar Thermal Electric Systems

Receivers transfer the concentrated thermal energy of the sun to a working fluid which may be steam, hot water or a chemical compound. This energy is then transported via the working fluid to either storage or energy conversion. In distributed generation plants the receiver is designed to produce heat utilizable by a small engine directly at the concentrators, while in central generation plants energy transport may consist of pipelines to circulate the working fluid from the receiver(s) to the energy conversion system.

The energy conversion system consists of heat engine(s) which produce mechanical energy from a heat flux. The heat flows from a high temperature input through the engine(s), converting some of the heat into mechanical work while rejecting the remainder at a lower tempera ture. All energy conversion systems require cooling. Some cooling systems require water and some depend on the humidity and temperature of the ambient air. Cooling requirements can be quite large. The make-up water required for evaporative cooling in a 1-MWe plant is estimated to be greater than 30 m^3 (1000 ft^3) per day.

d. System Resources. The first category of siting issues discussed in the siting study were systems resources. They deal primarily with the plant's consumption of site resources.

1) Insolation. Insolation is the most important site specific resource required by solar power plants. To determine its value, its availability must be compared to demand and the present and projected future cost of conventional electricity generating technologies at each site.

Solar radiation has a direct component and a diffuse component. Direct insolation is primarily visible radiation which has penetrated the earth's atmosphere without being deflected. Diffuse insolation is also visible radiation that has penetrated the earth's atmosphere, but has been scattered by gas molecules, water droplets in clouds, and dust particles. Clouds absorb insolation, can re-radiate absorbed energy, and can reflect all direct insolation back into space only allowing diffuse insolation to reach the earth's surface.

In order to generate electricity using solar thermal electric technology, high temperatures are required which can only be achieved by concentrating insolation. Since diffuse insolation cannot be concentrated, solar thermal electric systems can only operate on days when direct insolation is available, when skies are relatively clear. As a result, solar thermal electric power plants are very sensitive to site specific atmospheric conditions and meteorological conditions. To illustrate the impact cloud cover has on the quantity of insolation available to concentrating solar electric systems, Figure 7-3 depicts the direct insolation reaching the earth's surface on a clear day and an unclear day measured in Goldstone, California.

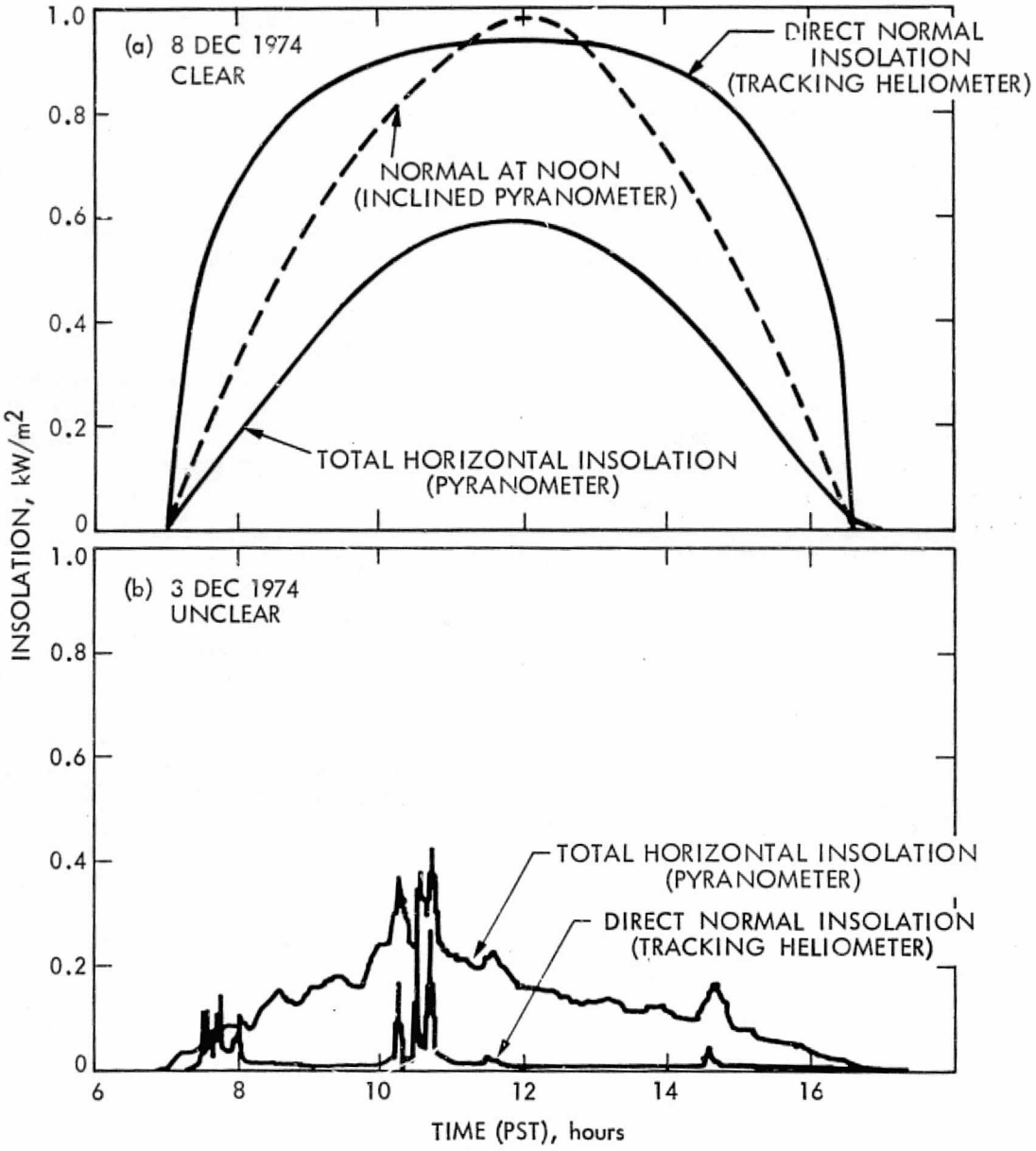


Figure 7-3. Representative Insolation - Goldstone, California

On the graph depicting clear sky conditions (a) direct insolation was measured with a tracking heliometer and total insolation indicated by the solid line was measured by a non-tracking pyranometer on a horizontal plane. The apparent discrepancy between the measured levels of total and direct insolation is a function of the measurement technique and the cosine effect. The dashed line indicates the amount of total insolation in kwh/m^2 during clear sky conditions as measured by a pyrometer tilted so that the sun's rays are perpendicular at noon.

On graph (b), insolation was measured under unclear sky conditions. The important fact to note is that the level of direct insolation in this case is far below that of total insolation because obstacles in the atmosphere reflected most of the direct insolation back into space and only the diffuse component penetrated. A solar thermal power plant could not operate in these conditions. Only systems able to utilize diffuse insolation are operational when there is so little direct insolation.

To fully evaluate a site for solar thermal-electric systems, the quantities of direct insolation available must be determined. However, insolation data like that depicted in Figure 7-3 is not commonly collected at most meteorological stations. Additionally, special instruments are required for insolation measurement such as pyroheliometers, tracking heliometers, diffussographs, and pyranometers. However, as the demand for insolation data increases, meteorological stations have been acquiring this equipment. Insolation also can be assessed using models able to calculate insolation data from general meteorological information. Insolation data is available from several institutions, including the Aerospace Corporation in El Segundo, California.

2) Land. The acreage of land required by solar thermal electric power plants depends on their rated generation capacity. The first Engineering Experiment will nominally generate 1-MWe and will require approximately 10 acres. This acreage contains all subsystems and support structures, such as maintenance buildings and roads for access and service. Additional land may be required for public information centers. However, the availability of acreage is not the only important siting criteria regarding land; the suitability of that acreage is also very important.

Land suitability depends on a number of site characteristics. Land use adjacent to solar thermal power plant sites is an important characteristic because of the possibility of damage to the plant or interference with its operating efficiency by incompatible, neighboring activities. Sites where neighboring industries produce effluent plumes, which may block insolation, corrode collector surfaces or produce particulates which may settle on collectors would be unacceptable. Sites near industries utilizing highly flammable or explosive materials should be avoided as well.

The height of adjacent land uses is also important. The plant should have an unobstructed view to the south down to an angle of 10 degrees above the horizon to ensure it receives the maximum amount of solar energy during the day. A new body of regulation dealing with the use of solar energy, "sunrights," may someday guarantee unobstructed sunshine to solar technologies during their entire lifetime.

Another group of site characteristics relative to land suitability deals with geology and topography. In the geological sphere, earthquake faults, landslide prone areas and unstable soils should be avoided when siting solar thermal plants. Contoured topography may require a plant to occupy larger land areas to avoid hindering solar plant operation from the shading of one collector by another. Site preparation, plant construction, and maintenance would be more difficult on a contoured site also. However, a site sloping north up to 10 degrees without other contours would improve the angle the plant intercepts the sun's rays. This decreases tracking requirements, but would not hinder construction, operation, and maintenance activities.

3) Water. The availability of water at a site for solar thermal power plant use will be important only if the technology selected is designed to utilize it. Water for cooling represents the largest water requirement in solar thermal electric plants. If the plant is designed to use wet evaporative cooling, one of the most efficient types, a water resource of approximately 30 m^3 (1,000 ft^3) per day must be available. Therefore, arid sites with excellent insolation may require utilization of alternate (less efficient) cooling methods. Water may also be used for energy transport, make-up for water lost through evaporation and blow-down, and collector maintenance. For those uses water quality is as important as the quantity of water available to avoid sedimentation in pipelines and damage to reflective surfaces.

4) Construction Materials and Manpower. A less important requirement is the availability of construction materials and manpower. Although these resources are vital to plant development, they are not requirements unique to solar thermal electric plants with the exception of special skills which may be required. If these resources are not available within the community, they can be imported as is commonly done in many development projects. However, their availability within the locality would decrease both construction time and cost.

e. Physical Environment. Issues in this group deal primarily with the hazard the physical environment of the site may present to solar thermal electric technology.

1) Wind. High wind speeds occur in areas not obstructed by topography or vegetation, or where wind is funneled through a topographic venturi. Solar thermal power plants may also be located at such sites

because of their requirement for terrain and vegetation which do not block insolation. Wind may impact solar thermal electric power plants in two ways. First, its force and speed alone may be damaging. As indicated in earlier sections of this report, the collectors in solar thermal power plants are large and relatively light-weight. As a result, the collectors may induce high drag forces in windy areas which may be damaging. Secondly, wind may carry particles of sand, dirt, and dust capable of scratching the reflective surfaces of concentrators.

2) Precipitation. Rain interacts with topography and soil-slope stability in creating potentially hazardous conditions to solar plants. The evaluation of sites in areas receiving heavy rainfall should include a detailed analysis of soil type and slope stability, because rain may precipitate landslides, erosion, and flash flooding. It is not expected that solar plants will be located near slopes steep enough to be concerned with landslides but sites susceptible to flash flooding, periodic flooding, and erosion should be identified, and mitigation measures instituted.

Hail, falling on fragile reflective surfaces, may be capable of damaging them, thereby rendering them useless as reflectors. The accumulation of hail and/or snow on collectors would block insolation and could overstress support structures. Additionally, the maintenance costs of keeping collectors free of hail and snow, if necessary, may be high.

3) Temperature and Air Quality. Extreme temperatures are of concern because of the potential thermal distortion of reflective surfaces. The accumulation of air pollutants on collectors can decrease their efficiency by blocking insolation and reacting chemically with reflective surfaces. Air pollutants can also deflect direct insolation in the atmosphere.

f. Social/Institutional Issues. Because solar thermal electric technology is relatively new, it has yet to be integrated into the existing legal-regulatory and community infra-structure. Thus, solar thermal power plants are very sensitive to the legal-regulatory and community aspects of their environment. The first Engineering Experiment will be particularly sensitive to social/institutional environmental forces because it is attempting to popularize solar thermal electric technology and provide experimental data to system engineers simultaneously. The issues in this section deal primarily with regulatory requirements which may be impediments to solar power plant development and operation, and with other social and institutional practices which may pose difficulties.

1) Legal-Regulatory. The body of law and regulation in the site locality is important to solar thermal electric power plant siting because of the possibility that some regulations may preclude solar development. Regulations can prevent the acquisition of construction

and operation permits, and regulatory agencies can attach conditions to permits which may cost the developer more than the benefits he expects to receive from his development. Additionally, the time required for permit acquisition may be too lengthy and procedures too complex for the time and money resources available.

Solar thermal electric power technology is new, therefore, no regulations specifically governing solar thermal power plant activities exist. Regulatory agencies are unfamiliar with solar plant processes and consequently are unsure which regulations may apply to them. Therefore, the first experimental solar systems may have to deal with conditional permits and time delays beyond those required of conventional development projects. Because of possible regulatory time delays and conditional permits, sites with proposal teams knowledgeable of regulatory agencies and their requirements are preferable.

2) Community Support. Solar thermal electric power plants will of necessity interact closely with the communities they serve. The electricity they generate, to be of greatest value, must be integrated into the distribution system of the local utility and be available during times of peak demand. The plants must comply with local regulatory requirements and will require services such as water, sewer, and telephone. They may require manpower and materials for site preparation, construction, and operation, and may need to share transportation facilities with local citizens. Because of the diversity of these interactions, it is very important that local public opinion be in favor of solar thermal power plant development.

All solar energy technology is novel and occupies a prominent position in the public eye. Concurrently, it must prove itself through research, development, and experimentation. The first solar thermal electric experimental power plants are primarily intended to provide the developers of solar thermal electric technology with important performance data that will be utilized to improve plant performance. It may take several years for the plants to attain acceptable efficiency. In the interim, plant performance is open to public scrutiny, which could lead to adverse publicity. This may injure development programs, preventing the research required to achieve maximum efficiency. Therefore, a site within a community positively inclined toward plant development or with a need for the type of generating capability a solar thermal power plant can provide may prove to be a more beneficial site than one in a community without this inclination or need.

Another function of the first experimental solar thermal electric power plants is to demonstrate and publicize the technology and its possible applications to those who may have a need for an electrical generating plant of this type and an interest in utilizing it. An extremely remote site with relatively few communication media, such as newspapers, newsletters, radio or television coverage, may not perform this publicity function as well as a site with access to these facilities.

Other important site conditions relating to community relationships are the community's capabilities to support solar thermal electric power plants with resources, financially and publicly.

3) Utility Interface. Several of the objectives of the first Engineering Experiment relate to the interfaces of the experimental solar thermal power plant with the local utility grid. The application for the first Engineering Experiment has been defined as a utility/small community with an electrical load of less than 100 MWe, preferably served by a single substation. The load restriction assures that operation of the 1-MWe experimental plant will have a measurable effect on utility grid parameters. It is also important that the plant site be located near the substation and convenient to a transmission line tie-in, and not isolated from the utility grid. Important grid parameters are the real and reactive load seen by the substation and the line reactance between the substation and the plant site.

To maximize the benefit of solar energy usage, it is desirable that a reasonable match exists between the energy demand and the available insolation. Since most sites will have a greater amount of insolation during the summer months and during the solar day, the seasonal demand peak should be in the summer and the daily peak should occur during the solar day.

g. Plant Impact on Site. As the protection of the natural environment becomes more important, the body of law protecting the environment increases proportionately. All developments of specified types must comply with the National Environmental Policy Act (NEPA) and in some states (like California) equivalent state legislation.

The careful monitoring of the environmental impacts of solar thermal electric technology is as important as assessing the tolerance of the plant to environmental forces. As an alternate electricity generation technology one of its advantages over conventional electricity generation is that solar thermal electric systems are non-polluting. Although some environmental degradation is unavoidable, the use of solar thermal electric technology as a replacement for conventional generation represents a net improvement in environmental quality.

A complete evaluation of the environmental impacts of solar thermal technology has not been performed because of the technology's newness, but to maintain its 'good neighbor' reputation with the general public, all potential environmental impacts should be thoroughly investigated.

1) Microclimate. Change of an area's solar radiation budget should be considered as a potential impact peculiar to solar thermal power plants. This change could result from the concentration and collection of a large amount of sunlight in an area instead of allowing it to be dispersed naturally. Solar radiation drives all climatological systems. Therefore, an alteration of insolation may result in an

alteration of climatological conditions. Plant size is expected to be an important factor in the degree of this impact; the smaller the plant, the smaller the impact. The impact of a 1-MWe solar power plant with regard to radiation budget and climatological changes is expected to be insignificant.

2) Ecology. The ecological systems in which all organisms live may be thought of as webs where each segment is vital to the survival of the whole. If a solar power plant were constructed on a site, destroying a segment of the ecological system, the repercussions of this act may adversely impact the ecology in an area many times greater than the site itself. However, on a site of approximately 10 acres ecological systems are not impacted so significantly that they would fail, unless the ecosystem is very small or extremely fragile. Some species of plants and animals are protected because they are rare, and are listed on federal and state endangered species lists. A site containing endangered species could not be utilized for solar thermal development unless major steps are taken to protect them.

Once construction is complete and the plant is operating, there may be additional ecological impacts. The plant subsystems including cooling will increase shading and require washing which may encourage different types of vegetation to grow than those existing previously. This may in turn attract new species of animals and birds. The intrusion of new species into an area can significantly impact existing ecology.

Additionally, chemicals may be used as transport media and as collector cleaning solvents which may be poisonous to some species. However, on a site where the ecology has already been heavily impacted by construction of the plant, disruption of the on-site vegetation may not constitute a significant impact.

3) Water Use. Regardless of the source, natural hydrology (rivers, lakes, and aquifers) or municipal water supplies, it must be determined that water use in the plant will not overburden the existing local water system and that plant water requirements will be satisfied even in times of drought.

Agriculturally based communities have seasonal water use patterns, while industrial, commercial, and residential communities have daily peaks. Each of these users may also require water of different qualities. In addition, water treatment facilities and water quality regulations vary from site to site. Some communities have minimal treatment facilities and regulations while others have very sophisticated treatment facilities and stringent regulations. Usually, sophisticated equipment and regulations are found in areas with limited water supplies. In these areas water treatment of some kind is a requirement prior to returning waste water to the reservoirs. It can either be treated by the user or in a community waste water treatment facility.

Solar thermal power plants must coordinate their disposal of waste water with the local regulatory agencies in all locations but particularly in the areas where water is in limited supply.

4) Land Use. The primary impact of land used for solar thermal electric power plants is compatibility and competition with existing and planned land uses for the sites themselves and for right-of-ways for access roads. A solar plant that is compatible with or well integrated into a community's existing land use patterns will serve the community and achieve success much sooner than plants which are not. Successful integration into an area's land use patterns can be achieved by following zoning ordinances, general plans, and land use trends.

5) Community Impacts. A community with a work force possessing appropriate skills, adequate quantities and qualities of materials, and equipment for solar power plant development will be least impacted by solar thermal power plant activities. They are more likely to be impacted favorably, if impacted at all, because of increased business from plant activities. Because the workers are in residence, city services do not require expansion to maintain adequate service.

A community without these resources may be impacted significantly. The importation of people, materials, and equipment will create more traffic, add to the demand on the water supply and sewage treatment facilities, make additional demands on electric utilities, and may drive plant costs up. If plant employees move their families into the area, schools, fire and police protection, and housing may also be strained. The significance of these impacts varies with the size of the community, the distance between the solar power plant site and the community, and the willingness and capability of the community to meet solar thermal power plant requirements.

6) Safety. Solar thermal power plants may have several safety hazards. The heliostats in a central receiver system may have focal distances of several hundred feet. The reflected sunlight from a single heliostat is only slightly concentrated, but eye damage is a potential hazard at the focal point of a misaligned heliostat. To alleviate concern over this issue, sites for central receiver plants may require guarded buffer zones.

Depending on the design, toxic materials could be hazardous also, however all liquid waste disposal will be regulated by water quality control agencies.

3. EE#1 Site Evaluation. This section of the report describes the first step of refining the issues identified in the siting study for site evaluation. A minimum set of site requirements for the first experiment have been identified and the issues have been refined into evaluation factors for site selection.

a. Background. Siting and site integration efforts for EE No. 1 will occur in parallel with power plant construction. An opportunity to allow the site proposers to screen themselves prior to proposal submission is planned in order to minimize proposal costs for a potentially large number of small community/utility offerors. This opportunity will be presented by a section in the Program Research and Development Announcement (PRDA) which will include a set of advisory qualification standards.

The objective of the first Engineering Experiment is to demonstrate the feasibility of the small power systems approach in a realistic application environment. To this end, sites are expected to (1) have an exploitable solar resource, (2) limit the potential expenses of construction and maintenance, (3) have regulatory requirements which do not preclude development, (4) include a community which is capable of plant support and which is not adversely impacted by plant activities, (5) pose minimum hazard to the continuous operation of the facility, (6) contain a utility grid readily acceptant of solar technology, and (7) contain no environmentally sensitive areas whose disruption might lead to actions that would overshadow results of the experiment.

b. Proposal Requirements.

1) Minimum Site Considerations. At a minimum, the site should provide an acreage of suitably unencumbered land for experimental power plant construction and operation. As stated in the Siting Issues Study, a 1 MWe power plant is expected to require approximately 10 acres. Additional characteristics identified in the study which are essential to experiment implementation are utility experience and integration into the local power utility's distribution network.

Important site management responsibilities in support of experiment implementation may include the provision of all permits and licenses necessary for plant construction, operation and maintenance, maintenance for several years following test, check-out, and acceptance, participation in design and construction reviews, and assisting in the selection of hardware equipment to be installed.

2) Additional Site Considerations. Beyond the minimum requirements discussed above, sites are also expected to have other characteristics identified in the Siting Issues Study. These characteristics will have a more relative importance than the issues defined as essential to experiment implementation. The preliminary proposal evaluation technique is described in the following paragraphs.

c. Evaluation Factors. The evaluation of proposals is intended to be comparative in nature once the minimum requirements are met. The emphasis will be on an indication of superiority in each of the major criteria areas.

1) System Resources.

a) Insolation. A basic consideration in siting the facility is the quality of the insolation resource. Unfortunately, the network of stations that provides accurate and complete measurements of direct insolation (SOLMET) is limited. It is necessary, therefore, to use a system for estimating the amount of available insolation based on published standard climatological data, supplemented by SOLMET. Together, they should allow for a reasonable estimate of insolation availability. Climatological data for each candidate site will be evaluated during site selection. Values derived that describe the available resource in watts/m^2/season could be compared to demand curves for the area and the capacity of the plant that is proposed, to determine suitable matches.

b) Land. It is desirable to keep construction and maintenance costs for the facility to a minimum. Therefore, sites that impose obvious difficulties shall be considered less desirable. Slopes at the site should not be so steep to cause difficulty in construction or maintenance of the facility, require extensive slope stabilization or cause serious modification of the plant design to accommodate surface irregularities. Ideally, slopes should be considerably less than 15% and south-facing. The seasonal effects of surrounding structures, topographic features and vegetation, on the amount of insolation generally available for the region will be important also.

c) Water Supply. Solar thermal power plants can utilize either wet or dry cooling, and also require water for maintenance purposes. Because a plant design for EE#1 has not yet been selected, a minimum of 1,000 ft^3 of water per day for evaporative cooling would improve a site's suitability, because it would allow design flexibility.

2) Physical Environment.

a) Climatological. Hazards are defined as those environmental factors that might periodically hinder the operation of the collector system or cause physical damage to it. Because most of the hazards included below can be considered as events, they may be evaluated in terms of their probability of occurrence.

Winds cause a reduction in collector efficiency and may, in extreme cases, cause physical damage to the plant itself. Critical values are: 30 MPH, above which collector efficiency is significantly degraded; 40 MPH, above which efficiency is so reduced as to warrant shut down of the collector; and 90 MPH, above which damage to the plant can be expected.

Brief intense storms can bring temporary flooding, but may also be accompanied by hail. Hailstones greater than 2 cm in diameter may dent the surfaces of collectors. Loading of snow or ice on the collector halts operation of the facility, but may also damage the mechanism if weights are excessive.

If the probability of damage to the facility from any one of the above mentioned factors is obviously high, that site will be eliminated from further consideration.

b) Landform. Hazards resulting from landform structure can also be considered as events and evaluated in terms of their probability of occurrence.

Periodic flooding from intense rainfall is undesirable but may often be unavoidable. Location of the plant in ephemeral drainage ways, however, poses serious periodic hazards of inundation of erosion that may damage the facility. Location of the plant in unprotected areas of the 100 year floodplain of major streams poses a less frequent threat to the facility but the magnitude of potential damage is considerably greater. Areas that have a potential for flooding damage or have experienced slope failure are a serious hazard and should be avoided.

Collector surfaces are susceptible to damage by abrasion from wind-borne materials and their efficiency can be reduced by coatings of dust. Care must be taken in selecting a site that is not downwind of potential source areas of wind-erodable materials. To assess this potential, it is necessary to note soil surface texture, surface conditions, direction and velocity of wind, the presence or absence of stabilizing vegetation, disruptive neighboring land uses, and the extent of disturbance that will accompany construction of the facility.

3) Social/Institutional.

a) Legal-Regulatory. Siting a solar power plant will require the acquisition of permits and licenses from local, regional, state and national regulatory agencies. At each site these regulatory requirements will differ as a function of local site conditions.

Sites having regulations which preclude solar thermal power plant construction and/or operation will be eliminated from further consideration. The capability to identify and deal with the most important regulatory requirements will be an important consideration.

b) Community/Regional Support. The interaction between the solar plant and the community it is located in is very important to experiment success, because solar plants will interact with communities in many ways. They will require services such as water, sewer, telephone, electricity, manpower, and materials for site preparation,

construction and operation and may need to share media and transportation facilities with local citizens. To determine the capability of the community with regard to the provision of these services and facilities, information describing the availability and type of the existing services and basic demographic data describing the community's population must be analyzed.

The attitude of the community's population toward the solar thermal power plant is very important. Public opinion may have a strong influence on the ultimate success of the experiment. The demonstrated interest and support of the community's population with regard to the solar thermal electric plant is evidenced by past community interest, support, and participation in alternate energy projects.

The availability of a community newsletter and a variety of other media types will be important, as well as the convenience of transportation services which link the community to major population centers. Public visibility, for example visibility from frequently traveled highways and tourist attractions, is also desirable.

c) Utility Interface. The community's electricity demand for the previous twelve month period, proposed plant connection to the utility grid, and projected trends in demand and cost of electricity generation for 1985, are important considerations to experiment implementation.

4) Plant Impact on Site.

a) Resource Competition. Solar thermal plants may be in competition with the present and planned uses of land and water at their sites. Sites with obviously incompatible land and water use for solar thermal power plant development will be eliminated from further consideration. Land use incompatibility can result either because of the hazard the surrounding land uses represent to the site or because of the threat the plant may represent to existing land use. Water use incompatibility would occur in areas where water used by the solar thermal power plant would decrease the quantity and quality of water available to present water users such that it would impact their activities. Incompatibility would also result if the costs of water treatment before or after power plant use were prohibitive.

b) Community Integration. The solar thermal power plant will have numerous and diverse interactions with the community it serves. As indicated previously, it will require various services and facilities. In addition to these services, local business will be impacted and additional public services like fire and police protection may be required. There is a possibility that these services may be strained by power plant activities and that the economic structure of the community may be impacted. The public health and safety may be impacted also by glare and misaligned heliostats.

It is not expected that community services or economy will be impacted significantly by the construction and operation activities of a 1 MWe solar thermal electric plant. However, a community severely impacted economically and whose services are impacted severely by the activities of a 1 MWe power plant would probably be eliminated from consideration by other criteria.