5103-93, Vol. II
Solar Thermal Power Systems
Point-Focusing
Thermal and Electric Applications Project

DOE/JPL-1060-31
Distribution Category UC-62

Annual Technical Report

Volume II: Detailed Report

Fiscal Year 1979

(NASA-CR-163023) THERMAL POWER SYSTEMS (TPS); POINT-FOCUSING THERMAL AND ELECTRIC APPLICATIONS (PFTEA). VOLUME 2: DETAILED REPORT, FISCAL YEAR 1979 (Jet Propulsion Lab.) 146 p HC A07/MF A01 CSCL 10A G3/44

N80-26770

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23621

January 15, 1980

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 79-118, VOLUME II)

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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 and electric power plants.

FOREWORD

This report documents the main technical activities of the Point-Focusing Thermal and Electric Applicatons (PFTEA) Project in FY 1979.

During the course of the year, the project's name was changed. It had been the Small Power Systems Applications Project. The present name denotes a realignment of the project's charter and reflects two significant changes: 1) technologies considered will be restricted to point-focusing distributed receiver systems, and 2) the project will be responsible for both thermal and electric applications.

The PFTEA Project is one of three managed by JPL for DOE's Thermal Power Systems Branch. The other two are the Advanced Solar Thermal Technology Project and the Point-Focusing Distributed Receiver Technology Project.

This report (Volume II) is a detailed compilation of key activities and results for FY 1979. Volume I of this report is an Executive Summary.

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SECTION I

INTRODUCTION

The Point-Focusing Thermal and Electric Applications Project is responsible for the development of systems which employ point-focusing distributed receiver (PFDR) technology for applications determined to be attractive and appropriate. The main vehicle for this activity is a series of engineering experiments that have as a primary objective the assessment of system feasibility for selected technologies in real user environments. System feasibility is achieved when a PFDR system is first successfully carried through design, installation and operation in an application setting.

During FY 1979 significant progress was made in the first engineering experiment, the Small Community Solar Thermal Power Experiment (SCSE), with the completion of the concept definition phase in which three contractors participated - each pursuing a different technology. The PFDR approach with distributed energy conversion (i.e., engine at the focus) was selected as the preferred technology for this first experiment.

Procurement activities began in FY 1979 for the Military Module Power Experiment, the first of a series of experiments planned as part of the Isolated Load Series. Both this experiment and the SCSE are discussed in detail in subsequent sections of this report.

The PFTEA project has two major elements: 1) the development and fielding of experiments as typified by the two discussed; and 2) supporting activities that provide the technical and economic basis for the management of the experiment program. Both areas will be briefly described as an introduction.

A. ENGINEERING EXPERIMENT SERIES

The engineering experiments are comprised of three series of subscale electric power plants or thermal energy systems designed and deployed to demonstrate system feasibility in selected, appropriate market sectors. An engineering experiment is defined as the smallest system level test that can be expected to establish system feasibility in a real user environment. Although it is currently not a part of this program, it is expected that the engineering experiments will be followed by other demonstrations in which prototypical hardware or commercially produced hardware will be tested at a pilot plant or full-scale commercial plant size.

Important elements of the engineering experiment program are summarized as follows:

(1) Experiments will test various PFDR technology options consisting of a combination of concentrator, receiver, power conversion (for electric power generation) and balance of plant subsystems.

(2) Experiments will test various market sectors. Thus, a particular experiment may be characteristic of a generic market category. Its deployment in that market area will provide an assessment of the market viability as well as the suitability of the technology for that market.

(3) Experiments will address the electric, electric plus thermal, and thermal applications as deemed appropriate and necessary.

(4) In general, at this time, applications of interest will be met by systems of less than 10 MWe rated capacity.

The application categories and the associated series of experiments defined to date are shown in Figure 1-1. Three broad market sectors constitute the main objectives of the three series of experiments. The grid-connected utility market sector includes such market subsets as the small community electric power application, dispersed siting in large utilities, repowering of existing fossil-fuel plants and eventually, the bulk electric market. The second isolated load series addresses the isolated load market sector typified by various remote sites needing a source of power, some applications within the military, and power needs of developing countries. These applications may have both electric and thermal requirements. The third series of experiments will be planned to explore the industrial market and will emphasize those industrial process heat applications for which PFDR technology appears best suited.

B. SUPPORTING ACTIVITIES

Three task areas provide the support and technical and economic base for management of the experiments. The primary responsibility of Systems Engineering and Development is the technical management of the design and development phases of the experiments. It draws support from the technical divisions at JPL to perform this function. The second task area, Experiment Implementation and Test, is responsible for the siting of the experiments and will be responsible for the fabrication, construction and operation phases when those stages are reached. The third task area, Applications Analysis and Development provides the information for selection of experiment applications. Thus, it is responsible for market analysis, economics of supply and demand, and user integration activities. A successful program will depend greatly on the degree of early involvement of potential users of the technologies being developed.

The remainder of this report is organized into four major Sections (II through V). Section II describes the project management aspects of the first two experiment series initiated to date and briefly discusses early planning of the third series. Sections III through V provide a summary of the technical activities in support of the experiments and other studies conducted in FY 1979. These latter sections are organized along the task area lines previously described

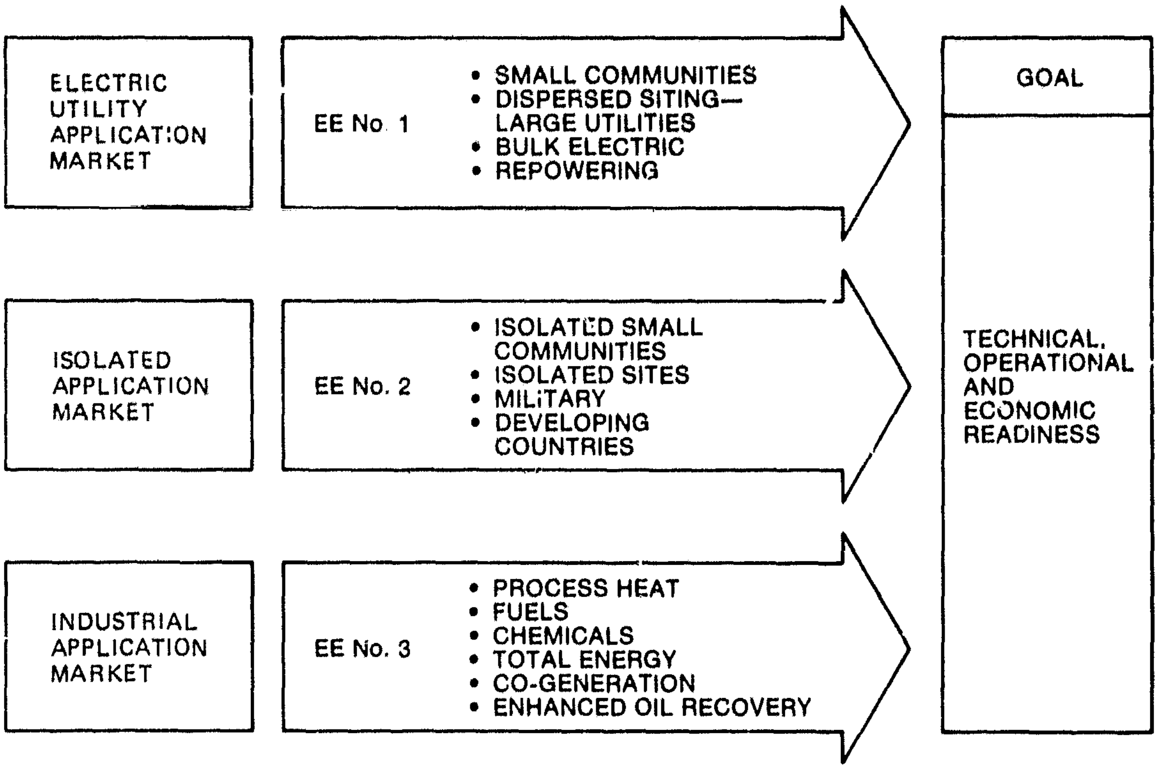


Figure 1-1. PFTEA Engineering Experiment Series

SECTION II

ENGINEERING EXPERIMENTS - MANAGEMENT OVERVIEW

This section provides a brief management overview of the engineering experiments under way or in the planning stage. Detailed technical information regarding these experiments is found in Sections III and IV.

A. SMALL COMMUNITY SOLAR THERMAL POWER EXPERIMENT (SCSE)

The first experiment in the Utility Series addressing the grid-connected utility market is the Small Community Solar Thermal Power Experiment (SCSE). This section is limited to a discussion of this experiment since no further experiments are currently in the planning stage within this category.

1. Introduction and Background

The program steps of the Small Community Solar Thermal Power Experiment strongly reflect the circumstances of its origins in 1977. The Project originated as a result of strong and continuous community pressure on Congress to provide an alternative electric power source compatible with anticipated diminished reliance on non-renewable energy sources. In response to these pressures, Congress appropriated funds for a five-megawatt solar thermal demonstration. A one-megawatt experimental plant was eventually agreed upon as being valid for the range of sizes of interest in the small community application. Augmenting the experiment were studies of the small community market and eventual requirements for commercialization of solar thermal power systems which show promise for this market.

Three categories established for the technology of this application were:

Category A	General (to include, but not limited to, central receiver and line focusing systems).
Category B	Point-focusing, distributed collector, central power conversion.
Category C	Point-focusing, distributed collector, power conversion at the collector.

A multiphase approach was adopted as the best means of meeting the objectives of the experiment in the shortest period of time. Phase I addressed the problem of exploring all competitive technologies for this application and recommended those which should be studied in greater detail. Competitive bids were received in each of the above listed categories, and awards were made on the bases of merit. One contractor was selected in each category as follows:

Category A - McDonnell-Douglas Astronautics Company

Category B - General Electric Company

Category C - Ford Aerospace and Communications Corporation

Within Phase I three tasks were identified:

(1) Development of preferred system concepts.

(2) Sensitivity Analysis.

(3) Phase II Program Plan.

2. The Project in FY 1979 - Phase I

At the beginning of the fiscal year, Phase I studies were underway and preliminary results were being reported at project review meetings and in periodic progress reports. As the Phase I studies progressed, the individual contractors identified the systems within each of the given categories which fulfilled the requirements set out in the RFP:

(1) McDonnell-Douglas Astronautics Company: Central tower with field of south-facing heliostats.

(2) General Electric Company: Field of parabolic dishes with steam piped to a central turbine-generator unit.

(3) Ford Aerospace and Communications Corporation: Field of parabolic dishes with a Stirling cycle engine/generator unit at the focus of each dish.

Soon afterward, the Department of Energy (DOE) directives and ongoing technical studies at JPL and elsewhere produced two important programmatic changes:

(1) Category A and the McDonnell-Douglas Astronautics Company were eliminated by DOE from further participation in subsequent phases of the experiment in order to achieve better program balance.

(2) Budget constraints combined with promising and timely results in the Point-Focus Distributed Receiver Technology (PFDRT) development program forced the decision that subsystem development within the experiment be minimized. Instead, designs for appropriate subsystems were to come from ongoing development work or from other existing sources. Possible candidates for the concentrator were the Low-Cost Concentrator (LCC) and the Test Bed Concentrator (TBC) which were being developed in the PFDRT project.

Receivers were also being designed in JPL technology development projects. It was expected that some additional development would be required to match specific needs of this experiment. In spite of these constraints, it was decided that the systems contractors would continue to maintain responsibility for the selection and integration of all components and subsystems.

Meanwhile, results of the technology comparison studies performed at the Solar Energy Research Institute (SERI) and at the Battelle Pacific Northwest Laboratories (PNL) indicated that distributed power generation was preferred to central power generation when using point focus technology for plants of the one megawatt size at low capacity factors. In addition the Shenandoah Total Energy Project was scheduled to be completed before the Small Community Experiment and would serve as verification and demonstration of the point-focus central generation concept. These factors, in addition to the JPL evaluation of the technology choices for this experiment, lead to a decision to select Category C and to proceed with this approach in Phase II. This decision meant that Ford, the successful contractor in this category, would continue in Phase II. The energy conversion subsystem recommended by Ford made use of the Stirling cycle, with the Rankine cycle engine ranked second. In the light of ongoing engine studies at Lewis Research Center and at JPL, (which indicated that Stirling engine technology was not yet ready for field experiments) it was decided to incorporate the Rankine cycle engine in the configuration selected for design and test in Phase II and III.

3. Phase II

In August 1979, a sole source RFP was issued to Ford Aerospace and Communications Corporation soliciting their participation to act as system contractor for Phase II of the experiment. The contractor is expected to conduct a preliminary design, component and subsystem development, subsystem and system level verification testing, and detailed design. Ford was also asked to complete the plans for site preparation and hardware implementation. As indicated above, the technology was restricted to distributed energy conversion using the Rankine cycle.

In its response to the RFP, the Ford Aerospace and Communications Corporation proposed the following system concept as its baseline in determining the cost of the program:

(1) Power Conversion - An organic Rankine cycle (ORC) engine/alternator; the working fluid is toluene at a maximum expander (turbine) inlet temperature of 427^{o}C (800^{o}F).

(2) Concentrator - The JPL-supported 12m Low-Cost Concentrator (LCC) currently under development by General Electric Company.

(3) Receiver - The JPL-supported steam receiver currently under development by Garrett AiResearch Corp., redesigned to operate with toluene.

(4) Energy Transport - The FACC-developed Phase I AC electrical system, with modification to accommodate the ORC power conversion system.

(5) Control - The FACC-conceived Phase I central microprocessor control concept with modifications to accommodate the ORC power conversion system and the LCC.

This baseline concept was chosen upon Phase I study results and preliminary analysis carried out by Ford to evaluate the data provided by potential subcontractors for the major subsystems. This preliminary system selection was also constrained by the requirements to: (1) select a concentrator at no additional cost to JPL; and (2) select a receiver design at minimal development cost to JPL. An additional influencing factor was the substantial effort required in Phase II to develop a comprehensive plant control system, including both hardware and software design.

a. <u>The Power Conversion Subsystem</u>. According to the Ford proposal, the most significant decision was the preference for the organic Rankine cycle (ORC) system over a steam system. (Figure 2-1)

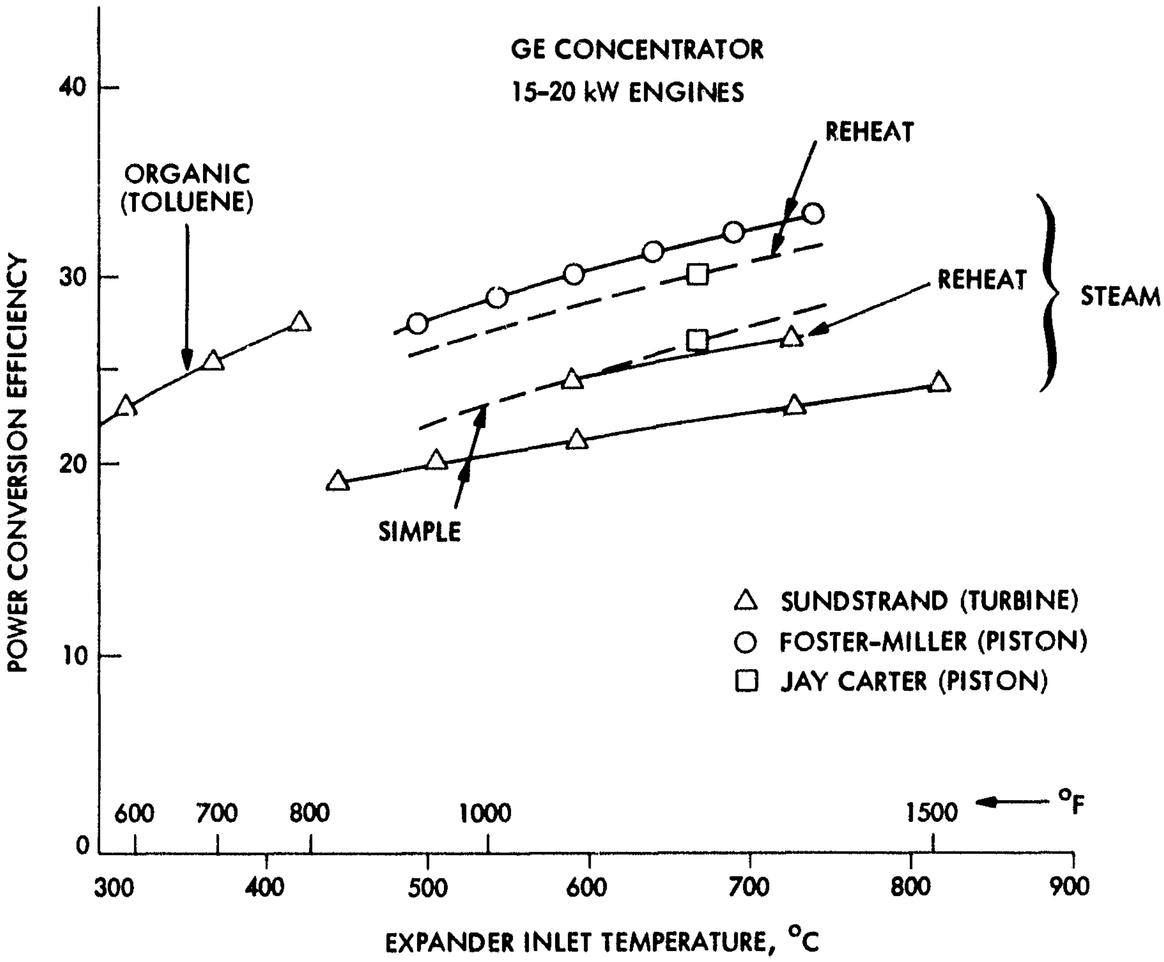


Figure 2-1. Comparative Rankine Engine Performance (Including Alternator)

A comparison of the performance of several Rankine alternatives is presented in Figure 2-1 which shows the sensitivity of the performance of the various systems to expander input temperature. The unfavorable performance displayed by the steam turbine has eliminated it from further consideration, so that only the piston expander need be considered as an alternative to the ORC turbine. Because of tight program schedules, the piston expander with reheat could not be developed in time. The conclusion was that the simple steam piston engine has about the same overall conversion efficiency as the ORC turbine expander, but at higher temperature. Ford feels that the problem of lubrication (and potential contamination of the receiver with lubrication oil) and corrosion, using steam at over 537.7°C (1000°F), present greater problems than does the dissociation of the organic fluid (toluene) at its corresponding operating temperature near 427°C (800°F). These considerations along with cost estimates and evaluation of the ability of potential subcontractors to meet delivery schedules has led Ford to consider the organic turbine. Several subcontractors have offered to provide appropriate ORC subsystems which would meet the requirements of the RFP. A more extensive assessment is underway and a final decision on the engine selection will be made early in Phase II.

b. The Concentrator. The baseline design selected by Ford for the purposes of their proposal is the first generation Low-Cost Concentrator (LCC) developed for JPL by General Electric's Advanced Energy Program at Valley Forge, Pennsylvania. A sketch of this concentrator is shown in Figure 2-2. A brief description follows:

The Concentrator is a point-focus, single-reflection parabolic dish which tracks the sun by rotation about two axes, azimuth and elevation. The reflecting surface, either glass or thin film plastic will be mounted on plastic segments which are, in turn, attached to the welded steel supporting structure. The plastic segments are constructed from molded glass-reinforced epoxy with an integral rib pattern on the back to provide stiffness. Eight internal ribs within the dish provide support and alignment for the segments, as well as added strength and rigidity to the assembled parabolic dish.

The mount subsystem selected for the concentrator uses the azimuth-elevation configuration. The dimensions of the dish and mount were selected so that it permits stow in the inverted position. The inverted stow reduces survival wind loads, provides for convenient access to the power module and offers good protection for the reflector surface. The mount configuration is an efficient, low-cost structure design which requires no field welding. The drive is accomplished with cables and drums, the cable being provided with a semi-circular track from receiver to counterweight. In addition to acting as a guide, this member also adds stiffness to the receiver/engine mount. Major features of this approach are low cost, low motor parasitic power, high drive stiffness and low sensitivity to environmental factors.

The foundation element is an azimuth track consisting of a rolled I-beam section mounted in simple pilings on concrete footings. By dispersing the foundation, the amount of concrete is minimized.

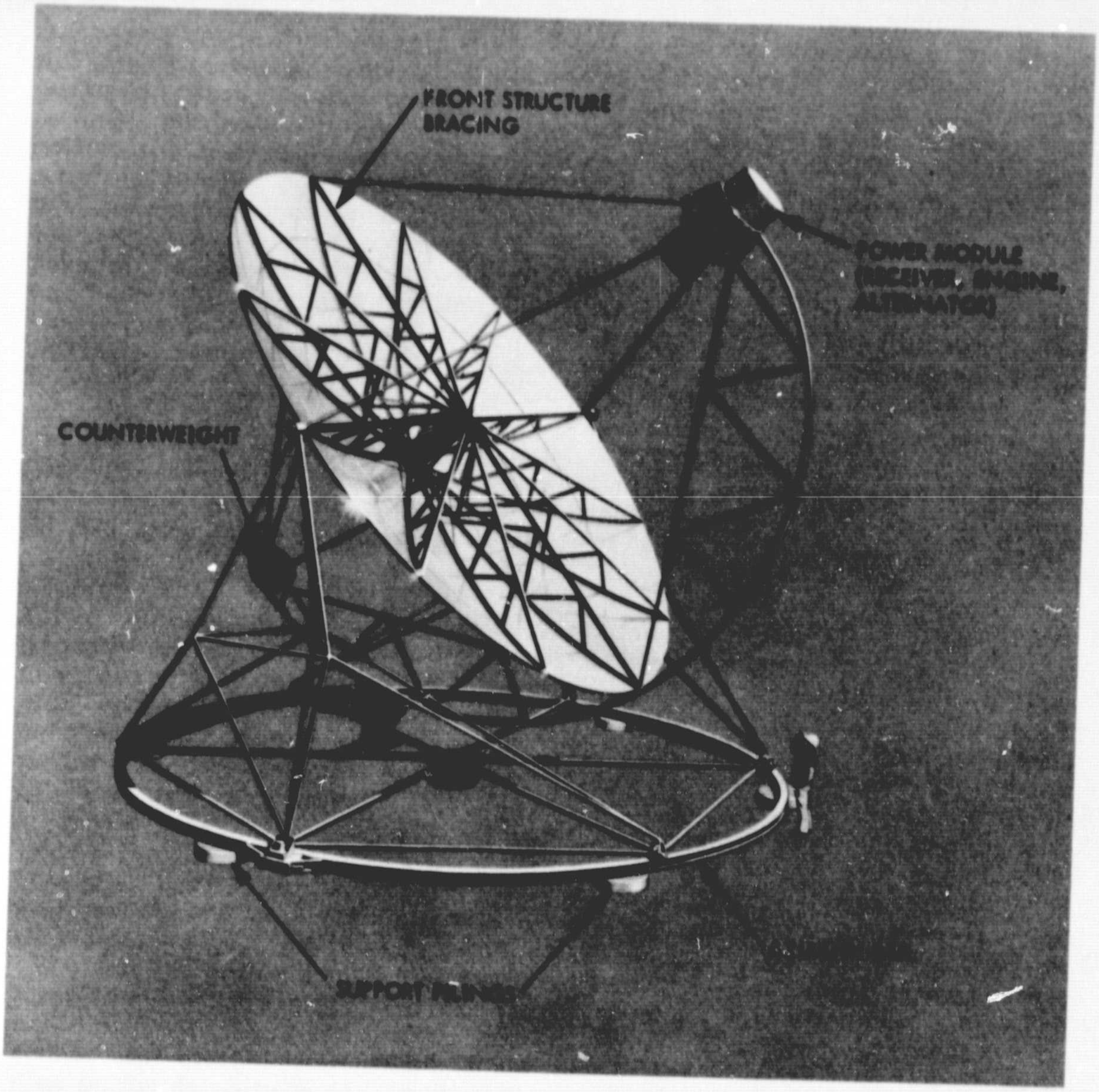


Figure 2-2. General Electric Low-Cost Concentrator

A summary of the concentrator dimensions and design characteristics is shown in Table 2-1.

Table 2-1. General Electric Low-Cost Concentrator, Preliminary Design Data

DESIGN SUMMARY				
● Dish Diameter	11 m*	● Tracking drive - azimuth/elevation with cable/drum drive		
● Concentration Ratio	1800	● Dish support structure		
● F/D	0.50	- Mount frame steel tube truss structure		
● In-Depth (In)	31.5	- Base frame hexagonal frame with end roller		
● Number of Gores	8			
● Segments/Gore	3	● Foundation: 12 reinforced concrete pilings and central pintle		
● Gore Material	Glass reinforced plastic	● Weight		
● Gore support	8 Aluminum internal ribs	- Equip. at focal point 681 kg (1500 lb) (max) (capability)		
● Gore Slope Error	1/8 degree	- Gores	1226 kg	(2700 lb)
		- Counterweight	681 kg	(1500 lb)
● Gore Deflection Limit @ 48.3km/hr (@ 30 mph)	1/4 degree	- Internal Ribs (Al.)	227 kg	(500 lb)
		- Support structure**	1317 kg	(2900 lb)
			4131 kg	(9100 lb)***

SPECIAL FEATURES

- Plastic Concentrator
- Distributed Foundation
- Vertical Down Stow
- Counterbalanced

*12m dish is now planned by General Electric.
**Includes all structural steel.
***Foundation not included.

The control subsystem is a hybrid system with a positive predictive mode for coarse control and a fiber optic based closed loop control on the receiver for final positioning.

c. The Receiver. Tentative receiver designs (for steam and organic) have been submitted by six potential subcontractors, and Ford has expressed the desire to consider a novel inhouse design of its own that employs a reflux boiler principle.

Although the receivers differ in many details, both as to geometry and materials, most employ a coiled tube with an insulated cavity which is exposed to the reflected radiant energy through a conical aperture plate. Figure 2-3 shows an artists sketch of a typical design. In the version shown, the helical coil heat exchange is made with larger diameter tubing in the superheat region.

d. The Energy Transport Subsystem. The energy transport subsystem consists of the following components:

(1) Electrical cables from each module to the central switch board.

(2) Switch board.

(3) Transformer.

(4) Switches/contactors/miscellaneous equipment.

The requirements for the energy transport subsystem for the proposed system are very similar to those studies during the Phase I effort, excepting for changes in the size and number of modules. All components selected for the entire electrical system are off-the-shelf items; their performance is known and there is no apparent risk in their use.

e. Control Subsystem. The Ford proposal has defined a control system that will completely operate a 1 MWe plant without an attendant on the site. The plant control subsystem consists of all hardware, software and related facilities required for automatic and manual control of the overall solar thermal plant.

The general functions performed by the control subsystem include:

(1) Automatic/manual control of plant subsystems - collector subsystem (concentrator and receiver), power conversion subsystem (engine and electrical alternator), and energy transport subsystem.

(2) Coordinated sequencing of plant systems for the various operating modes - startup, shutdown, normal operation, intermittent operation, and emergency operation.

(3) Plant system protection against failures (grid faults, environmental conditions, etc.) by means of monitoring key measurement variables and commanding automatic emergency sequencing.

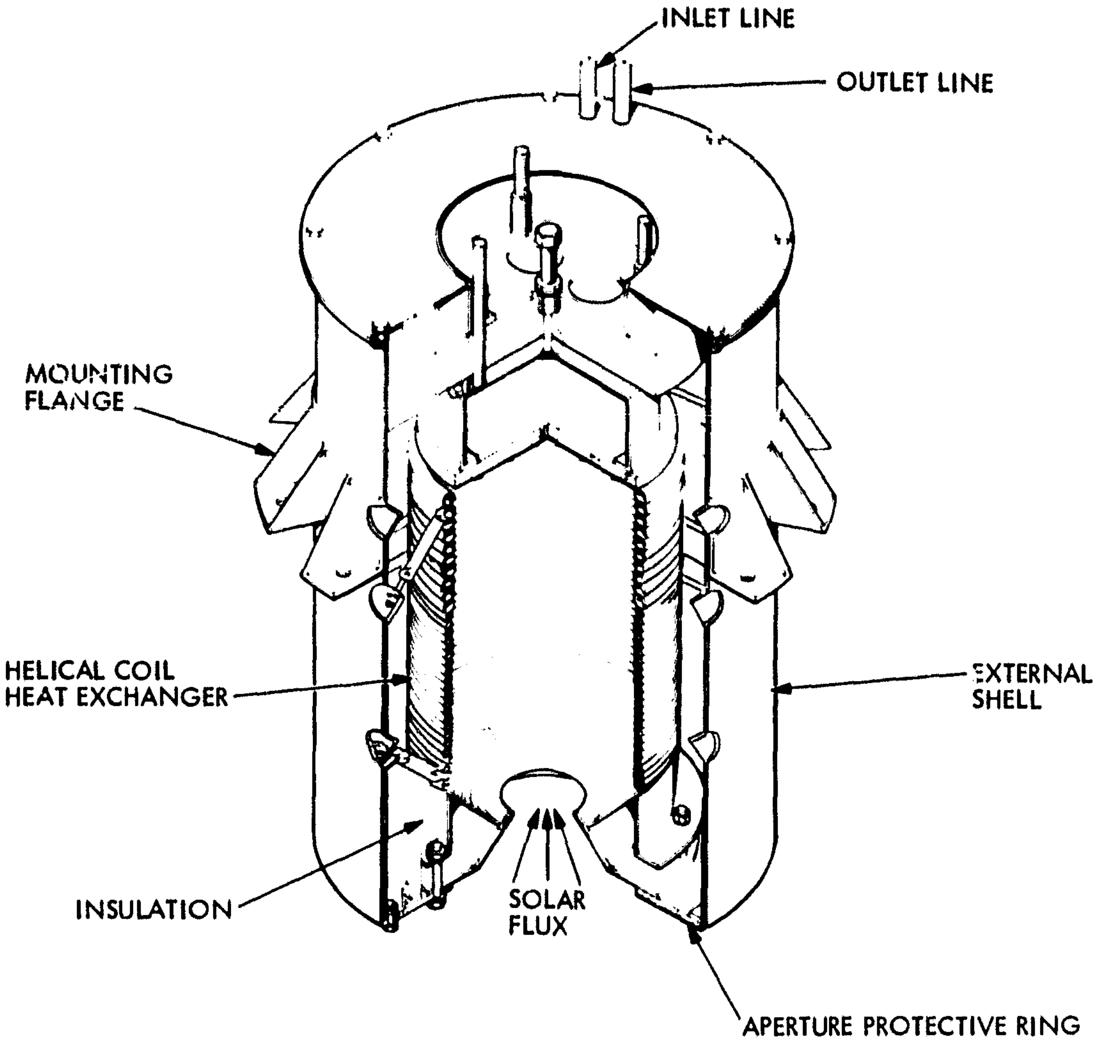


Figure 2-3. Garrett/AiResearch Steam Receiver Modified for Use with Toluene (Baseline Design)

(4) Status monitoring of relevant plant variables for control room terminal display and recording.

The baseline control system concept employs a central microprocessor for direct digital control, sequencing, protection, monitoring, etc. of all plant subsystems. Most control functions will be implemented as algorithms in the microprocessor software however, in specific cases, local analog electronic control loops will be used and only supervisory-level control will be provided by the central microprocessor.

4. SCSE Siting Activities

The SCSE Site Participation PRDA was scheduled to be released in FY 1979. The PRDA was delayed because of decentralization of this part of the DOE program and the consequent shifting of management of the siting activities from DOE headquarters to the Albuquerque Operations Office. The PRDA will be issued in the early part of FY 1980. The siting activities associated with the SCSE are addressed in detail in Section IV.

B. ISOLATED APPLICATION EXPERIMENT SERIES

1. Introduction and Background

The Isolated Application Experiment Series is the second major activity within the PFTEA Project. This is a series of small (100-200 kWe) solar thermal experiments, each of which will address a separate isolated load application.

This series of experiments employs point-focusing distributed receiver technology with emphasis on electric and thermal power applications. The program is closely integrated with the PFDRT Project with the objective of utilizing the technologies being developed under that program.

The Isolated Application Experiment Series will be designed, installed, and operated to permit JPL, DOE, and industry to better understand solar thermal plant application, technical feasibility, and operational problems. The time period for deployment and test of first generation systems is 1982-86.

The objectives of the series are to:

(1) Test the feasibility of the technology at the system level and verify that the solar thermal plant can produce electrical and/or thermal energy from solar radiation to meet energy requirements for isolated applications.

(2) Characterize the total performance of the plant (site preparation, components, subsystems, and modules) as a function of load characteristics, insolation, weather, operations and maintenance activities, safety regulations, environmental regulations, seismic factors, and legal and socio-technical factors.

(3) Identify and understand plant failure modes.

(4) Identify and quantify the impact of solar hybrid* plant operations on the daily operations activities or user personnel and on user manning requirements.

(5) Identify and quantify the impact of solar hybrid plant installation and operations on the local environment.

(6) Identify and quantify the impact of solar hybrid plant installation and operation on the acceptance of solar power plants by local public officials, local power system officials, and the local public.

(7) Economically provide testing of technologies and markets, meeting principal program objectives without large expenditures.

(8) Involve a large constituency of industrial suppliers and users.

(9) Address the potential for near-to-mid-term market for small power systems that is needed to provide the initial incentive to manufacture these systems.

(10) Increase programmatic flexibility to employ a number of small and varied experiments.

2. Military Module Power Experiment (MMPE)

The first experiment in the Isolated Application Experiment Series was initiated in FY 1979 and is co-sponsored by the U.S. Navy under the auspices of the Civil Engineering Laboratory (CEL). CEL and JPL have worked together to develop system requirements. The Military Module Power Experiment will be a modular system using hybrid fired Brayton cycle energy conversion. Subsequent experiments will test different versions of similar hardware in applications which are now being selected.

During FY 1979 preliminary system and operational requirements for the experiment were developed with U.S. Navy representatives. Approval to proceed on the experiment was obtained from DOE, and detailed experimental planning began. A procurement package for the experiment was completed in late FY 1979 for release to industry early in FY 1980. This procurement will select the system supplier for the military module power experiment.

*Initial experiments in this series are planned to operate in a hybrid mode; i.e., natural gas or other fossil fuels will be used in conjunction with solar to provide high availability and capacity factor. Other experiments may not be hybrid.

This experiment will utilize JPL PFDRT First Generation hardware whenever possible. The components (concentrator, receiver, engine) will be assembled into individual power modules. A number of such modules will be interconnected to form a power plant.

The baseline for the system is the JPL Point-Focusing Distributed Receiver Technology (PFDRT) Project, first generation dish Brayton system hardware which consists of:

(1) Solar concentrator (General Electric Company, Space Division).

(2) Gas receiver (AiResearch Manufacturing Company of California).

(3) Brayton cycle engine, alternator, and hybrid fossil combustor (AiResearch Manufacturing Company).

The degree of module self-containtment for the experiment will be driven by both economics and reliability. Each module will contain (at a minimum) concentrator, receiver, hybrid combustor, turbine, recuperator, compressor, alternator, module controls, starter, concentrator drives, tracking devices and sensors, some fuel storage and necessary exhaust hardware. A completely self-contained module is desired with only the true plant functions centrally located. These will be: power combination and conditioning equipment, module and plant performance indicators, grid interconnection equipment (if employed in the experiment), computing and data recording facilities, instrumentation and plant safety and control equipment. The normal mode of module operation will be unattended, however each module will be equipped for safety or emergency shutdown, both manual and automatic. Although a fixed installation is expected, individual modules will be transportable, field erectable and field serviceable.

Plant power output will be AC 60 Hz, three phase. Load-shedding devices will be incorporated if required for equipment protection. The details of the power combination/conditioning method and grid interface will be investigated by the system supplier. The plant will be connected to a 3 phase electrical grid for backup and reserve power supply. The power rating of the plant will be approximately 100 kWe under nominal insolation conditions.

Long-term thermal storage will not be included in the plant. No thermal buffering will be provided except by the heat capacity of the installed components and working fluid. The hybrid combustor control system will provide the desired transient response characteristics.

Military Module Power Experiment emphasis will be on:

(1) High reliability and safety.

(2) Early plant deployment.

(3) Complete test and evaluation.

Site selection has been a U.S. Navy responsibility. It has been conducted in parallel with other experiment activities and has been independent of the technical tasks. Preliminary site screening and selection of three most promising candidate sites were completed in FY 1979. Visits were made to each site and technical discussions were held with site power engineers and administrative personnel. Tentative site selection at the Marine Corps Air Station, Yuma, Arizona was made late in FY 1979.

3. Planning for Future Experiments

Additional Isolated Application Series Experiments are now being planned. Applications are being selected which will support the JPL market penetration strategy with experiment deployment schedules based on technology readiness and the availability of funding.

C. INDUSTRIAL APPLICATION EXPERIMENT SERIES

JPL has begun preliminary planning on the accelerated introduction of point-focusing distributed-receiver solar thermal power systems in industrial applications in small communities. These applications are characterized by their extremely large annual energy consumption. The experiments will be designed to test solar thermal energy systems for these industrial applications.

The key elements of the approach are:

(1) Rapid deployment of existing technology.

(2) Small, low/cost, low risk experiments.

(3) Near-term applications, preferably thermal.

(4) User and system supplier on Contractor team.

(5) Deployed hardware.

The technical feasibility of PFDR systems must be demonstrated in many different locations and applications. This is a critical point. Every major study of the attitudes of potential industrial users has arrived at the same conclusion. To be of value to a particular user, an engineering experiment must prove system feasibility in an application and region similar to the user's.

The Industrial Application Experiment Series planning was initiated in FY 1979, and the overall approach was determined. Activities during FY 1980 will include detailed experiment planning and the procurement associated with the selection of the first experiment contractors in this series.

SECTION III

SYSTEMS ENGINEERING AND DEVELOPMENT

Three major activities are described in this section: 1) a comprehensive system analysis that considered and ranked various small power system technologies for the small community/utility application, 2) support provided to the engineering experiments, and 3) the development of the solar energy simulation (SES) computer code to support this task.

A. COMPARATIVE ASSESSMENT OF SMALL POWER SYSTEM TECHNOLOGIES

1. Introduction and Background

The major thrust of the PFTEA project centers around a series of engineering experiments whose purpose is to test small solar thermal power systems under varying conditions in order to establish technical feasibility. The solar thermal power plant comparative study was performed to aid JPL in managing the experiment activity, as well as to support decisions for the selection of the best technological approach. The study was initiated in early FY 1978. This summary identifies the systems evaluated, the methodologies utilized, and the results obtained.

Shortly after the start of this study, DOE initiated two additional independent efforts in order to provide a more detailed base of comparative data. Thus, the Solar Energy Research Institute (SERI) and Battelle Pacific Northwest Laboratories (BNL) conducted evaluations of a similar set of small power system options. References 3-1 and 3-2 provide the results of these independent studies.

The solar thermal power systems described in this study were rank-ordered by using the multi-attribute decision analysis methodology of Keeney and Raiffa (Reference 3-3). Various individual rankings were determined and were then aggregated into several overall rankings by utilizing formulation from the collective choice theory (References 3-3, 3-4). This methodology was applicable because qualitative as well as quantitative criteria could be considered in the ranking of the systems. The four criteria used to evaluate the systems were cost, performance, negative impact and industrial and commercial potential (Figure 3-1).

2. Analysis

In order to establish the costs and performance necessary for the ranking procedure two additional analyses were conducted. The costing analysis was based on manufacturer surveys, various solar energy reports, and resident JPL expertise . The performance analysis utilized a computer simulation model (SEC Computer Code) along with the results of the costing effort to establish optimal capital costs, energy costs, and the performance of each plant studied.

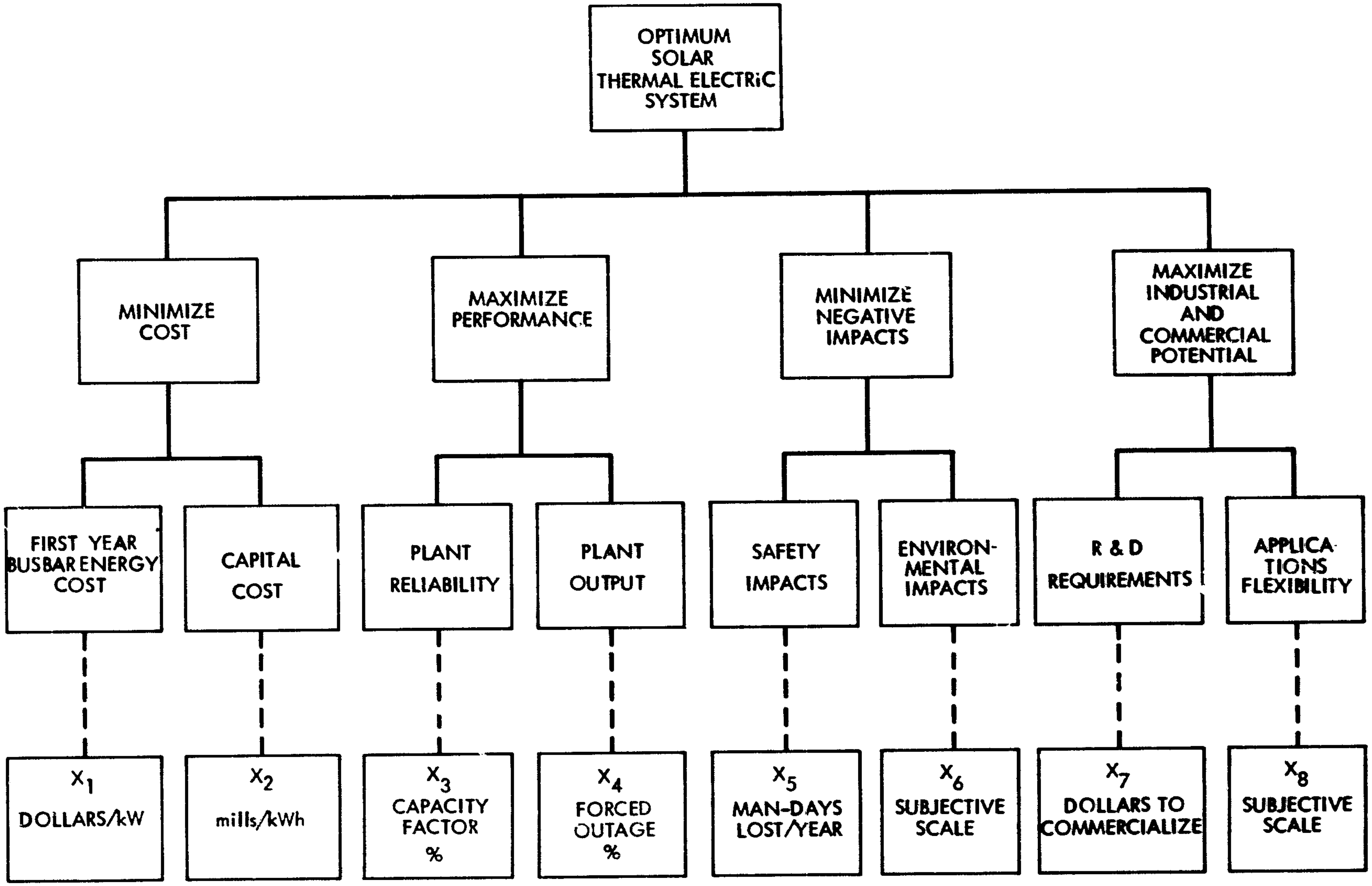


Figure 3-1. Multiattribute Decision Analysis Criteria and Factors

Ground rules which were established early in the study to ensure consistency and to allow a comparison with other results were as follows:

(1) All plants had a thirty-year lifetime.

(2) It was assured that all the electrical energy produced by the plant would to be utilized without regard to variations in load demand.

(3) Plant sizes provided were 1, 5, and 10 MWe.

(4) Capacity factors of 0.4 and 0.7, plus the capacity factor for zero storage were examined.

(5) All plants were assumed to be located in Barstow, California.

(6) The annual insolation at the plant site was based on the data for 1976, as measured by WEST Associates and analyzed by the Aerospace Corporation. This insolation was assumed to exist for the total lifetime of the plant (Reference 3-5).

(7) Bus bar energy cost calculations were analyzed by using the JPL/EPRI evaluation methodology as described later in Section III (Reference 3-6).

It was further assumed in this analysis that the year of commercial operation for all plants would be 1990. The intent of this was to minimize the economic uncertainties which could develop if the construction and operations period were extended too far into the future. The time period in which technologies were considered to be fully developed was 1985-1990. The reason for this stipulation was to provide equal opportunity to all technologies in terms of development and cost reductions, if these improvements could be achieved by 1990 as a result of present or anticipated development programs. Because the various technologies are developing at different rates, the assumption that they will all have sufficient time to develop by a reasonably early date should minimize any potential distortion in the results.

Figure 3-2 summarizes the graphic plant concepts evaluated in the study. Although other configurations are possible, they were eliminated because of redundancy and/or potentially high costs. The system abbreviations as shown in Figure 3-2 are defined as follows:

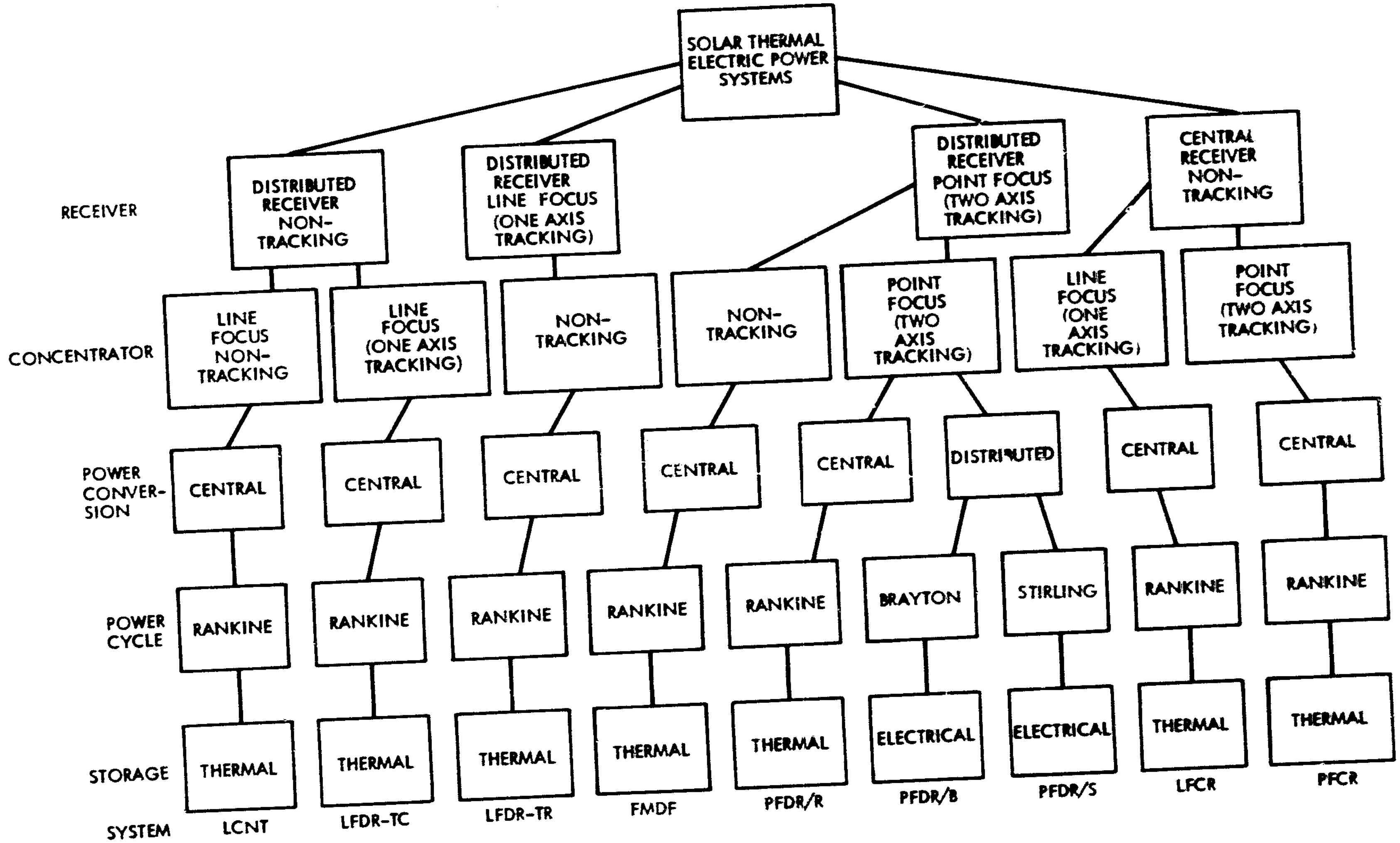


Figure 3-2. Flowchart of Solar Thermal Plant Technology Options

Abbreviation	Concept
LCNT	Low Concentration Non-Tracking
LFDR-TC	Line Focus Distributed Receiver-Tracking Concentrator
LFDR-TR	Line Focus Distributed Receiver-Tracking Receiver
LFCR	Line Focus Central Receiver
FMDF	Fixed Mirror Distributed Focus
PFCR	Point-Focus Central Receiver
PFDR/R	Point-Focus Distributed Receiver/Rankine Engine
PFDR/B (ceramic)	Point-Focus Distributed Receiver/Ceramic Brayton Engine
PFDR/B (metalic)	Point-Focus Distributed Receiver/Metallic Brayton Engine
PFDR/S (ceramic)	Point-Focus Distributed Receiver/Ceramic Stirling Engine
PFDR/S (metalic)	Point-Focus Distributed Receiver/Metallic Stirling Engine

At the time of publication, the document containing the results of this analysis is in review. It is expected that this report (Ref. 3-7) will be published in the third quarter of FY 1980.

B. ENGINEERING EXPERIMENT SYSTEMS SUPPORT

Three major activities in support of the engineering experiments were conducted in FY 1979; 1) technical support of the SCSE Phase I contract and evaluation of the results of Phase I constituted a major portion of the effort in this task area; 2) development of Phase II system design specifications supported the writing of the Phase II RFP; and 3) completion of special studies that provided the necessary background and technical detail to evaluate experiment design alternatives. The first study was a power management study for PFDR, distributed conversion systems. The second study surveyed the work being done on advanced battery systems. Each of these items is discussed in following paragraphs.

1. Evaluation of SCSE Phase I Results

The conceptual design studies (Phase I) initiated in FY 1978 with industry for the Small Community Solar Thermal Power Experiments (SCSE) were completed in FY 1979.

Contractor	Conceptual Approach
McDonnell Douglas Astronautics Co.	Point-Focus Central-Receiver Central-Generation
General Electric Energy Systems	Point-Focus Distributed-Receiver Central-Generation
Ford Aerospace & Communications Corporation	Point-Focus Distributed-Receiver Distributed-Generation

Project reviews of the contractors' study progress were conducted at three intervals during the course of the contracts and a comprehensive final report submitted by each at the end of the contracts (7/5/79).

Summary descriptions of the conceptual designs developed by each contractor are described later. Detailed information is found in the Phase I final reports (References 3-9, 3-10, 3-11).

Project evaluation of these designs in conjunction with consideration of the near term goals of the DOE small solar thermal program resulted in a decision to select the Point-Focus Distributed-Receiver Distributed Generation concept studied by the Ford Aerospace and Communications Corporation.

On August 15, 1979, a JPL Request for Proposal was submitted to Ford for a Phase II effort to design, develop, and qualify the hardware for a module for this Experiment and conduct a System Verification Test of that module at the JPL Parabolic Dish Test Site. The Ford proposal was received on September 19, 1979. The contract was extended on 26 December 1979.

a. <u>McDonnell Douglas Astronautics Company (MDAC) System Concept.</u> The system concept selected by MDAC during the Phase I study is the small central receiver plant illustrated in Figure 3-3. The completed system is composed of five major subsystems: the collector, power conversion, energy transport, energy storage, and the plant control subsystems.

The collector subsystem consists of the solar concentrator, receiver, and tower assemblies. The concentrators comprise a field of two-axis tracking heliostats, which reflect and concentrate solar radiation onto a tower-mounted receiver. The heliostat field is located north of the receiver tower. The heliostat, Figure 3-4, is a second generation version of the Barstow 10 MWe plant design. It consists of four sub-assemblies: 1) the reflector panels; 2) the drive unit; 3) the pedestal support and foundation; and 4) the control.

Figure 3-3. McDonnell Douglas Astronautics Company Proposed 1 MWe Solar Power Plant

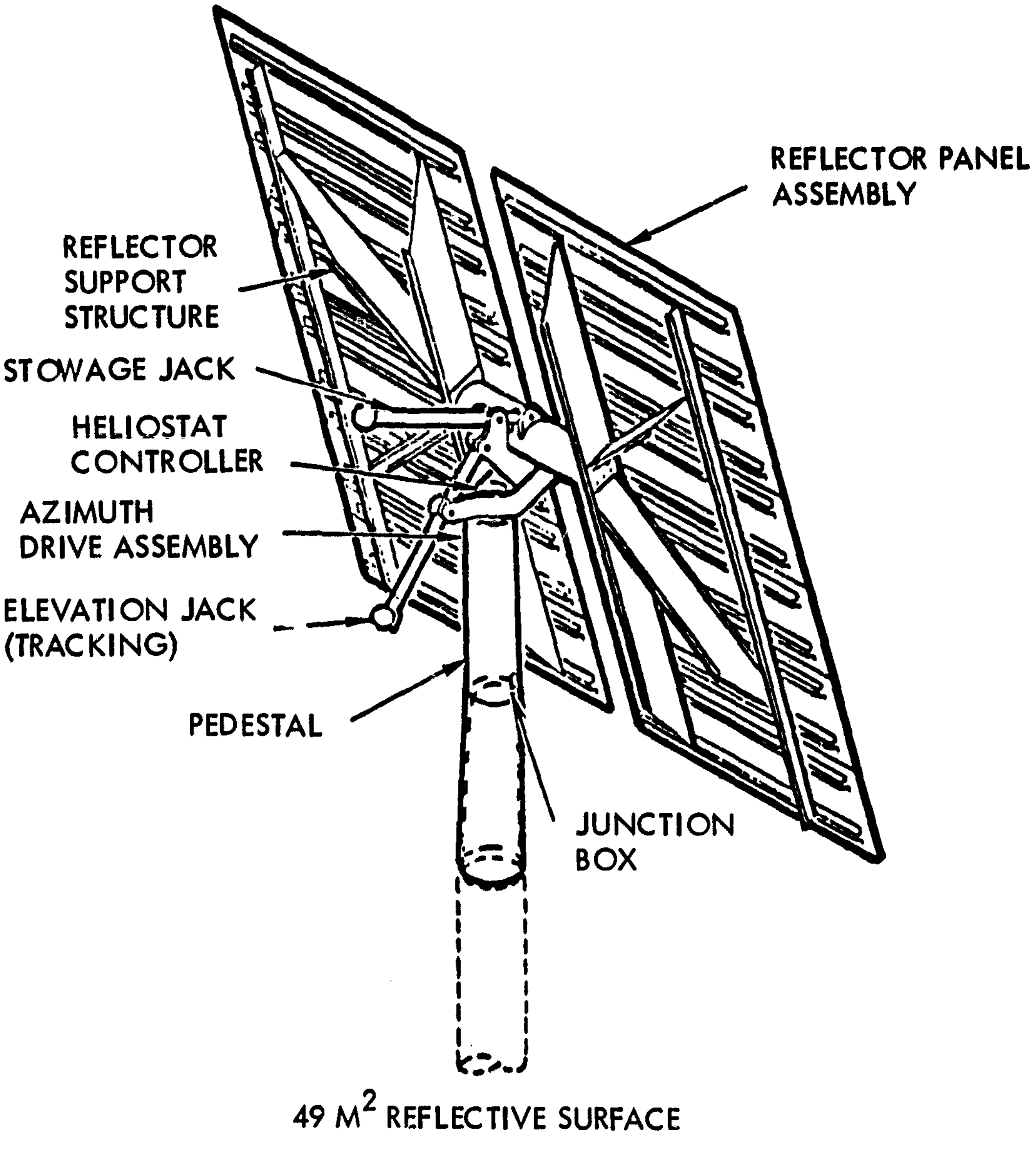


Figure 3-4. Second-Generation Heliostat

There are two reflector panels per heliostat and each panel is made up of six mirror modules. The receiver, shown in Figure 3-5 is a partial cavity-cone design and is composed of an absorber unit, structural assembly (including housing and doors), instrumentation, insulation, and heaters. The receiver faces south with the aperture tilted downward 20° from the vertical. The tower assembly illustrated in Figure 3-6, provides support for the receiver as well as the thermal transport fluid (HITEC) riser and downcomer.

Elements of the energy transport, energy storage and power conversion subsystems are shown in the SCSE system schematic drawing, Figure 3-7.

The energy transport subsystem collects thermal energy from the receiver and transports it to the energy storage subsystem and then to the power conversion subsystem. HITEC is used as the transport fluid because of its relatively low melting temperature (142°C) and common use in industrial processes.

The energy storage subsystem both isolates the power conversion subsystem from the collector subsystem and stores thermal energy for extended operation. A simple two-tank configuration, which does not require development, is utilized in the design.

Steam produced from the steam generator drives a steam Rankine cycle turbine which in turn drives an electrical generator to produce electricity. For the recommended system, an existing axial steam turbine is utilized. Waste heat from the turbine is rejected by a wet cooling tower. A power plant building will contain the entire power conversion subsystem with the exception of the cooling tower and waste water pond. The building will also contain the plant control subsystem and will provide facilities for plant management, visitor control, and technical support. The balance-of-plant equipment involves state-of-the-art equipment and processes.

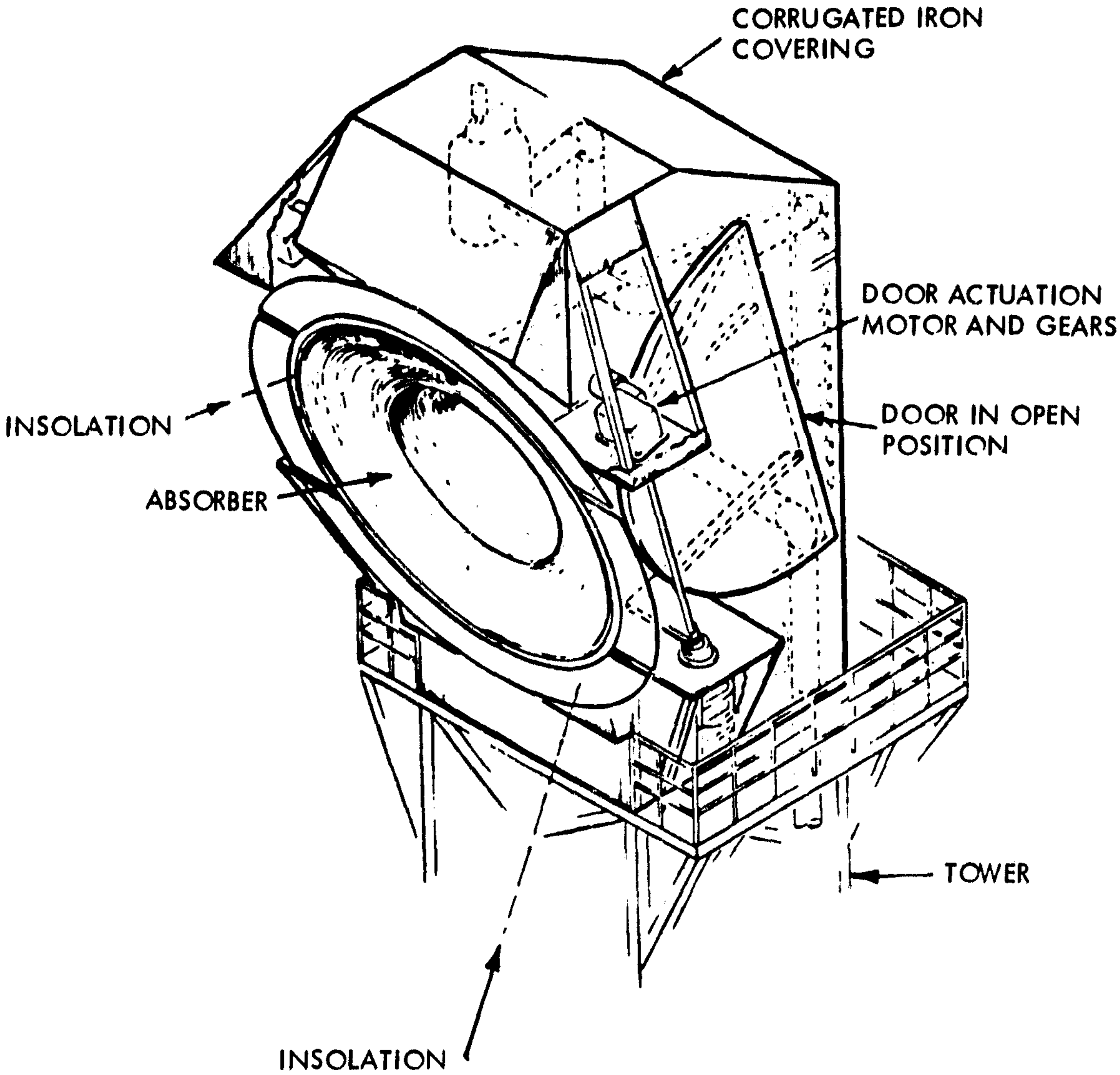
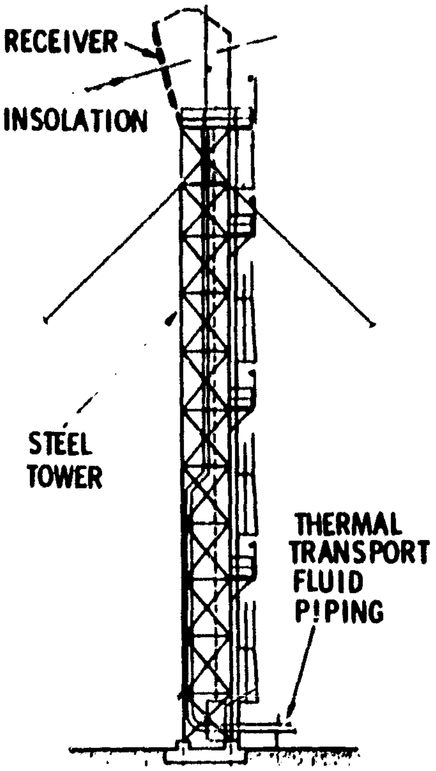
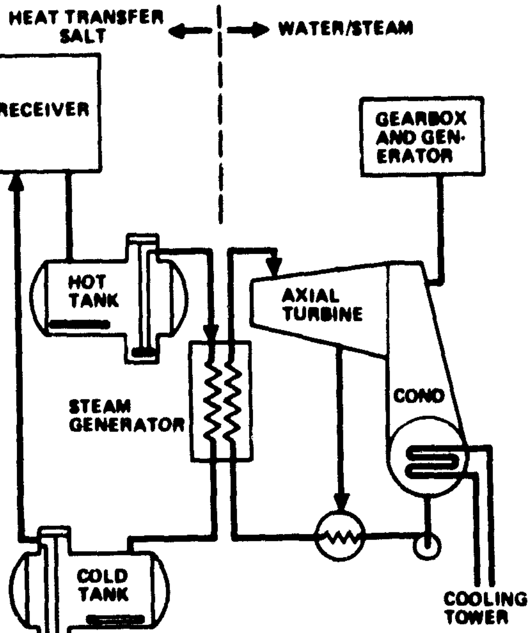


Figure 3-5. Isometric Sketch of Receiver In Place On Top of the Tower



- HEIGHT· 40 m (131 FT) - EE NO. 1 PLANT
  36 m (112 FT) - COMMERCIAL PLANT
- GUYED STEEL - FOUR 2.5 cm (1 INCH) DIA CABLES
- ASSEMBLED FROM STANDARD STEEL SECTIONS
- CONCRETE BASE - 27.5 m^3 (36 CU YD)
- OPERATING DEFLECTION · 1.5 cm (0.6 IN) IN 16 m/s (36 MPH) WIND
- SERVICE ELEVATOR FOR EE NO. 1

Figure 3-6. Collector Subsystem (Tower)



3.5 and 4.5 YEAR SYSTEMS

Figure 3-7. System Configuration

The performance and design characteristics of the MDAC concept for SCSE are summarized in Table 3-1.

Table 3-1. System Characteristics Summary for MDAC Concept

SYSTEM DATA	
Rating	1 MWe (Net)
Capacity factor	0.4
Availability	0.95
Operating life	30 years
Land used	4.1 hectares (10 acres)
Efficiency	16.3% at 1 MWe and no storage
Type	171 north field heliostats with tower mounted central receiver
COLLECTOR SUBSYSTEM	
Collector efficiency	60%
Concentrator module	
Reflecting area	49 M^2/heliostat, 3380 m^2 total area
Error	3.5 mrad total slope & pointing error
Control	Open loop
Receiver Module	
Aperture	4.28 m diameter aperture
Type	Partial cavity-cone
Height	42 m to centerline of receiver
Output	6.05 MWt at 510°C (950°F)
Input	288°C (550°F)
POWER CONVERSION SUBSYSTEM	
Type	Rankine cycle axial, marine type steam turbine
Net output	1 MWe
Parasitic loss	0.11 MWe
Inlet temperature	482°C (900°F)
Cooling	Wet cooling tower
Efficiency	31.0%
ENERGY TRANSPORT SUBSYSTEM	
Type	Steel piping with Hitec transport fluid
Efficiency	99%
ENERGY STORAGE SUBSYSTEM	
Type	Hot tank/cold tank, Hitec,* sensible heat
Storage	14.9 MWe-hr (4 hours)
Maximum temperature	510°C (950°F)
Minimum temperature	288°C (550°F)
Efficiency	96.5%

* 53% KNO_3, 40% $NaNO_2$, 7% $NaNO_3$

b. General Electric Company System Concept. The GE basic system concept is a solar power plant which utilizes two-axis tracking, point-focusing distributed collectors to generate steam which is then transported through low-loss piping to a central steam turbine generator unit. This basic concept is divided into five major subsystems as shown in Figure 3-8.

The collector field is divided into two parts: 1) The Saturated Field (80% of collectors); and 2) The Superheated Field (20% of collectors). These two fields are connected by a steam accumulator as shown schematically in Figure 3-9. Basically, the system operates by generating saturated steam in the Saturated Field, collecting this saturated steam (quality varying with insolation) in a steam accumulator, and then superheating the available steam from the accumulator in the Superheated Field prior to entry into the steam turbine. This concept requires only the turbine control valves for controlling the collector field.

For visualization purposes, an artist's rendering and a layout of the recommended system are shown in Figures 3-10 and 3-11. A 1150 kWe steam turbine generator unit is centrally located within the collector field along with the steam accumulator, dry condenser, various power conversion subsystem components, electrical subsystem, control room, and office/storage space. This equipment is skid-mounted at the factory in order to minimize on-site installation time and costs. A dry condenser was selected because it was assumed that a wet cooling tower was environmentally unacceptable for arid areas such as Barstow, California. It should be noted that performance improvement resulting in an approximate 7% reduction in the number of collectors and associated equipment could be achieved if site conditions (i.e., availability of water) permit a wet cooling tower.

The collector field consists of 96 collectors (10 m aperture diameter, unenclosed, JPL low-cost, first generation) which utilize cavity-type receivers. Six collectors make up a branch where each collector has manual shutoff valves, and the branch has an automatic shutoff valve. The branches feed into main header pipes which run through the middle of the field to the power conversion subsystem. The piping is wrapped with standard insulation to inhibit excessive heat loss. The saturated field collectors are located a great distance from the steam accumulator while the higher temperature superheat field collectors are located near the steam accumulator in order to reduce piping heat losses. The collector field is modular; the loss of a collector will automatically cause a shutdown of its particular branch only, while the remainder of the field continues to provide steam to the steam turbine, which will operate at only a slightly reduced output. If personnel are at the site, the damaged collector can be manually isolated from its branch and the five collectors on the branch permitted to supply steam once again. The collectors throughout the field are interchangeable with the exception of the cavity receiver and associated up/down piping which is different for the saturated and superheat fields.

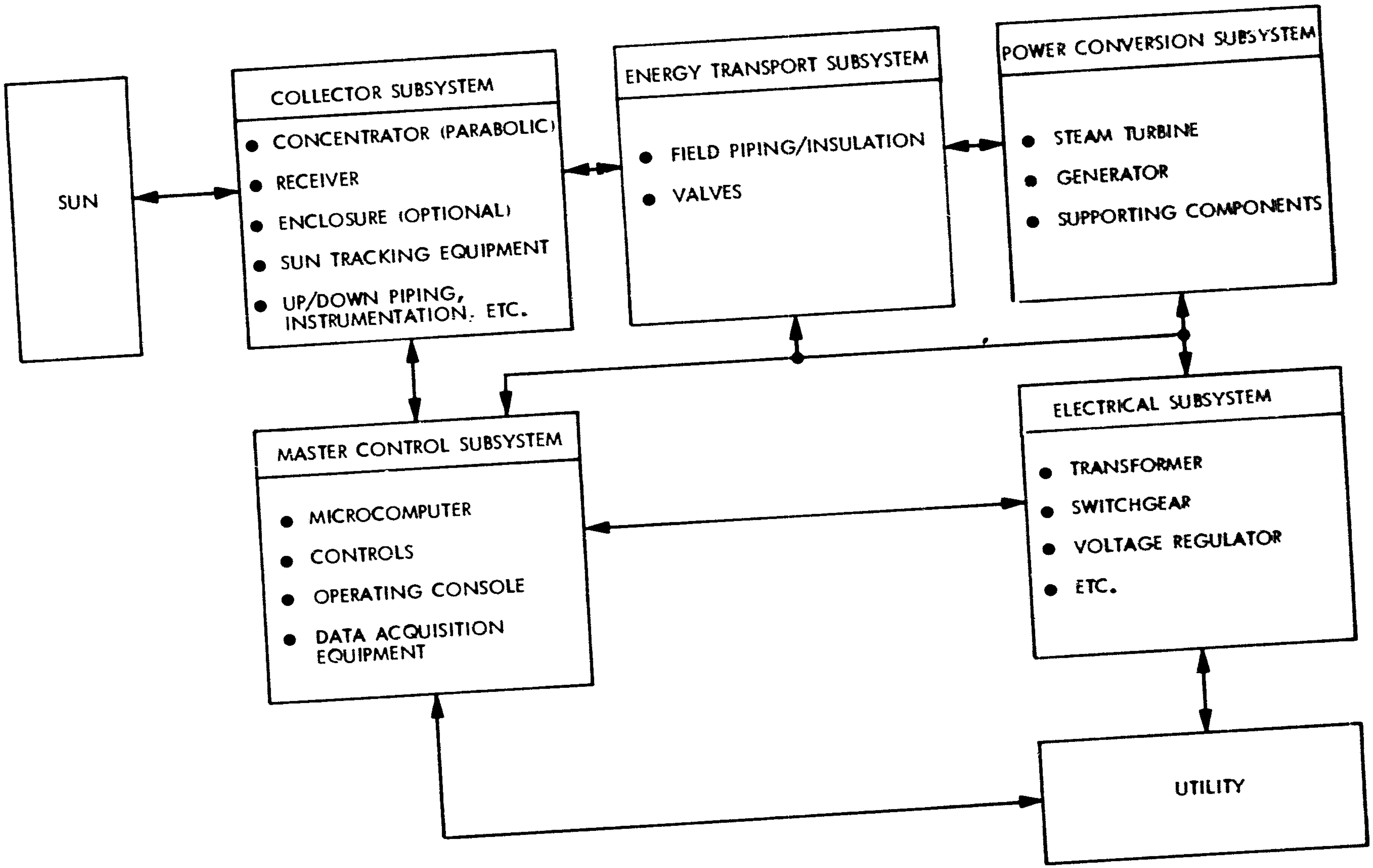


Figure 3-8. General Electric Basic System Concept

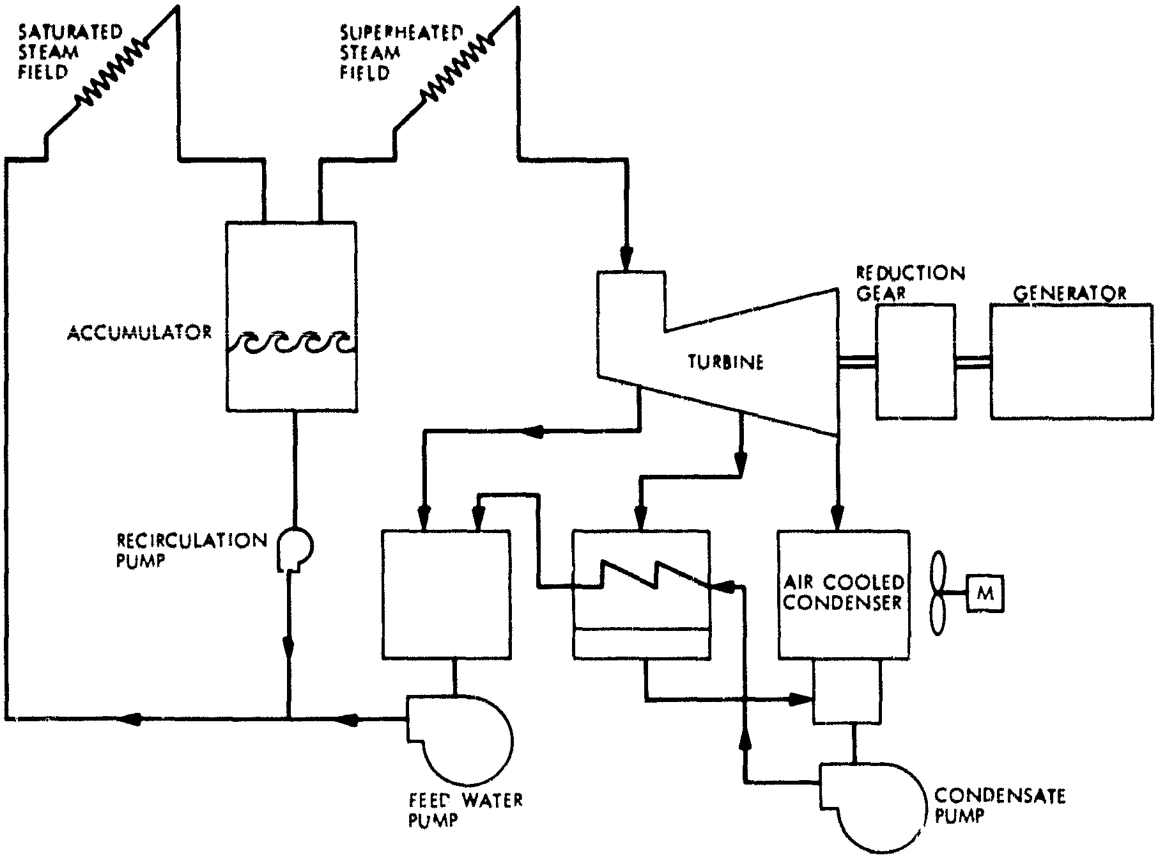


Figure 3-9. General Electric Basic System Schematic Drawing

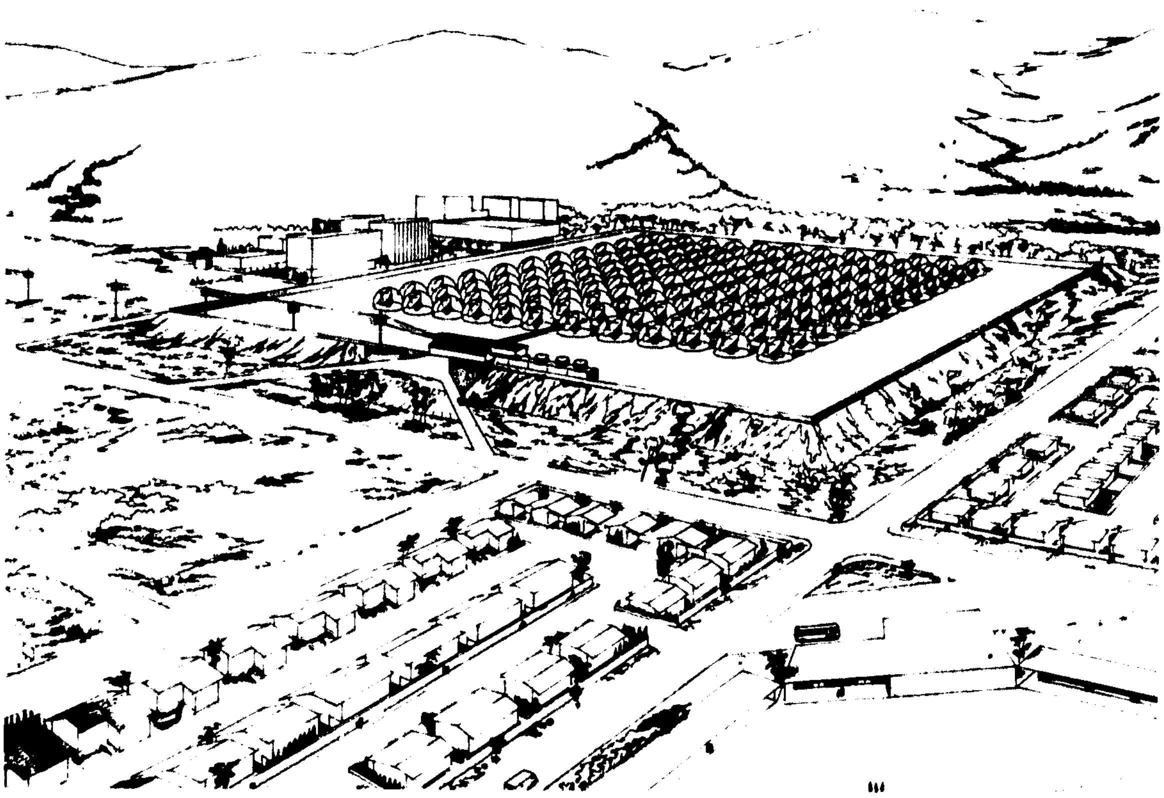


Figure 3-10. General Electric Enclosed Collector Concept for SCSE

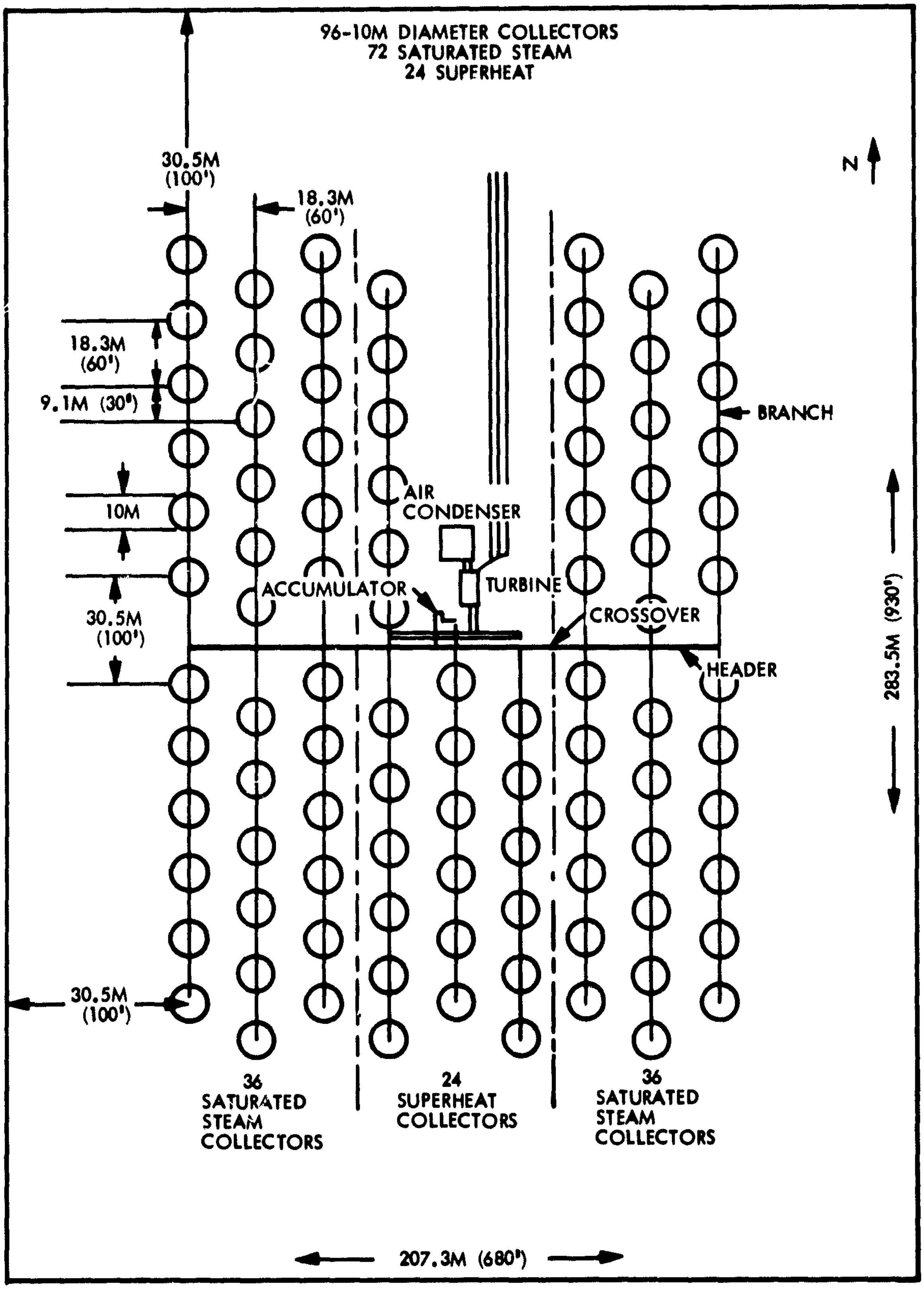


Figure 3-11. Overall Plant Layout for the General Electric Recommended System

The collectors may be defocused in branches if the insolation is too high that the steam turbine generator capacity is exceeded.

The land area required for the recommended plant is approximately eight acres for a tight perimeter around the collector field. As shown in Figure 3-12, with a 3.5m (100-foot) spacing around the perimeter of the collector field, approximately 5.87 hectares (14.5 acres) of land are required. An advantage of the distributed collector concept is the fact that the plant site does not have to be square or even, but may have a wide variety of acceptable plot plans.

The characteristics of the recommended system are summarized in Table 3-2. System and subsystem performance estimates are shown in Table 3-3. The recommended system will provide slightly greater than 1000 kWe net to the utility grid during most of the year with Barstow, California insolation/weather conditions. The use of JPL first generation Low-Cost collectors is recommended because their use will result in the lowest collector field cost for this experiment and these collectors, being designed for mass production, will offer an attractive step toward the demonstration of commercial feasibility of the system. A dry condenser is recommended because early applications of such small solar power plants will probably be located in arid regions of the U.S. where higher insolation levels are available.

c. <u>Ford Aerospace and Communications Corporation System Concept.</u> The system concept selected by Ford Aerospace & Communications Corporation (Ford) in the Phase I study is comprised of multiple dish concentrators employing Stirling cycle heat engines with direct-coupled AC generators for power conversion at the focal point of each concentrator. A field layout sketch of the baseline 1 MWe system is shown in Figures 3-12 and 3-13. The baseline system (assuming energy storage is required) is comprised of 19 parabolic concentrators 18.6m in diameter with the United Stirling (Sweden) P-75 Stirling cycle engine used for power conversion. If an energy storage subsystem were not required, only 18 concentrators would be needed.

The collector module comprises both the collector subsystem and major elements of the power conversion subsystems. Each module includes the parabolic concentrator and a cavity receiver with an integral sodium pool boiler, the sodium thermal transport hardware, and the engine/generator assembly. The parabolic dish concentrator is a front-braced design (see Figure 3-14), with an Az-El mount and tripod structure. The reflector surface is composed of back-surfaced, high-reflectivity (95%) drawn fusion glass mirrors segments.

A sketch of the receiver thermal transport equipment and power conversion hardware is shown in Figure 3-15. The selected receiver design consists of concentric cylinders fabricated of Type 316 stainless steel with sodium filling the annulus. During operation, the vaporized sodium is transported by natural convection to the heater head of the engine, condensed, and returned to the boiler by gravity.

Table 3-2. General Electric Recommended System Characteristics

- 14.28 overall system annual efficiency
- 482°C (900°F), 8.62 million pascals (1250 psia) steam turbine inlet conditions
- 2834 MWe/hr annual energy to utility grid with Barstow, California environmental/insolation data
- 1115 kWe net plant rating (1250 kWe gross rated steam turbine generator)
- 0.25 capacity factor at 1115 kWe net rating
- 96, 10 m* aperture first generation JPL low-cost point-focus collectors
- Standard insulated piping
- No dedicated energy storage
- Dry condenser for arid sites
- Minimum total cost for 1 MWe size plant
- Operational in ~3.5 years from Phase II go-ahead
- Meaningful step along commercialization path

*Original LCC diameter

Table 3-3. Recommended System Performance at Reference Points for General Electric

	At 950 W/m^2 Insolation Level				At 800 W/m^2 Insolation Level			
Component/ Subsystem	Component Loss (kW)	Component Efficiency (%)	Output (kW)	Output Efficiency (%)	Component Loss (kW)	Component Efficiency (%)	Output (kW)	Output Efficiency (%)
Solar Incidence	--	--	6588	100.0	--	--	6030	100.0
Collector	1530	76.7	5038	76.7	1439	76.3	4801	76.3
Energy Transport	187	96.3	4851	73.9	203	95.6	4398	72.9
Power Conversion	3599	25.8	1251	19.1	3298	25.0	1100	18.2
Auxiliary Power	136	89.3	1116	17.0	127	88.5	973	16.1
Net Output	--	--	1116	17.0	--	--	973	16.1

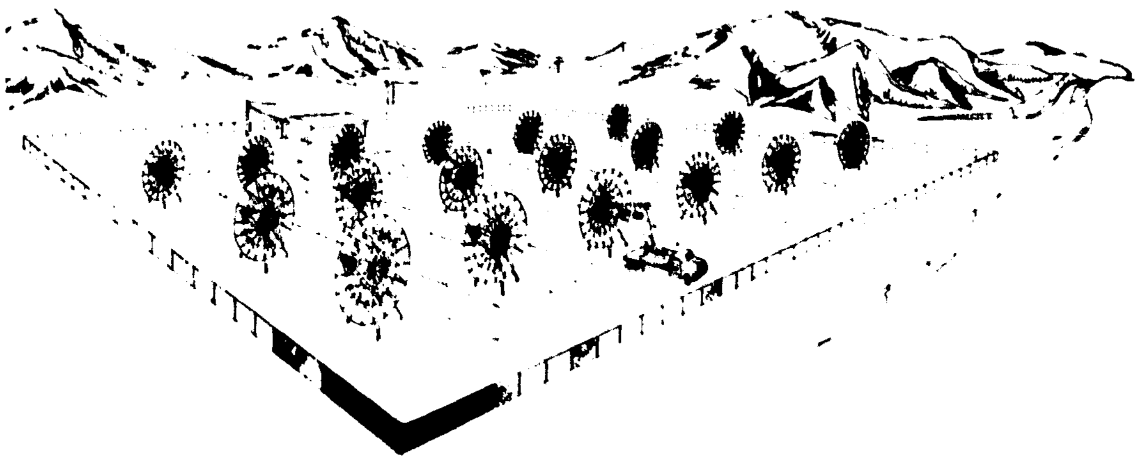


Figure 3-12. Field Layout for Baseline Dish - Stirling System

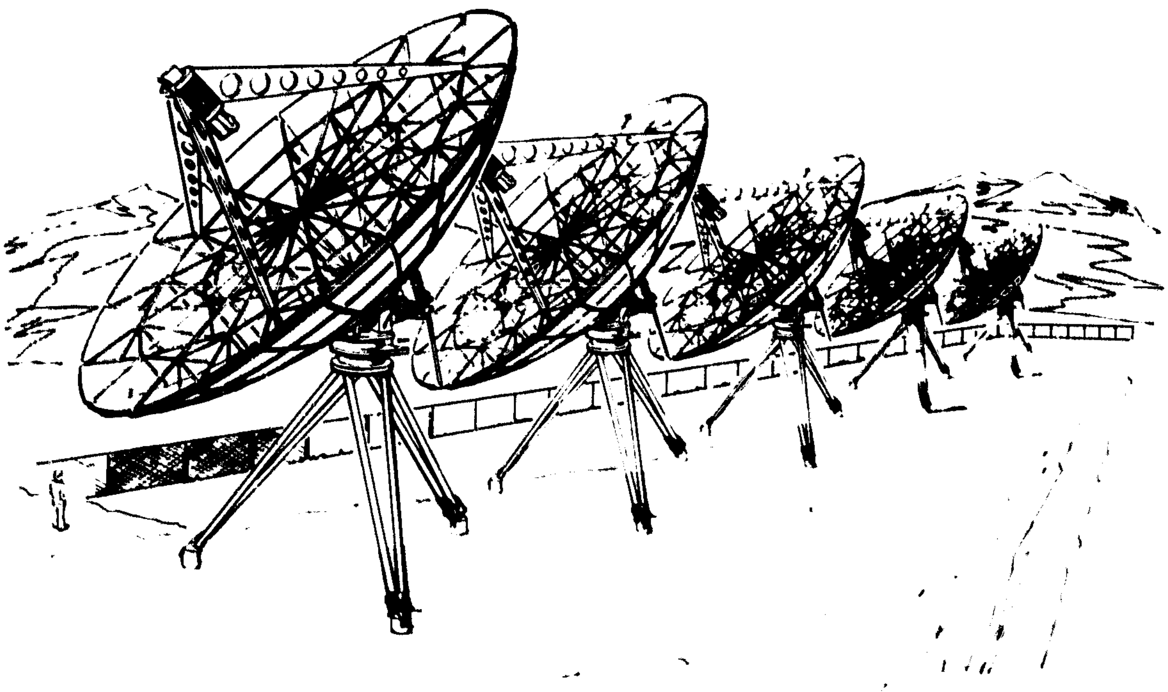


Figure 3-13. Field Layout for Baseline Dish - Stirling System (Partial view of field)

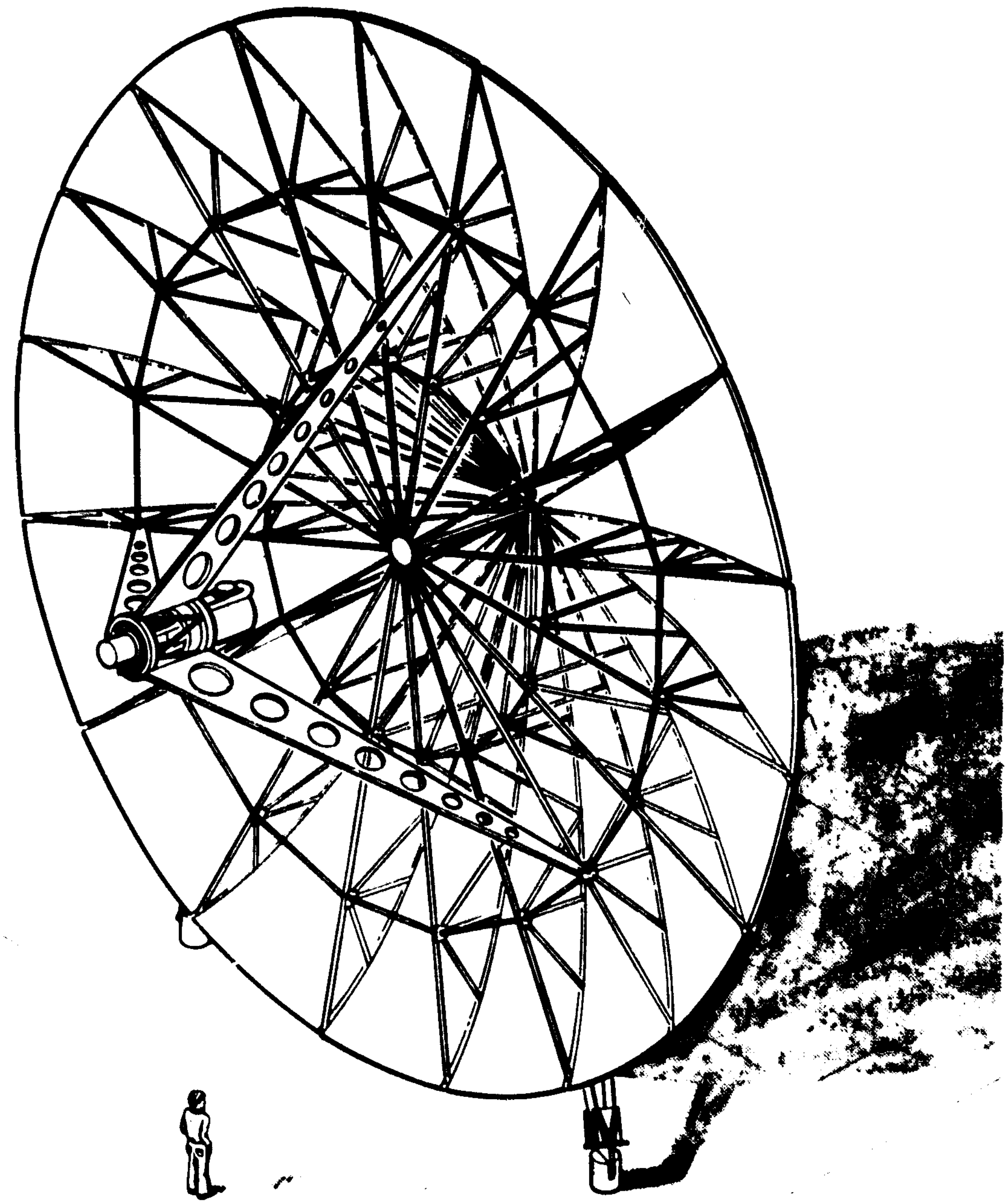


Figure 3-14. Ford Baseline 18.6 m Front-braced Collector

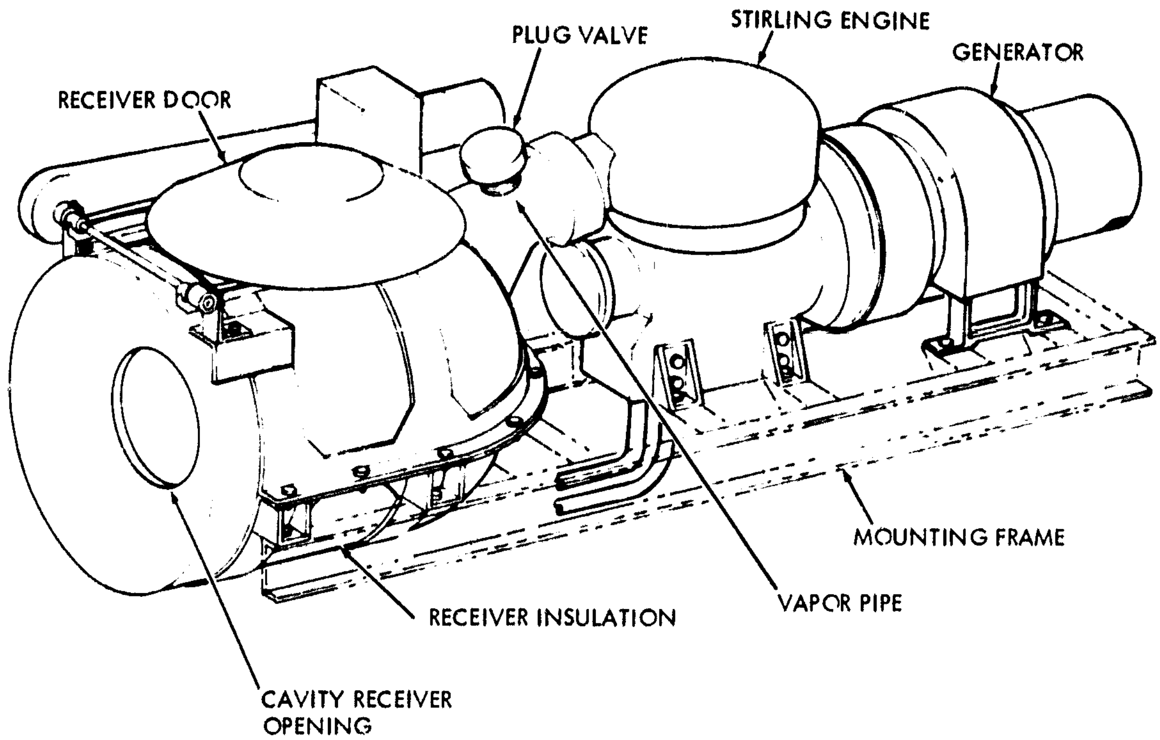


Figure 3-15. Stirling Engine Receiver/Thermal-Transport/Power Conversion

The selected baseline USS P-75 engine is a U-crank configuration and operates at a rated shaft power of 63.4 kW at 1800 RPM and about 115 atmospheres near pressure level using helium as the working fluid. Maximum heater temperature is 800°C. Figure 3-16 shows a schematic of the selected P-75 power plant which is currently under development at USS for automotive applications. The selected generator is a direct coupled, 75 kW, 480V, 3-phase, 60 Hz synchronous AC running at 1800 rpm. Output power from each of the generators is collected and transported by a conventional distribution subsystem. Flexible copper cables are used to carry the generated power across the rotational axis to the ground. The remaining power cables (up to the transformer) will be designed with insulation suitable for direct burial in earth.

Conventional lead-acid batteries were chosen for the baseline energy storage subsystem. The batteries would be grouped in 180 cell strings at a fluid voltage of 2.25 V/cell.

Performance and key parameters of the baseline system and subsystems are summarized in Table 3-4.

d. Alternate Engine Considerations in the FACC (Ford) Phase I Study

Ford considered Brayton, Stirling and ORC power plants in their design and optimization studies to arrive at their preferred Category C system. At the outset of the study, the Stirling engine was generally regarded as a less mature technology than that of the Brayton and Rankine engines. However, Ford found that as a result of a detailed examination of heat engines suitable for solar use, that all candidates required some development effort (i.e., none of the candidates could be considered off-the-shelf hardware).

The analyses of the Stirling system utilized engine data provided by United Stirling of Sweden (USS) for their P-40 and P-75 engines. The major part of the engine data for use in the Brayton System analyses was provided by Garrett AiResearch for their CCPS-40-1 closed-cycle engine. For the open-cycle engine, Ford assumed a paper engine based on the rotating components of the CCPS-40-1 closed-cycle engine. The ORC engine data was supplied by Sundstrand. (Early in the study, Ford concluded on the basis of engine availability as well as design simplicity and state-of-the-art technology, that an ORC engine rather than a steam Rankine engine was a better choice for the Engineering Experiment.)

Table 3-5 is a summary comparison of the performance of the various systems employing the engines noted above. Figure 3-17 shows comparative energy costs (over a range of engine rated power) for systems employing Stirling, Rankine and Brayton engines. Because only a few specific engines were available at the time of the analysis, a generalized systems analysis was carried out using "rubber" engines with varying output power but with the same efficiency and general performance characteristics as the engines identified above.

Major results of the analyses are summarized in Table 3-5 and Figure 3-17. Based primarily on these results, Ford concluded that the Stirling cycle machine is a better choice for the Engineering Experiment than an alternate

Table 3-4. System Performance Summary
(Ford Baseline System with Storage)*

SYSTEM DATA	
Rating	1MWe
Capacity Factor	0.4
Land Use	2 hectares (5 acres)
Efficiency (Annualized)	25.6%
Type	19 parabolic dish concentrators with solar receiver and engine generator mounted at focal point
COLLECTOR SUBSYSTEM	
Collector Efficiency	.74%
Concentrator	
Diameter	18.6 m
Slope error	2.62 mr (0.15 deg)
Pointing error	1.75 mr (o.10 deg)
Rim angle	65°
Control	Open-loop programmed via the central microprocessor with sun sensors for fine control.
Receiver Thermal Transport	
Type	Cavity with integral pool boiler/thermal-transport
Temperature	830° (max operating)
POWER CONVERSION SUBSYSTEM	
Type	USS P-75 Stirling engine with commercial 75kw 73.5kVA, 480 volt, 3 phase, 60 Hz, 1800 rpm generator connected directly to the engine shaft
Net Output	63.4 kW
Engine Heater Head Temperature	800°C
Efficiency	35.4%
ENERGY TRANSPORT SUBSYSTEM	
Type	Aluminum cable except for copper cable from each generator to the ground, high voltages 1250 kVA/1000kw commercial transformer
Efficiency	96.4%
ENERGY STORAGE SUBSYSTEM	
Type	Conventional lead-acid batteries
Storage	3-hour rating
Efficiency	77.5%

*Plant Ratings 4.5 years after initiation of Phase I

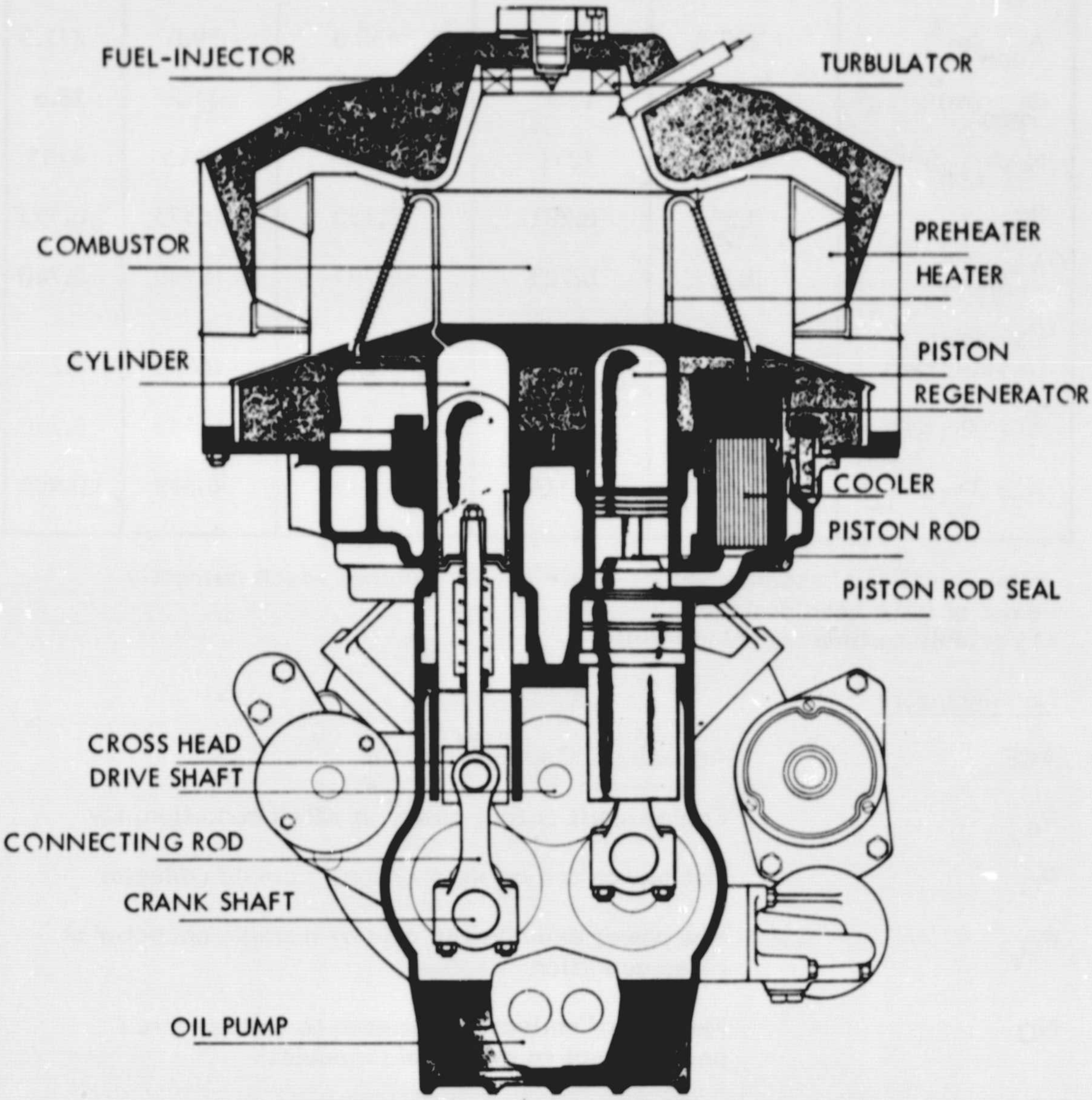


Figure 3-16. Schematic Diagram of USS P-75 Stirling Engine-U-Crank Configuration

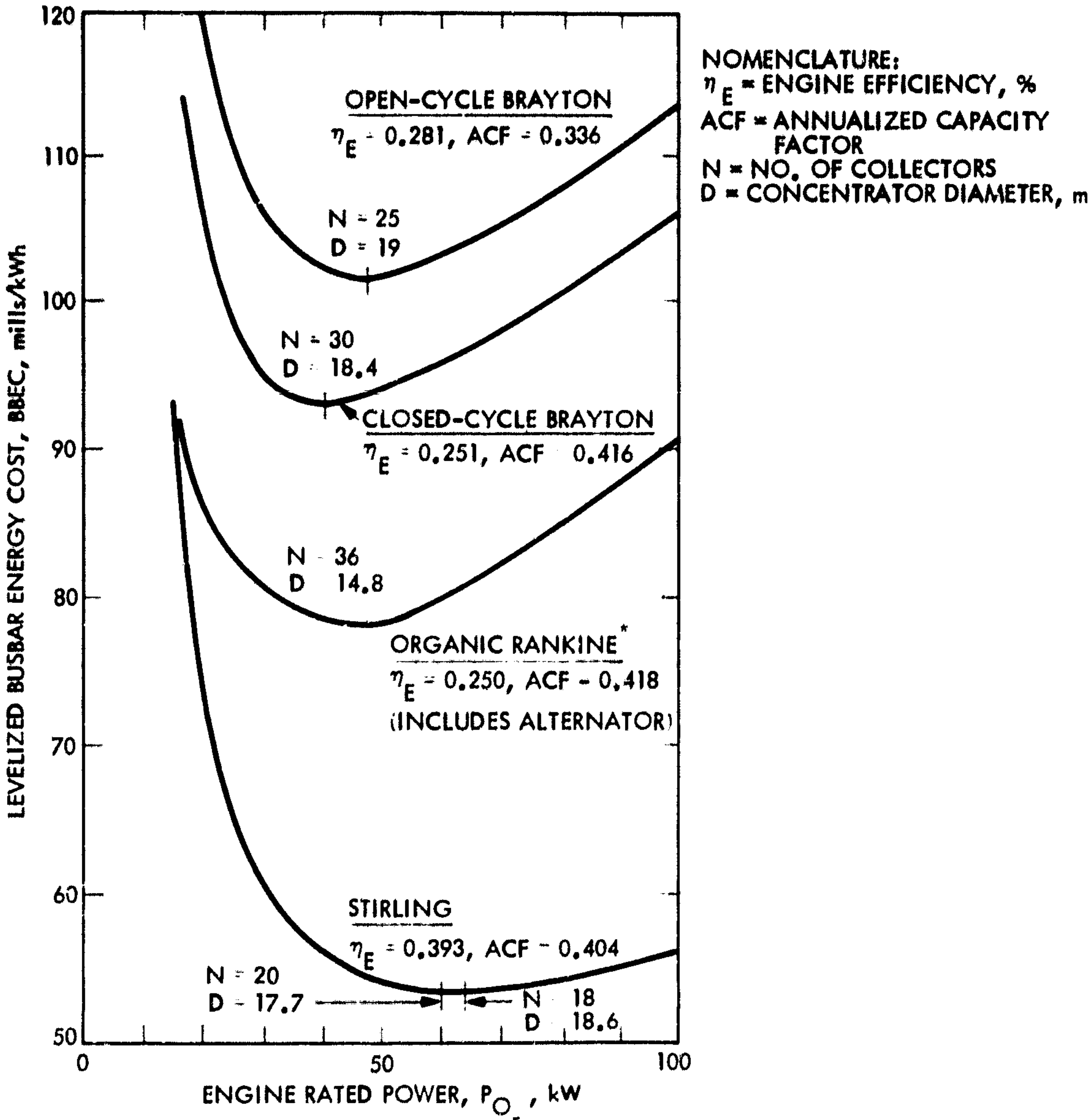
Table 3-5. Comparative System Performance (No Storage)*

Parameter	Brayton		Rankine**	Stirling	
	Closed	Open		P-40	P-75
P_{o_r}	30.2	30.2	77.5	21.9	63.4
N_O	39	39	15	55	18
$A_{con}(m^2)$	207.8	185.4	450.0	99.0	272.5
$D_{con}(m)$	16.3	15.4	23.9	11.2	18.6
$N_O A_{con}(m^2)$	8104	7231	6750	5445	4905
η_{E_r}	0.251	0.281	0.250	0.373	0.393
η_{COLL_r}	0.723	0.723	0.793	0.740	0.740
η_{System} (Annualized)	0.160	0.145	0.193	0.228	0.256
$ACF(P_G \leq P_{G_r})$	0.346	0.309	0.347	0.335	0.340
$ACF(P_G \geq P_{G_r})$	0.416	0.336	0.418	0.399	0.404

*The engine performance values shown are for engines which currently exist or have been designed.
**Variable turbine and fan speeds.

Nomenclature

ACF	Annualized Capacity Factor
P_{o_r}	Engine shaft output power at rated condition, kw
P_G	Net power delivered to grid by a single collector
P_{G_r}	Net power delivered to grid by a single collector at rated condition
N_O	Number of collectors required to deliver rated power direct to grid (basic modules)
A_{con}	Concentator aperture area
D_{con}	Concentrator diameter m
η_{COLL_r}	Collector Efficiency at rated condition %
η_{E_r}	Engine efficiency at rated power %
η_{System}	System efficiency %



* Variable turbine and fan speeds

Figure 3-17. Comparative Energy Cost with Alternate Engines engine. Its higher efficiency and projected low production cost result in substantially lower energy costs and, according to data derived in the study, it has a substantially lower development cost. Ford concluded that, although the ORC system energy cost is 40-50% more than that of the Stirling system, the ORC engine showed promise and was considered a possible alternative to the Stirling engine. The Brayton system was considered least attractive.

2. SCSE Phase II

a. <u>Selection of Distributed Generation and Rankine Cycle for Small Community Solar Thermal Power Experiment.</u> The Point-Focus distributed-receiver distributed generation concept utilizing Rankine cycle conversion technology has been selected for the first Small Community Solar Thermal Power Experiment SCSE (and Ford will proceed in Phase II with this approach). With this concept, small Rankine cycle engines with electrical generators attached are mounted adjacent to the receiver at the focal point of each of the solar concentrators in the collector field. The electrical output of the individual generators is then controlled, phased, and mixed with the others prior to being transmitted to the utility network.

Recent technology comparison studies performed by the Battelle Pacific Northwest Laboratories, the Solar Energy Research Institute, and JPL in-house studies have consistently indicated the superiority of an electrical only transport system over a thermal transport system for a plant producing electrical power at low capacity factors. This is primarily due to the high cost of high-pressure, high-temperature thermal transport networks required to collect the thermal energy from the distributed receivers and transport the energy to the central conversion and power generation system.

Rankine cycle conversion systems were studied by each of the three contractors during the Phase I studies for this Experiment. Although, for the long term, other cycles like the Stirling and Brayton may have a potential for higher performance, it was found that for the near term, the Rankine cycle provided an excellent technology approach for distributed generation as well as central generation. This is primarily due to the greater experience with the lower temperature design and materials requirements of the Rankine cycle and the longer experience history with it in the power generation and transportation fields.

A further advantage of the distributed generation approach is the complete modularity of the system. Each collector/power conversion module in the field converts photon energy from the sun to electrical energy supplied to the utility network. This translates into: (a) higher availability/reliability of the plant; (b) an earlier start-up time for at least part of the plant during the construction phase; and (c) simplicity in increasing plant size at a later date by adding on more modules.

The selection of the distributed generation approach with the Rankine cycle also contributes to the overall balance of the current DOE small solar thermal program. The Shenandoah Project is currently constructing a plant with a thermal energy transport system and will determine the advantages and disadvantages of it. The JPL experiment using an electrical transport system can then be compared with that. The second set of JPL experiments (Isolated Application Experiment Series) intends to use Brayton cycle conversion systems.

The experience gained with the Rankine cycle used in the initial experiment can then be compared with the experiences gained with these later experiments. The actual results obtained with these experiments in the field can then be contrasted with the projections advanced to date.

As soon as the design and development contract (Phase II) for this experiment is awarded, the contractor will perform a definitive study and data gathering activity of the near term available options of Rankine cycle hardware. This will include studies and comparisons of:

(1) Organic fluids vs steam for the cycle working fluid.

(2) Reciprocating vs rotary conversion equipment.

(3) Conversion equipment mounted at the focal point of the collector vs mounted at the base immediately adjacent to each collector.

This Project will review and approve the contractor's recommended technology and implementation approach prior to including it in the preliminary design of the plant.

3. Special Studies

a. Distributed Generation Power Management. A study was performed to assess electrical system cost and efficiency of a solar electric plant. The baseline power plant was comprised of many small (92 m^2) solar generation units (SGU) connected in parallel to provide rated output power of 5 MWe. Electrical storage units (ESU) were used to provide rated output power for up to six hours in the absence of solar input. An AC link operation was considered.

A 5 MWe plant with an annual capacity factor of 0.55 required about 440 SGUs and a storage system with the capacity for six hours of operation. AC power from a group of 110 SGUs is collected at 480 V, transformed to higher voltage (13.8 kV), and transported to centralized ESU at the utility bus interface. It is then combined with power from three other identical groups.

The major electrical components required to build a baseline plant using the selected conceptual approach were identified and listed. Specific cost and efficiency estimates for components in the parts list were presented to assist the Project in comparing the dish-electric approach with other conceptual approaches and in designing the dish-electric system.

Electrical component costs were grouped functionally and normalized with respect to key design parameters (concentrator field area, plant output power rating, and energy storage capacity). Estimated generator costs were found to be in the range of $13-33/$m^2$. Normalized electric transport costs were found to be $16/$m^2$. Plant control costs were not included.

b. Advanced Battery Study. A study was performed to evaluate existing and advanced electrochemical storage and inversion/conversion systems that may be used with terrestrial solar-thermal power systems. It assessed the status, cost and performance of existing storage systems, and projected the cost, performance, and availability of advanced systems. A prime consideration was the cost of delivered energy from plants utilizing electrochemical storage.

The report addressed three broad areas: (1) the electrochemical, or battery, component of the storage system; (2) the balance of system, or all components other than the battery; and (3) the overall solar-thermal plant with electrochemical storage. Included in the latter area was a tabulation of the levelized costs of delivered energy from complete plants with fifteen different advanced electrochemical systems. This tabulation ranked the systems in order of economic attractiveness.

The results of the study indicated that the five most attractive electrochemical storage systems are the: (1) zinc-bromine (Exxon); (2) iron-chromium redox (NASA LeRC); (3) sodium-sulfur (Ford); (4) sodium-sulfur (Dow); and (5) zinc-chlorine (EDA). The key parameters describing these systems are shown in Table 3-6.

C. SOLAR ENERGY SIMULATION COMPUTER CODE DEVELOPMENT

In the past year there was a substantial effort devoted to improving and verifying the Solar Energy Simulation (SES) code. In order to do this, the logic and theory of the code was first reviewed. Then, various sample test cases were evaluated for consistency and sensitivity. Next a comparison was made with another more complicated, independently derived code. Lastly, a review of the Technology Ranking Study results for which the code was utilized was conducted.

The logic review resulted in several improvements to the code. For example, in the POWER program:

(1) Engine continuous overrun capability was not utilized for generating power.

(2) The unavailable stored energy fraction was correctly treated as an available energy source.

(3) A correction was made to the way in which stored energy was treated.

(4) It was possible to generate electrical energy even though the plant was shut down.

(5) Stored energy output efficiency was not included in calculating the amount of energy available from storage.

In addition to correcting these problems, several other improvements from a user's viewpoint were also made, including the elimination of unnecessary variables and some expansion of the model's capabilities.

Table 3-6. Cost and Performance of Advanced Electrochemical Storage Batteries

Battery Type	Initial Cost	# Cycles At 80% DOD	Battery Efficiency	Throughput Efficiency[3]	Projected Availability	Probability of Availability[2]
Na-S (Ford)	$43/kWeh	2500-5000	75%	69.1%	1985	0.80
Na-S (Dow)	$33/kWeh	3000	90%	83%	1990	0.20
Fe-Cr Redox (LeRC)	$132/kWe + $22/kWeh	10000	75%	69.1%	1990	0.95
$Zn-Cl_2$ (EDA)	$59/kWe + $27/kWeh	2500-3500	71-74%	65.4-68.2%	1985	0.95
$Zn-Br_2$ (Exxon)	$32/kWeh	2500-5000	80%	73.72%	1990	0.70

[1]Updated to mid-1979 dollars

[2]Predicated upon EPRI data, vendor data, and best engineering judgment

[3]Throughput efficiency (efficiency of battery + converter/inverter) - see Appendix B

A summary of these changes is as follows:

(1) Annual average field efficiency is now calculated.

(2) Several variables which were not initialized have now been initialized in the program.

(3) Due to round-off errors, it was possible in certain instances to get small negative values for stored thermal energy. This was corrected.

The ECONOMICS code was updated as follows:

(1) The subsystem costing equations were simplified and verified.

(2) An improvement was made in the treatment of two different inflation rates was performed as a weighted average of the two rates.

(3) Corrections were made to the O & M calculation in the combination of electrical and thermal factors and included various oversimplifications.

In addition, a capability was added to treat subsystem replacement if this value is less than the plant life. Finally, the algorithm that selects the optimal plant configuration was improved so that it would work correctly when faced with unusual cost curves such as those with highly positive slopes.

Upon implementing these changes, it was found that the overall cost and performance results realistically reflected power plant operation and that the code successfully handled the interaction of the three major programs.

The next effort involved a review of plant performance generalizations which are included in the SES code. These generalizations were made for two primary reasons. First, the assumptions made enabled the resultant code to successfully accommodate widely varying power plant system designs with relatively little effort. Secondly, it was the opinion of the project staff that adding the extra complexities would not significantly impact the relative cost ranking results. It was decided to compare the SES model against a model developed by Sandia Laboratories which was not as adaptable to all generic systems but which had a more complex formulation of solar plant performance. The model which is known as STEAEC (Reference 3-12) is analagous to the FIELD and POWER programs in SES and contains various parameters which are approximated or ignored in SES. These parameters are as follows:

(1) Energy losses and delays incurred in start-up.

(2) Effects of charge rate on deliverable energy in storage.

(3) Receiver minimum thermal power requirements.

(4) Several levels (rated/derated) of plant operation.

(5) Receiver and engine stand-by requirements (of steam and/or electrical power).

(6) A mathematical representation of a thermocline thermal storage system.

(7) Different part-load engine efficiencies, from storage and from the collector field.

(8) A number of auxiliary power requirements.

(9) The provision for engine operation with receiver steam augmented by storage steam in thermal storage systems.

(10) Wind effects on heliostat tracking error.

(11) Wind and ambient temperature effects on receiver efficiency.

(12) Fifteen minute time intervals.

STEAEC inputs and results for a 100MWe central receiver solar plant were available for the comparison. The analysis involved using the STEAEC inputs in SES, and evaluating the results for the two models.

It was found that the difference in energy produced as calculated by the two codes was 4.9% (which is considered acceptable given the uncertainty of many of the input variables).

In conclusion, it can be stated from the validation efforts to date that:

(1) SES operates in a logical and consistent manner.

(2) The energy costs calculated by SES are a relatively accurate representation of solar thermal electric power plants.

(3) Simplifying assumptions in SES for a number of real world complexities are valid.

SECTION IV

EXPERIMENT IMPLEMENTATION AND TEST

A. INTRODUCTION

The overall objective of the Experiment Implementation and Test (EIT) Task area is to integrate activities during the implementation phase of the PFTEA Project experiments. This effort builds on the study, design and development activities accomplished in other PFTEA tasks as well as EIT study and planning efforts. Integration activities are coordinated with the various experiment managers.

The task includes four major areas: 1) site selection; 2) site integration; 3) experiment construction; and 4) test and evaluation. These work areas follow task responsibilities more or less chronologically through experiment activities. In addition, study efforts are pursued to provide background and support for these work areas.

1. Site Selection

In FY 1979 there were efforts related to both the Small Community Solar Thermal Power Experiment (SCSE) and the Military Module Power Experiment (MMPE) with the Civil Engineering Laboratory (CEL). SCSE activities included publication of a revised report, "Siting Issues for Solar Thermal Power Plants with Small Community Application," (Reference 4-1) preparation of a site participation Program Research and Development Announcement (PRDA) for DOE and the development of evaluation criteria for site proposal evaluation. Activities included support of the CEL site evaluation criteria and participation in the CEL evaluation process.

2. Site Integration

Site integration activities for both the SCSE and the MMPE experiments will get underway in FY 1980. In FY 1979 a major activity was the publication of a study report, "Regulations Applicable to Solar Thermal Power Plants: Interim Report" (Reference 4-2). A follow-on study is forthcoming.

3. Experiment Construction

Activities in this work area will take place primarily in future fiscal years and will include: final power plant design, fabrication, and construction and installation.

FY 1979 efforts included review support of system design activities, the publication of the report "Costs and Considerations in Site Preparation for Solar Thermal Power Plants: A Preliminary Study," (Reference 4-3). Contracted site preparation studies with two A & E firms are also underway (Reference 4-3, 4-4).

4. Test and Evaluation

Activities in this work area will take place in future years. Subtasks will include: system test and check-out, experimental operation, and evaluation.

B. SMALL COMMUNITY SOLAR THERMAL POWER EXPERIMENT (SCSE) SITING

1. Experiment Definition

a. Application Definition. The first experimental plant will be located in a small community and will be between 100 kWe and 1 MWe in size, depending upon technical considerations and the availability of funding. It will be designed to augment small community electricity requirements utilizing technology available in the time frame of the experiment, and is scheduled for initial experimental operation in 1983. The primary objective of the experimental plant will be to obtain data and thus it will provide only intermittent electrical power to the community, especially during the early years of experimental operation.

A small community has been defined as a district, urban or rural community, with a peak electrical power requirement of less than 100 MWe and a variety of electrical customers. It is preferable that the community is not part of a metropolitan area, has a peak electrical power requirement of less than 20 MWe and is served by an electrical distribution network owned and operated by a local utility.

b. Experiment and Community Size. The application for SCSE as described above evolved as experimental objectives were defined. The size of the SCSE resulted from assessment of the factors listed below:

(1) Utility and System Design Concerns - the plant must be large enough to enable utilities to extrapolate operational data but small enough to be exempt from utility regulations.

(2) Community Concerns - the plant must be large enough to be perceived by the community as a substantial and important experiment deserving of their support, but small enough so as not to have a significant impact on its socio-economic structure and physical environment.

(3) Sponsor Concerns - the plant must be large enough to take advantage of the economies of scale in concentrator manufacturing but small enough to keep costs low.

The size of the community hosting SCSE was determined as a function of SCSE size. That is, SCSE's electricity production should be equivalent to at least 1% of the community's total electricity load. These conditions will allow the utility and the system experimenters to discriminate between electrical fluctuations in the grid due to normal operation and those due to the operation of SCSE.

The influence of the experiment on the distribution network and the community is also the reasoning behind the desire that the community not be a part of a large metropolitan area and served by its own electrical network. Remote communities are considered representative of the types of communities in which solar thermal power will be viable for early applications.

c. Relationship with Power Plant Development. Experiment activities have been divided between a system contractor who will design, fabricate, install and test the solar thermal power plant and a site participant who will provide the site, access roads, utility services, use permits, and an interface between the experimental plant and the local electrical distribution network. By virtue of this contribution to the experiment, the site participant will be a cost sharing partner in SCSE. Once the experimental operating phase of the plant is complete it is anticipated that the site participant will assume control of plant operation and distribution of the electricity. Accordingly, minimum funding for site participation activities is anticipated.

2. Site Procurement Approach

Site proposals will be solicited by a PRDA. This document has been designed to keep proposal costs low by including a set of advisory qualification criteria. Potential proposers who do not satisfy advisory criteria will not be disqualified. However, they will be at a competitive disadvantage and therefore they may decide not to prepare a proposal.

Mandatory requirements were kept at a minimum to encourage a variety of responses. To ensure that the selected site is the best for all experimental purposes, the strengths and weaknesses of each proposal will be balanced with those of other proposals during technical evaluation. The PRDA is designed not to be overly geographically restrictive. The experimental system need not have an optimum environment because solar thermal power technology is applicable in a wide variety of environments.

Out of respect for proposal teams which may have limited resources, the PRDA is designed to request information that is easily accessible to municipalities and small utilities and indicates that elaborate proposals are neither necessary nor desirable.

PRDA preparation was completed in August, 1979. The PRDA is scheduled for release on October 31, 1979, with proposals due on December 28. Following evaluation, site selection is planned for March, 1980 with the contract scheduled to start in May.

The first step of the proposal evaluation procedure will be to determine whether the proposals are complete and contain the necessary legal information. Next, small groups of scientific and engineering personnel will evaluate the proposals in each criterion. The results of this technical criterion evaluation will be presented to a DOE evaluation committee who will determine which proposals are in the competitive range.

They will delineate the strengths and weaknesses for those proposals that they determine are in the competitive range. Oral and written discussions will then be conducted with all the proposers remaining in the completion to obtain clarifying information. Once all additional information has been assembled, a final evaluation will be completed and the strengths and weaknesses of the remaining proposals will be delineated. A DOE official will make the final site selection.

3. Site Evaluation Characteristics

All sites for SCSE should contain some combination of the following site characteristics. A weakness in one characteristic may be balanced by strength in another characteristic.

a. Community Characterization and Support. SCSE will be sensitive to the nature of the community in which it is located. A community agency will be part of the proposal team. The plant will interact with the community's electricity distributing utility; it will require materials, manpower and equipment from the community and will occupy several acres of land (Reference 4-5). A community for SCSE must satisfy the small community definition regarding size and separation from metropolitan areas. An ideal community would be easily accessible, maintain channels of communication to the rest of the United States, have the resources (manpower, materials and equipment) required by SCSE, and would hail the experiment as a positive step toward solving energy supply problems and would be an object of civic pride.

b. Insolation Resource. While solar thermal power systems are expected to have application in broad geographic areas, the availability of reasonably good direct insolation is necessary for good data for this first experiment. Sites with average daily insolation of at least 5 kWh (18 megajoules), (approximately 2800 hrs. of sunlight per year) would provide a favorable experiment environment. Sites with a lesser insolation resource may be acceptable if they have superior characteristics in other criteria.

c. Energy Cost, Finance and Need. A community's need for a solar thermal electric power plant is based on its present energy expenditures and the projected cost of new energy supplies. Communities which have high electricity costs during periods where direct insolation is available are optimal for SCSE. Thus, in this criteria insolation availability is balanced against energy costs.

d. Utility Interface. The nature of the utility interface is very important to the successful testing of SCSE. It must provide for intermittent electricity generation, transmission, and data collection. It is desirable that the distribution network serve customers with a variety of demand loads, that there be local dispatch capability, and that the experiment be integrated into the electricity distribution network near a main line or major substation.

e. Site and Permit Acquisition. Clear title to sites must be attained within one year of the contract and the site must be available for a period of five years following the start of experimental operation. It is desirable that: 1) the site be zoned appropriately for use by SCSE; 2) land use trends are compatible with SCSE activities; 3) there are no federal, state or local regulations that preclude SCSE activities from taking place on the site, and 4) other regulatory requirements do not require long lead times for permit acquisition.

f. Site Suitability. The physical environment of the site will greatly influence SCSE's efficiency. The site must not be subject to characteristics which will preclude SCSE's operation, such as high wind speed, seismicity, wind erosion, flooding, or shading. Site conditions will be compared with estimated system tolerances when evaluating a site's adequacy.

g. Site Development Characteristics. This category of site characteristics is closely related to the previous category, Site Suitability, because they are both concerned with the nature of the site's physical environment. However, the characteristics of concern in this category are somewhat mitigable and expensive. Of concern are the costs of constructing the SCSE to operate effectively regarding topography, soil type, slope, seismic activity, landslides and drainage. The ideal site would require few mitigation measures and thus would be low cost.

h. Environmental Impact. The less a site is disturbed the less SCSE will impact the site and the surrounding environment. Thus, low cost site development (provided that it is in full compliance with all environmental protection agency regulations) will impact the environment less than an expensive site development. It is imperative that SCSE activities will not significantly disrupt or destroy any endangered species, critical habitats or other environmental conditions both physical and social on or in the vicinity of the site.

i. Management Plan. The success of SCSE depends a great deal on the capabilities of the site participation team. It is necessary that all members of the site participation team are firmly committed to making SCSE a success, that the plan they propose for performing all their responsibilities is logically based and that all members of the site participation team clearly understand their responsibilities and obligations.

j. Extent of Participation. The site participant will be responsible for providing the site and services described above. The government will supply the power plant and train local utility personnel in its operation and maintenance. Once testing is complete, it is intended that operation of the plant will revert to the community's utility and the generated electricity will be available for use by the community. An ideal community for SCSE would provide all site participation activities described above with minimum reimbursement expected in addition to the electricity from the SCSE and the experience with solar power plant operation.

4. Site Participation Tasks (Reference 4-6)

Once the site is selected, the site participation team will be expected to perform the following tasks subject to negotiation.

a. Task 1 - Site Data Development (To be performed in parallel with Task 2). This task provides a data base for other site participation tasks as well as information for use in solar thermal projects. Task 1 is expected to:

(1) Provide a suitable location for JPL installed insolation and environmental measuring equipment and make periodic inspections to assure proper operation.

(2) Identify and describe the permits, regulatory requirements, etc., required for site acquisition, plant construction and operation, including those associated with implementing an experimental plant.

(3) Provide data and information pertinent to the development of environmental assessment or impact reports to be prepared by JPL in the event the site is used for a solar power plant in the future.

(4) Provide a study of the potential socio-economic impact of an experimental solar thermal plant on the community. This should include a survey of community interest and support, descriptions of past and present alternative energy projects, and basic demographic data.

(5) Describe the equipment necessary for the interface between the solar plant and the electrical network. This description should include protection, control and measurement equipment.

(6) Participate in project reviews, and provide consultation and assistance to JPL, as required.

(7) Provide quarterly reports within two weeks after the completion of each quarter's activity and final task report within four weeks following completion of the Task 1 activities.

b. Task 2 - Site Acquisition and Planning. This task is expected to:

(1) Provide a project manager and a specifically designated technical team to accomplish the indicated site oriented objectives and to interface with the cognizant JPL Technical Representative,

and personnel of other JPL and government contractors. This team is expected to continue tasks beyond Task 2. It is expected that technical team membership should not change more than is consistent with good management practices.

(2) Provide a site of approximately 4 hectares (10 acres) of suitably unencumbered, relatively flat land for construction, installation and operation of an experimental solar thermal power plant. This land shall be available for this experimental power plant within one year of the signature of award to the successful site participation offer and shall continue to be available for a period of at least five years following completion and start-up of the plant. Either private or (non-federal) government land will be considered, subject to meeting all other requirements of the PRDA. No funds are available for purchase of real property.

(3) Provide the required permits, leases, easements, zoning approvals, etc., and all other necessary and required approvals and releases necessary for the construction, installation, and operation of an experimental solar thermal power plant, and provide information for environmental assessment or impact reports. These permits include those required to provide access and utility services to the site and easements for solar access.

(4) Develop plans to provide access and utility services (domestic water, sewage, electricity, telephone) to the site for the construction, installation and operation of the experimental power plant.

(5) Plan and coordinate community public relations and publicity relating to the experiment.

(6) Participate in design and project reviews and provide consultation and assistance to JPL in the development of project plans and power plant design.

(7) Provide quarterly reports within two weeks after the end of each quarterly period, and final report within four weeks after the end of the Task 2.

c. <u>Task 3 - Site Preparation.</u> This task is expected to:

(1) Provide access to the site, as mutually agreed, for construction, installation and operation of the experimental power plant.

(2) Provide normal utility services to the site including water, sewer connection, electricity (including commercial electricity during construction and installation) and telephone services.

(3) Provide a suitable connection to the utility electrical network, including provisions for dispatch control, safety and measurement.

(4) Coordinate the accomplishment of items a, b, and c above, with the system contractors who will be responsible for construction and installation efforts at the site.

(5) Participate in construction review and provide consultation and assistance to JPL and other contractors relative to construction and installation activities.

(6) Prepare quarterly reports within two weeks after the end of each quarterly period and a final task report within four weeks after the end of Task 3 activities.

d. Task 4 - Experimental Operation. This task is expected to:

(1) Provide normal housekeeping, grounds maintenance and security services for the experimental power plant facility grounds and support buildings.

(2) Participate in initial checkout and test operation of the experimental solar thermal power plant, and provide personnel for training in the operation and routine maintenance of the plant.

(3) Provide for dispatch operations to incorporate the electrical output of the experimental plant into the utility electrical network, and obtain measurements of appropriate parameters as mutually agreed. These efforts are to be coordinated with the testing and experimental operation of the plant.

(4) Coordinate access and public visits to the experimental plant.

(5) Prepare quarterly reports within two weeks after the end of each quarterly period and a final task report within four weeks after the end of task and activities.

e. Task 5 - Extended Experimental Operation. Provide activities as mutually agreed at the option of JPL.

C. MILITARY MODULE POWER EXPERIMENT (MMPE)

1. Experiment Definition

MMPE is the first experiment in the Isolated Application Series. These isolated load applications have the potential for early penetration due to high power costs. Early experiments in this series will utilize hybrid systems for stand-alone capability. MMPE is co-sponsored by the U.S. Navy under the auspices of the Civil Engineering Laboratory (CEL). It will consist of a six modular parabolic dish concentrator system using hybrid fired Brayton cycle energy conversion to produce approximately 100 kWe. As in SCSE, a system supplier contractor will be selected through competitive procurement to perform system design, integration and plant installation. Because CEL is a co-sponsor in MMPE, the Navy is responsible for site selection, site preparation, grid connection, test and evaluation, and data collection. The objective of the experiment is the deployment, test and evaluation of a modular hybrid power system. It will be tested as a military base load power generation system in accordance with CEL and PFTEA requirements to obtain performance and operational data.

2. Site Selection Approach

Originally, twelve military bases were under consideration by CEL in the southwestern part of the United States. Each of these bases was first evaluated by a set of minimum requirements and then by a set of evaluation criteria listed below:

<u>Minimum Requirements</u>

- Two to five unencumbered acres on a military base
- Good Insolation
- Base personnel to provide technical support

<u>Evaluation Criteria</u>

- Meteorology
- Interface with existing electricity supply
- Visibility and publicity
- Need and cost

After initial evaluation the three bases remaining in the competitive range were: 1) Miramar Air Force Base in San Diego, California; 2) China Lake Naval Weapons Center in China Lake, California; and 3) the Marine Corps Air Station in Yuma, Arizona. The Marine Base site in Yuma, Arizona was selected because it has excellent insolation, lower wind velocities and a less complex regulatory environment.

Prior to final site selection, several site visits were made by the Experiment Implementation and Test Task accompanied by the CEL representative and the PFTEA Experiment Manager. On these visits information was obtained relative to the environmental impact that the experiment activities would have on the sites. The impact that the site environments would have on the experiment was investigated.

3. Description of Selected Site (Reference 4-7)

The Yuma site is located in the southeastern corner of the Marine Corps Air Station and is adjacent to housing on the north side. Orange groves on the east and south sides and Ordnance Storage Facilities are located on the west. The following environmental and regulatory conditions were identified for this site:

(1) The orange grove east of the test site is generally aerial sprayed between two and four times per year. Flood irrigation frequency during summer is twice a month and once a month in winter.

(2) All Station construction must meet basic building requirements, standards and practices such as National Fire Protection Codes, National Electric Code, NAVFAC Guide Specifications, etc.

(3) Environmental Impact Assessments have not been required on recent Station construction projects. There are no endangered species or critical habitats on the site.

(4) Noise generation from the site must be that it will not cause undue disruption in family housing located approximately 244 meters (800 feet) distant.

(5) Land acquisition would not be required because the test site is within the Station boundary. An Interservice Agreement would be required prior to construction between the Naval Facilities Engineering Command (NAVFAC) Western Division and the Department of Energy (DOE).

(6) The Yuma County Health Department has been delegated responsibility by the State to monitor and enforce all Environmental Protection Agency regulations. Areas of cognizance include air, water and sewage quality. The Station currently owns and maintains the water system while sewage is treated by the City of Yuma. Therefore, use permits will have to be obtained from the Yuma Health Department.

(7) Construction permits are not required for on-station building activities.

(8) The soil type in the area of the Missile Assembly Ordnance Facility should be similar to the proposed test site. Typically, the surface layer is light brown sand about 127mm (5 in) thick.

The substratum is light brownsand 1524mm (60 in) thick or more containing small clay lens and soft lime segregations. Permeability is rapid, 157.5-508mm/hr (6.3-20"/hr).

(9) Afternoon temperatures reach 37.8°C (100°F) (on the average) from June through September. Average minimum temperatures in January can reach 3.9°C (38.9°F). The highest recorded temperature was 50.6°C (123°F). Average annual rainfall is 76.2mm (3 in). The prevailing wind direction is from the north, northwest. Occasionally, high winds of 121kph (75mph) may approach from the south.

(10) The deep water table and sandy soil associated with the Yuma Mesa site has resulted in only minor earthquake damage from seismic activity.

D. REGULATORY REQUIREMENTS STUDY

1. Regulations Applicable to Solar Thermal Power Plants: Interim Report

Regulations are becoming increasingly significant in all types and phases of energy development. The electric generating industry has historically led the industrial sector in the amount of regulatory control under which it must operate and more regulation is added every year. The introduction of alternate energy technologies into the electric generating industry raises questions concerning the applicability of the existing regulations.

To assess the applicability of existing regulations to an experimental 1 MWe solar thermal-electric power plant, a two-part survey of regulatory requirements is being conducted in conjunction with experimental system design and siting. The first part surveys regulations generally applicable to solar facilities. The second part surveys regulations specific to solar thermal-electric technology. The preliminary results and planned activities of the survey are discussed in the following pages (Reference 4-8).

a. Objective. The objectives of surveying the regulatory requirements applicable to solar thermal-electric power plants are:

(1) To inform systems engineers early in technology development of performance standards required by various regulatory agencies.

(2) To enable site selection teams to include regulatory requirements in site selection criteria.

(3) To inform prospective site contractors of the types of permits and licenses which may have to be acquired for plant implementation.

(4) To expedite the site participant's acquisition of permits and licenses required by regulatory agencies with jurisdiction.

(5) To ensure positive relationships with regulatory agencies in authority and to establish a cooperative image.

To accomplish the above objectives, regulations specific to the unique aspects of solar thermal-electric technology are delineated. The roles of the system contractor and the site participant with regard to permit and license responsibility are indicated, and the regulations applicable to solar thermal-electric power plants specifically as well as the regulations applicable to all electricity generating facilities are identified.

b. Scope. The Interim Report discussed the issues investigated in the first half of the survey. These issues include zoning and solar easements, environmental impact assessment and reporting procedures, power facility siting procedures, and utility regulatory agency authority. These issues were selected for initial evaluation because they represent national trends or involve federal regulatory agencies. The initial part of the survey also identified the scope of the subject matter to be included in the final report.

The majority of the regulations applicable to solar thermal-electric power plants are administered by local, regional and state regulatory agencies. The evaluation of these requirements is the focus of the second part of the survey. To delineate the regulatory requirements at this level, several representative sites were selected for site specific study. The regulatory issues evaluated are those which apply to site preparation, construction, utility interface, operation, and maintenance. Primary emphasis is placed on those aspects of the plant which are unique to solar thermal-electric technology.

c. Environmental Impact Report Procedures. Subsequent to a review of general federal (Reference 4-9) and state environmental impact assessment procedures, it was determined that the environmental review process for SCSE could be expedited by requiring the proposals of prospective site participants to include brief descriptions of the environmental impact that the plant may have on the proposed sites. After preliminary screening, DOE or a DOE designate will compile the environmental information from the proposals that meet the requirements into an EA for use in the final stages of site selection. The preparation of this document will involve contact with the proposers and site visits to clarify the environmental information used in the proposals. The EA is also submitted to the NEPA Affairs Division of DOE where the determination of the significance of the environmental impact of SCSE and the necessity of preparing an EIS will be made.

At the state level, it is anticipated that the lead agency responsible for administering environmental review will be the local planning agency or its equivalent.

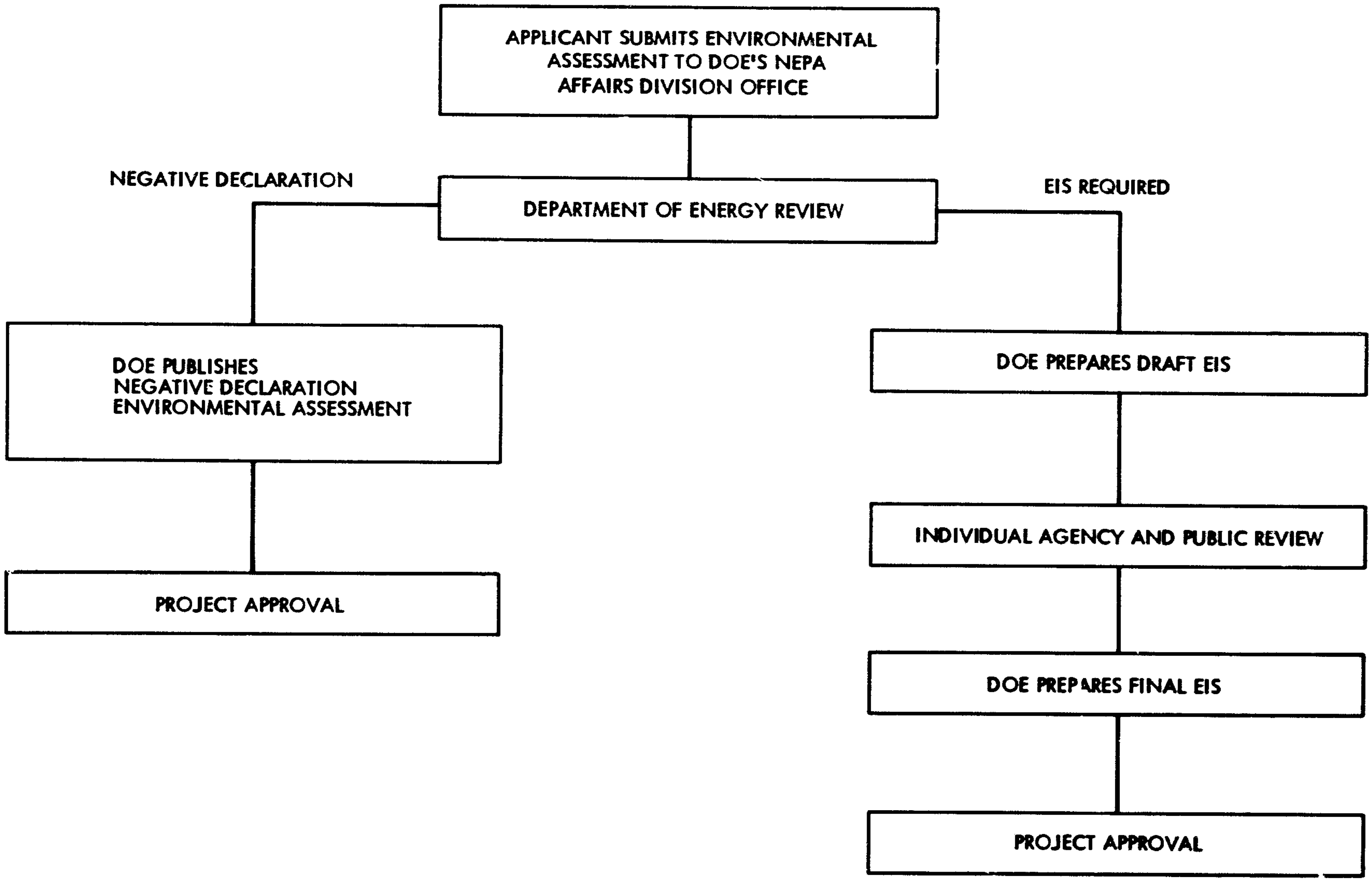


Figure 4-1. Environmental Impact Assessment Procedures

It is expected that every site proposed for use by solar thermal-electric power plants will require a zone change. It is unlikely that the existing zoning at any proposed site will guarantee solar access to the degree that would merit the investment at that site. The petition for a zone change will initiate the environmental review process. Local planning agencies usually have a zoning jurisdiction and thus become responsible for environmental assessment procedures. But each state has adopted its own form of environmental protection legislation, therefore the procedures of the state selected to host SCSE must be clearly understood prior to site selection.

d. Access to Insolation (Reference 4-10). It is obvious that a solar facility can only operate if it receives sunlight. Yet this simple fact stimulates a great deal of speculation over the legal rights of solar energy users to guaranteed solar access versus the rights of surrounding property owners to develop their land. Many approaches to this dilemma have been suggested, the most viable are discussed in the following paragraphs.

An express easement is an easement in which the specific limited use of the land is clearly defined. Express easements to sunlight can be obtained by prospective solar energy users through negotiation with neighboring property owners. Drawn correctly, express easements firmly establish the solar user's right to receive sunlight by restricting the rights of the neighboring property owners from erecting structures or growing vegetation which blocks the passage of sunlight to the solar energy facility.

The acquisition of express easements is optimally suited for developed areas in which the land use is established and unlikely to change. The growing popularity of solar heating and cooling devices and the resultant demand for the protection of solar access rights has prompted several states to pass legislation allowing solar easements to be recorded. If the easement is recorded it becomes an encumbrance on the land and remains in force even though the property ownership changes and the previous owners do not make allowances for its continuance.

Some states in the southwest have established solar access rights called "prior appropriation," based on the "first-come-first-served" principle. Initial users of sunlight establish a right to that sunlight. Litigation arising from a dispute concerning solar rights where solar access is protected by "prior appropriation" are decided in favor of the initial user and other activities are enjoined.

A restrictive covenant is a form of land use restriction commonly used in subdivisions to ensure the homogeneity of a development with regard to architectural style, height, paint, character, etc. Restrictive covenants can also be applied to ensure access to sunlight in developing areas by restricting the height, set-back and density of future development. Or a simple provision may be included in the description of covenants for a development that gives authority to a controlling body to protect access to sunlight in the area on a case by case basis.

The use of restrictive covenants is a workable solution to the problem of guaranteeing solar access to solar facilities in a locality.

Zoning and land use planning can be effective tools to provide solar access. Zoning is based on protection of public health, safety and welfare. The conservation of fossil fuels in a time of increasing prices and decreasing supplies is a benefit to the public welfare. Therefore, zoning to provide for the needs of solar facilities is within the bounds of a city's zoning authority.

Zoning devices must be used cautiously to prevent undue hardships in developed areas. Like restrictive covenants, zoning to provide solar access is most appropriate in developing areas.

The implementation of solar thermal-electric technology requires a guarantee of solar access to protect the investment at that particular site. If introduced into a developed area, express easements negotiated with the owners of the surrounding property may represent the most secure guarantee of access. However, because of the relatively large amounts of land required for solar thermal-electric power technology (1 MWe plant requires approximately 4 hectares), it may be more realistic to assume that these plants should be located in sparsely populated and undeveloped areas. In this case, use can be made of restrictive covenants, zoning and land use planning to provide relatively permanent solar access.

e. Utility Regulation (Reference 4-11). The introduction of solar thermal electric power plants into existing utilities may cause many changes in the body of regulation dealing with electricity generation. Present regulation has developed jointly with fossil fueled generating technology and in many instances, may be too restrictive for the developing solar industry. In a time when alternate energy sources, like solar thermal electric power production, are becoming technologically feasible but are not yet economically competitive, changes in the utility regulatory structure can greatly enhance the timing and integration of solar facilities into the existing electricity generating network. While these issues may not all be pertinent to small experimental facilities like SCSE, they are important to the implementation of 10 MWe commercial solar thermal power plants. Examples of a few important issues for the integration of solar technology are:

(1) Inclusion of solar installations in a utility's rate base.

(2) Introduction of solar technology into a utility's service area in relation to contracts or franchises held by the existing utility.

(3) Allocation of low cost natural gas to utilities who do not risk investing in solar facilities while those utilities risking a solar investment are bypassed.

(4) Differential rate structures for solar users.

(5) Classification of a small solar plant serving a neighborhood as a public utility.

(6) Control over siting solar electric facilities by utility commissions.

f. Site Specific Regulations. As indicated earlier, an in-depth discussion of the regulations governing site preparation, construction, utility hook-up, operation, and maintenance will appear in the final report. While the regulatory requirements discussed are site specific, there are general categories of regulation applicable to every site.

1) Water Quality Protection. At every potential site it is expected that a permit will be required for waste water discharge. The federal mandate for this requirement originates in the Federal Water Pollution Control Act and is implemented through the Environmental Protection Agency (EPA) administered National Pollution Discharge Elimination System (NPDES) (Reference 4-12). The legislation does not stipulate discharge standards because the capability to absorb released substances depends on the characteristics of the receiving water. The legislation instead requires that all proposed discharges be carefully evaluated to determine their environmental impact and that mitigation measures be implemented to prevent the released material from causing environmental degradation.

Solar thermal electric power plants may use water for working fluids and maintenance activities. However, at this stage in the technology development, the quantities of water required for these activities is undefined.

When the system design for SCSE is finalized and a site is selected, those portions of the plant design which deal with the use and disposal of liquids will be reviewed by the water quality agency with jurisdiction. After review, this agency will issue the appropriate permits for water use and disposal subject to conditions requiring additions to the water use and disposal system necessary to protect local water quality, the environment, other users, and the general public. If the quantity of water utilized by solar thermal electric plants is very small and the discharges do not pose a threat to the environment, the plant may be able to utilize the local sewers for disposal, and thus are only subject to control regarding the quantities of water they use.

2) Air Quality Protection. Air Quality regulations are promulgated by the EPA as mandated by the Clean Air Act (Reference 4-13). The EPA has adopted several review procedures. Sources emitting lower quantities of pollutants are subject to less complex procedures. Air pollutant sources are categorized by threshold levels of emissions. Projects are categorized then reviewed to determine the quantities of pollutants that they may emit at specific sites and not significantly degrade air quality.

It is anticipated that the most important air quality issue, relative to solar thermal-electric power plants, is the impact the local air quality has on the efficiency of the plant and not the impact of the plant on local air quality. This is one of the outstanding advantages that solar power technology may have over fossil fueled electricity generating facilities. The largest impacts solar plants may have on air quality are expected to occur in the site preparation and construction phases of plant implementation. These impacts could include emissions from fossil-fuel-burning construction equipment and dust from grading.

3) Plant Construction, Operation and Maintenance. Additional major areas of regulation include the Occupational Safety and Health Administration (OSHA), the standardized codes regulating various construction activities like grading, foundations, and structure emplacement, the standarized codes dealing with electrical lines, plumbing and other equipment and possibly solid waste disposal. This is by no means an exhaustive list. The second half of the regulatory survey is devoted to the identification of specific solar thermal electric plant processes and the regulations which apply to them.

g. Responsibility for Permit and License Acquisition. Permit acquisition responsibility for SCSE is divided between the system contractor who provides the plant hardware and the site participant who provides the site. One of the objectives of this regulatory survey is to determine how permit responsibility is allocated. At this point in the survey, it appears that the site participant is responsible for all permits and licenses required to obtain use of the site for solar thermal power plant activities and to prepare the site for plant installation, while the system contractor's responsibility encompasses all permits and licenses required for plant construction and operation. Some overlap in responsibility occurs because the system contractor must supply system description data to the site participant. The DOE, because it is the funding agency, has primary responsibility for federal environmental documentation procedures. JPL, the project coordinator, has the responsibility for monitoring all permit and license acquisitions. Responsibility for permit and license acquisition is shown in Table 4-1.

2. Interim Regulatory Report Follow-on Study

a. State Inventory. The overview of regulations contained in the 'Interim Report' identifies several areas of regulation (utility regulation and solar access regulation), whose applicability to small solar thermal power plants is unclear. The report also indicates that these areas of regulation are undergoing rapid change in response to the Public Utilities Regulatory Policy Act (PURPA) and the popularity of solar energy utilization.

For the purposes of siting the SCSE, investigation of utility and solar access regulation is continuing. An inventory of state legislation is being conducted to ascertain the current status of these regulations in each state (Table 4-2).

Table 4-1. Regulatory Tasks and Responsibility

X   Review & Monitoring Responsibility or Delegated Responsibility
XX   Primary Responsibility

		JPL	Site Participant	System Contractor	DOE
1)	Site Characterization Data Collection	X	XX		
2)	EA Preparation	X			XX
3)	Environmental Impact Significance Determination				XX
4)*	EIS Preparation	X	X		XX
5)	State Environmental Procedures	X	XX		
6)	Zone Change		XX		
7)	Utility Regulatory Agency Requirements	X	XX	X	
8)	Water Use & Discharge Permits		XX	XX**	
9)	Air Pollution Permits		XX	XX**	
10)	Miscellaneous Site Specific Permits		XX		
11)	Safety and Construction Code Compliance: Site Prep.		XX	XX**	
12)	Safety and Construction Code Compliance: Plant Construction		X**	XX	
13)	Safety Code Compliance O&M	X		XX	

*Unnecessary if DOE NEPA Office determines significant impacts will not result from plant implementation.

**Primary responsibility in these areas depends on the negotiated agreements with the site participant.

Table 4-2. Inventory Questions

(1) Does your state require new power facilities to obtain certificates of public convenience and necessity? If yes, does the approval process include environmental and siting issues?

(2) If your state does not require new power facilities to obtain certificates of public convenience and necessity, describe the power facility approval process your state does require, if any, or enclose a copy of the procedures. In the description, indicate whether environmental or siting issues are considered in the approval process.

(3) Has your state implemented or is it planning to implement special legislation delegating authority for siting new power facilities to an agency other than the agency which regulates utilities presently? Does it require the present agency which regulates utilities to address siting issues specifically as part of the power facility approval procedure?

(4) Does your state exempt or is it planning to exempt small power facilities from new plant approval procedures? If so, indicate the size of the exempt facilities in megawatts.

(5) Has your state implemented any legislation or is it planning to implement legislation dealing specifically with solar power plants? If so, please describe the legislation or enclose a copy of it.

(6) Has your state implemented or is it planning to implement legislation concerning the protection of solar access rights for solar energy users? If so, what type?

- (a) Recordation of Easements
- (b) Prior Appropriation
- (c) Priority of Access
- (d) Other

Please describe the procedure that a prospective solar user must follow in your state to acquire the protection provided by your solar access legislation, or enclose a copy of the legislation.

Of particular interest are the environmental and siting regulations being adopted by state utility regulating agencies and the degree state legislation can provide long-term solar access to solar power plants.

Historically, utility regulating agencies did not include environmental and siting considerations when evaluating the necessity of new electricity generating facilities. Approval procedures only dealt with the public's need for additional generating capacity and the rates at which the public would pay for electricity. Recently, with the passage of the National Environmental Policy Act (NEPA) and in response to PURPA, many states have incorporated environmental and siting criteria into their new facility approval procedures. Some states have incorporated these criteria into the already existing utility regulating agency's procedures. Others have created new and separate agencies to administer the environmental and siting criteria, while the utility regulating agencies continue to administer the traditional criteria of need and cost. In both cases, addition of the environmental and siting criteria lengthens new facility approval procedures and increases their complexity.

In many states small power generating facilities are exempt from the environmental and siting criteria being adopted. The definition of small ranges from state to state, but in all states is equal to or less than 100 MWe. It would be advantageous to site SCSE in a state which exempts small generating facilities from utility regulatory agency environmental and siting criteria.

As indicated in the Interim Report, there are many types of solar access legislation which can be implemented. By far the most common type of solar access legislation adopted by the states is the recording of easements as agreed upon between property owners. Easement recordation is well suited for solar heating and cooling systems currently the most common solar technology. Although the recording of solar easements may be successfully applied to large stand-alone solar installations as SCSE (depending on the site) land use and planning techniques providing solar access may be more suitable. Several states have legislation which allow the consideration of solar access in land use plans and zoning. A site for SCSE in a state with this type of legislation may be more advantageous than a state which only allows solar easements to be recorded and provides another avenue of solar access acquisition. A state with any kind of solar access legislation would be more suitable for SCSE than a state without legislation dealing with solar access.

3. Site Specific Regulatory Requirements

Three sites have been selected on which a site specific regulatory study is being conducted. The sites were selected because they were considered representative of potential solar thermal power plant sites. The response to the regulatory inventory indicated that the states in which these sites are located have different regulatory environments, the sites represent different geographic areas and they possess many of the characteristics required of SCSE. The three selected sites are: 1) Alliance, Nebraska; 2) Savanna, Oklahoma; and 3) Yuma, Arizona. The information we hope to gather for each of these sites are the permitting procedures required for solar thermal power plant activities and the length of time necessary to acquire them.

The primary contact in each city will be the planning agency or its equivalent because it is expected that this agency will have jurisdiction over the first permits required (conditional use permits, land use trend compliance and zoning compliance) and will therefore become the lead agency regarding regulatory compliance. To allow them to respond appropriately, an information request package has been forwarded which contains an introductory letter explaining project objectives and the reasons their city was selected, a description of the regulatory study and its objectives, a copy of the Siting Issues Report, a brief technology description and a list of potentially applicable regulatory requirements. By providing this material, the community planning agencies will be able to indicate which permits a solar thermal power plant must acquire in their city, and the procedures for acquiring all necessary permits. This information will then be utilized to assist the site participant selected for SCSE in acquiring permits in the most expeditious manner.

E. SITE DEVELOPMENT COST CONSIDERATIONS

1. Objectives

Site preparation costs may be a significant part of total construction costs for solar thermal power plants. The objective of site development and cost studies are to examine existing and proposed solar thermal facilities regarding the cost of site preparation activities. Of particular interest is how costs can be computed so that the PFTEA project may better assess and control them.

The long-term value of these studies is a better understanding of the relationship between proposed system technologies and site preparation costs. Because the economic viability of commercial solar thermal plants is based on tight cost constraints in all phases of plant construction and operation, it is essential to have hard cost data regarding site preparation to back up system analyses. This is especially true because of the extensive use of land and thus extensive site preparation requirements inherent to solar thermal power plants.

2. Approach

The site development and cost studies have been approached in three stages: 1) an in-house preliminary study which utilized estimates from several solar thermal power experiments, literature information, standard construction estimation guides, and interviews with project and construction engineers; 2) results of this preliminary study led to the definition of requirements for site-specific studies which followed. These studies were accomplished by two local Architectural-Engineering (A&E) firms at two California sites of approximately 4.1 hectares (10 acres).

They provided estimates of work items and costs and identified permit requirements and site variables; and 3) reports of these A&E studies will be received early in FY 1980, and a final effort and report fill in gaps and summarize results and conclusions.

3. Preliminary Study Results

The results of this study are reported in a JPL internal report titled, "Costs and Considerations in Site Preparation for Solar Thermal Power Plants: A Preliminary Study" (Reference 4-4).

a. Approach. The first step in this preliminary study was to identify the elements of site preparation. These elements with items considered in this study are listed below:

(1) Land survey/soil testing

(2) Grubbing and clearing

(3) Rough site grading/fill/compaction

(4) Trenching/tunnels for utilities

(5) Retaining walls and bridges

(6) Site drainage/catch basins

(7) Fine grading

(8) Roads and paths - Preparation and paving

(9) Ground cover

(10) Fencing

It should be emphasized that the above grouping in no way evaluates the relative importance of the various elements, as to cost or technology. Rather, it is offered as a convenient breakdown for study purposes only. Great variability between the relative effort expended can be expected, depending on site specific properties and on the main uses of the facility. Some of the elements will probably be missing altogether because of specific site characteristics.

Other elements which may seem closely related technologically have not been listed because they will normally be included as a subset of another task for purposes of analysis and cost estimate. Such items are:

(1) Land acquisition.

(2) Building foundations.

(3) Collector/Heliostat foundations.

(4) Steam/Heat transfer fluid pipe supports or tunnels.

(5) Power transmission system pads and foundations.

(6) Thermal storage system excavations/foundations.

(7) Power generating equipment pads and foundations.

(8) Cooling tower pads and foundations.

If a proposed plant is to be a joint venture, it can be expected that the elements in the above list, as well as those in the preceding one, may be the responsibility of different participants. Both for cost control and management purposes, it would seem desirable to maintain as detailed a breakdown of these elements as possible, at least until responsibility for design or construction has been delegated.

These elements were considered using the general construction estimating standards of the Richardson Rapid System as well as information from The Solar Total Energy System (STES) in Shenandoah, Georgia and the 10MWe Central Power Pilot Plant in Barstow, California.

b. Site Comparisons. For many of the site preparation tasks, the expenditures for solar plants will be roughly equal to those of conventional plants of similar peak power output. However, site preparation tasks which are tied to land area or land perimeter, will not be equivalent to those of conventional power plants due to the large land area required by solar plants.

The resources which must be expended in site preparation for a solar power plant are dependent upon highly variable site characteristics. For this reason it may not be possible to predict site preparation costs without detailed surveying of the specific site and investigation of the legal and institutional constraints on its use. However, by estimating site preparation costs on several specific sites it is possible to determine which site preparation activities are the most significant regarding cost and which activities are most sensitive to specific site conditions. Two specific sites were analyzed for this purpose: 1) Shenandoah, Georgia; and 2) Barstow, California (Table 4-3).

The Shenandoah, Georgia site is the Solar Total Energy System (STES) experiment managed by Sandia Laboratories in Albuquerque, New Mexico. The solar facility to be built there will supply electric and thermal power to the Bleyle Knitwear plant. It will occupy 2 hectares (5 acres) adjacent to the plant and is a short distance from a local creek. Extreme caution is being taken against contaminating the local area with Syltherm 800, the fluid to be used as the heat transfer medium. The entire collector field will be paved and an extensive drainage system will be implemented (Reference 4-14).

The Barstow, California site is the site for the 10 MWe Central Receiver Power Plant experiment managed by Southern California (SCE). The plant's output will be incorporated into the local electricity grid. The site, 53 hectares (130 acres) in size, is adjacent to roads and utilities, and the terrain is gently sloping.

Table 4-3. Grading Cost Comparison

	SHENANDOAH	BARSTOW	STUDY
Peak Power	.4 MWe	10 MWe	1 MWe
Area	2.3 hectares (5.7 acres)	53 hectares (130 acres)	3.6 hectares (9 acres)
Earth work cy x 10^3	25	200	19
Grading cost $/cy	$1.84	$1.73	$1.84
Total grading cost	$45,000	$345,000	$34,600
Unit grading cost $/.4 hectare ($/acre) (1978)	$ 7,867	$ 2,650	$3,800
Total Site Preparation Cost $/.4 hectare ($/acre)(1978)	$62,000	not available	$35,000

The following are conclusions coming out of this study:

(1) Site preparation costs are highly site-specific, and are affected more by the nature of the site than by differences in proposed near-term system technologies.

(2) The plant design which has the minimum impact on the site will be most desirable in terms of site preparation costs, zoning or environmental law compliance, and possible building delays.

(3) A "straw man" site preparation plan for a hypothetical 1 MWe plant should be initiated which assumes a real site location and makes use of professional A&E consultants to provide a standard for comparing SCSE proposals and designs.

(4) Several of the elements and issues which were touched upon should be explored individually and in greater depth:

- Low-cost ground cover/dust control
- Low-cost site drainage technologies
- Liquid waste disposal

(5) Several issues which surfaced during this study were outside its original scope, but nevertheless are important cost items. The most important of these is the cost of collector foundations. An intensive investigation of the real loads which can be expected as a result of wind, as well as the specification of the separate effects of this wind load on tracking accuracy and structural survival, is indicated as a high-priority study. The possibility of favorable stowage positions, aerodynamic spoilers, and wind baffles offer the promise of significant savings in structure and foundation costs.

(6) Reduction of foundation costs and installation costs should be a major consideration in concentrator design. The feasibility of arriving at designs which can be used in sites with little or no grading or preparation should be the subject of further study.

4. Site-Specific Studies

a. Introduction. Site specific studies were contracted to two Architect-Engineer firms: 1) Neptune and Thomas Associates with Bechtol and Emerson, and 2) Architect Engineer Collaberative with Robert Denluck and Associates (ARC). Both of these firms have had an extensive background in site planning and preparation for a variety of applications and both were currently working on open-end contracts with the JPL facilities division.

These firms each selected, with JPL concurrence, a site for which they had existing file information for another project. They made rough layouts of site preparation work appropriate for a 1 MWe, approximately 4.1 hectares (10 acres), solar thermal power plant site and prepared cost estimates for this site preparation work. The contractors also discussed factors affecting site preparation costs, possible cost reductions and the effects of plant size on costs per hectare (acre).

b. Site Description. The site in Lancaster selected by AEC is adjacent to existing unimproved roads. No experimental solar power plant is planned for this site. However it is representative of the kinds of sites on which solar thermal power plants would be feasible. The site slopes gently to the north, is 1.21km (3/4 of a mile) from a major drainage channel, and is 4.1 hectares (10 acres) in size.

The Ventura site is approximately 3.9 hectares (9.6 acres) in size, has a general slope of between 5% and 9% and is adjacent to existing roads. There is a major water course approximately 183m (600 ft) to the south of the site but site drainage is expected to be channeled by a storm drain system into the natural drainage course that traverses the site.

c. Site Preparation Cost Elements and Costs. The following elements were considered in the testing studies:

Table 4-4. Site Preparation Cost Estimates for a 4.1 hectare (10 acre) Solar Thermal Power Plant

Category Description*		Category A $\$ \times 10^3$	Category B $\$ \times 10^3$	Category C $\$ \times 10^3$
1.	Clearing & Grading	60	98	45
2.	Paving	138	57	46
2.	Landscaping, Fencing, etc.	203	55	52
2.	Drainage	5	39	10
3.	Street & Utility	64	50	38
2.	Miscellaneous & Continuing	34	45	34
3.	Engineering, permits, etc.	62	116	92
	TOTAL	566	460	317

* Category 1 Costs vary approximately directly with area

Category 2 Costs vary approximately with square ratio of area

Category 3 Costs are approximately independent of area

d. Discussion of Cost Factors. The site preparation element costs calculated for these sites vary markedly because of varying site conditions. It was determined that variation in site conditions is a more significant cost factor than variation in system design. In addition, systems that have the least impact on the site have lower preparation costs.

The most sensitive site preparation activities with regard to site conditions and cost are rough grading, ground cover, grading and road construction. These activities are commonly performed in conjunction with conventional power facility construction and are not expected to present any unique or novel problems when performed in conjunction with the construction of solar thermal electric power plants. However, because of the land intensive nature of solar thermal electric technology, these activities represent a larger percentage of total project cost than is typical of conventional electricity generating plants. There are several interesting relationships between these costs and total site size as well. As the size of the site is decreased the unit costs of activities which are on the entire area, like grading and ground cover, increase. Activities that are related to the size of the site's perimeter i.e., fencing increase but at a slower rate. A breakdown of costs for a hypothetical solar power plant are given below:

5. Preliminary Conclusions

Site preparation is, by definition, extremely site dependent as are site preparation costs. This has been borne out in preliminary study results. These results also show that site preparation is a major power plant cost, varying from less than $250,000 to more than $500,000 for a 1 MWe solar thermal power plant.

The major site preparation cost elements can be categorized as:

1) Grading, surfacing, elevation

2) Perimeter preparation (landscaping, fencing, lighting)

3) Access and connection

4) Engineering, permits, fees, etc.

These categories may have approximately equal costs at some sites and differ widely at others. These cost categories also vary with site size. Grading and surfacing costs will be roughly proportional to site while access, connection, engineering and permits costs are only slightly size dependent and perimeter preparation costs will vary approximately as the square root of size.

Some of the perimeter preparation may seem to be unnecessary, but our A and E studies emphasized that this was indeed necessary to obtain local licenses and approvals. Site preparation is not a high technology endeavor, and it will be difficult to greatly reduce most site preparation costs as the solar thermal technology matures.

Efforts can be made to minimize site preparation by designing systems which can be placed in site. This however may increase other system costs and will increase field area due to more random shading patterns. These areas will be investigated more fully in the coming year following receipt and evaluation of the A and E study reports.

SECTION V

APPLICATIONS ANALYSIS AND DEVELOPMENT

A. INTRODUCTION

The objectives of the Applications Analysis and Development (AA&D) task fall into three main categories: 1) market definition and characterization to determine the most attractive market sectors for small solar thermal power systems in order that a proper selection of engineering experiments can be made; 2) market development wherein direct involvement of potential users of small power systems is sought through workshops, seminars, and interviews; and 3) development of methodologies and the performance of analyses to understand the economics (both supply and demand) and the aspects of market penetration that will lead to the greatest possibility of a successful development program.

To accomplish these objectives, the AA & D task is organized into three sub-task areas: 1) applications analysis and requirements definition; 2) supply analysis and industrial development; and 3) demand analysis and market development.

Applications Analysis and Requirements Definition involves characterizing the electrical energy requirements of the major application categories that have been investigated, including:

- utilities
- manufacturing and industrial applications
- military installations
- isolated military and civil applications
- other, i.e.
    - agriculture
    - irrigation
    - mining and mineral industries

In each case, an extensive data base has been developed in terms of energy consumption, costs, demand profiles and geographic distribution. A preliminary applications analysis was performed to evaluate the potential for solar thermal electric power systems. This work has been performed by JPL and by contracts with Science Applications, Incorporated (SAI), the BDM Corporation, and Burns and McDonnell Engineering Company. The results of all of these activities will be integrated, assessed and documented in FY 1980.

Supply Analysis and Industrial Development (the supply side of the economic equation) involves industrial engineering and costing of the processes and facilities required to mass-produce PFDR modules and also the broadening of the industrial base to ensure multiple suppliers of critical components. Detailed engineering drawings have been prepared of Brayton, Rankine, and Stirling PFDR systems. In each case, detailed economic and technical assessments have been made for JPL of engine mass production processes and facilities through on-site analyses of manufacturers' assembly lines. Industrial engineering analyses of Rankine and Stirling engines and glass mirror panels have also been conducted by contract with Arthur D. Little, Incorporated (ADL), as an important element of a comprehensive study to analyze the production processes and facilities for an entire module.

Demand Analysis and Market Development the demand side of the economic equation involves the expert utilization of professional market surveying techniques to identify where, when, why, and to what extent small solar thermal electric systems are likely to penetrate the electric power market and to transfer information about the technology to potential users.

B. APPLICATIONS ANALYSIS AND REQUIREMENTS DEFINITION

This section discusses, 1) small community utilities; 2) utility, industrial, and military installations; and 3) workshop for potential users of small solar thermal power systems.

1. Small Community Utility Applications

In 1978 there were 3,433 utilities in the United States (Reference 5-1) with combined generating capacity of 560,000 MW (Reference 5-2). There were 272 investor-owned systems (usually large), 933 rural electric cooperatives, and 2228 municipal utilities and public power districts (Reference 5-3). All but 65 of these utilities are grid-connected and the number of non-grid connected utilities is expected to decrease in the 1980s (Reference 5-4). Data Resources, Incorporated (DRI), forecasts a total of 1,011,000 MW of generating capacity in the year 2000. In 1990, annual additions to capacity will aproach 20,000 MW/yr (Reference 5-5). The utility application represents the largest potential market for solar thermal electric power systems. A subset of this application category is the small community utility application, which includes small municipal and cooperative utilities serving about 9% of the U.S. population (Reference 5-3).

The small community utility market is and will continue to be a significant market throughout PFDR system development and commercialization for the following reasons:

- In small communities, small demonstrations represent full-scale applications of modular PFDR technology.
- Small-sized demonstrations in small communities are relatively inexpensive, fully-operational scale models of modular systems suitable for larger applications.

- Small utilities face alternatives which, without exception, reflect the highest costs in the utility industry, namely:

- purchase power from large (often investor-owned) utilities; generate power locally, incurring high unit-price fuel expenses; or enter into joint ventures for larger power stations which are often too small to take full advantage of conventional economies-of-scale in turbine sizing, pollution control equipment utilization, operating economies, etc.

To assess the potential economic impact of solar thermal electric power plants in small community utilities, a study was performed by the Burns and McDonnell Engineering Company (Reference 5-6).

This section summarizes the economic impact of the point focusing distributed receiver (PFDR) system on two statistically representative synthetic small utilities. These are an oil-fired municipal and a coal-fired municipal representing all such municipal utilities in the 20-500 MWe 1974 peak load range. Of the seven synthetic small utilities developed by Burns and McDonnell and used in the study, the oil-fired municipal is considered because it offered the highest breakeven capital cost for solar thermal plants. The coal-fired municipal is considered because it represents the largest potential market among small utilities, as shown in Figure 5-1.

The synthetic utilities were expanded to meet projected demand in the 1980-2000 time period. Solar plants were assumed to be commercially available in 1985, but generally did not begin to enter the generation mix until around 1990 due to the retirement schedule for existing units. Siting was assumed to be in the Southwestern United States, represented by insolation typical of Albuquerque, New Mexico. During the sensitivity analysis, Fort Worth, Texas, insolation was used to represent the South Central region.

a. General Economic Assumptions. All costs (except those in Figure 5-1) are reported in end-of-year 1975 dollars (1975 is the base year for escalation of prices).

Fuel prices used in the study are shown in Table 5-1.

Table 5-1. Fuel Prices in 1975 Dollars*

Fuel	Price (1975)($/Million Btu)
Nuclear	0.60
Coal	1.20
Oil #6	2.05
Oil #2	2.45

*Fuel price escalation and general inflation since 1975 have been such that the results of this study would be appreciably affected. In general, this makes the solar alternative look more attractive.

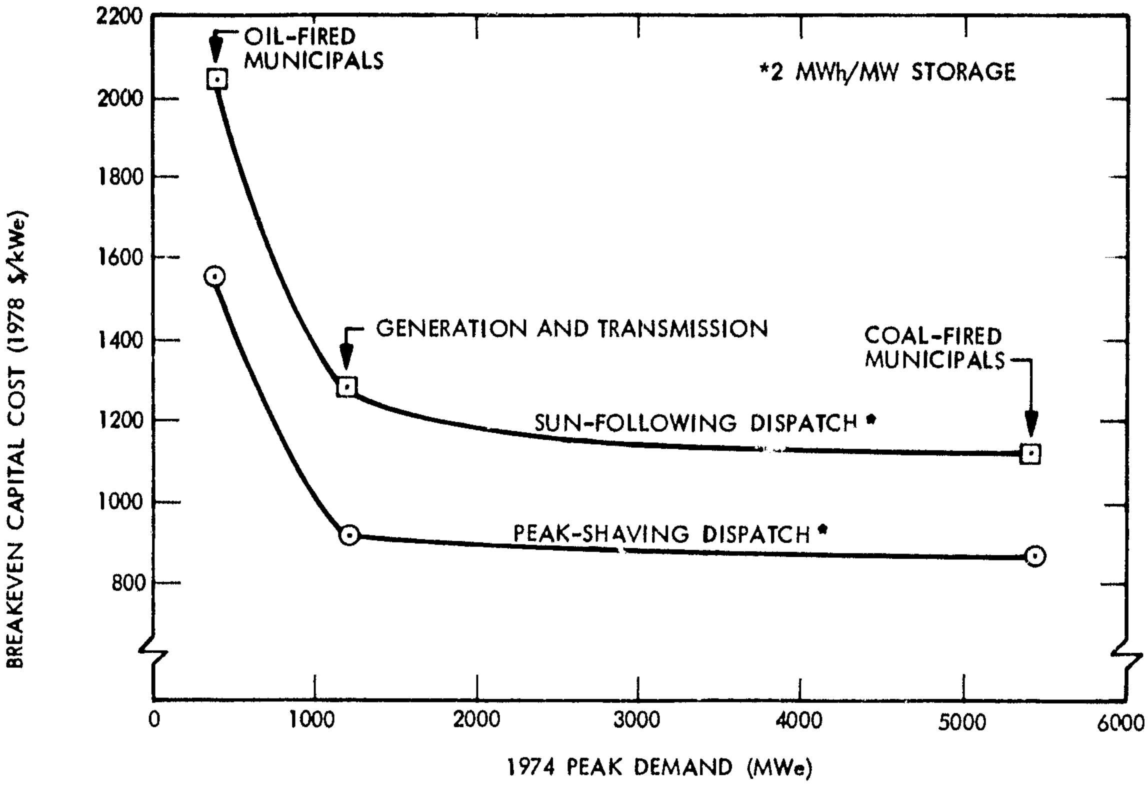


Figure 5-1. Solar Thermal Plant Breakeven Capital Cost vs 1974 Peak Demand in Small Utilities of the Southwestern United States

The annual rate of inflation was assumed to be 6 %. The annual escalation rate of fuel prices was assumed to be 2 % above inflation. Municipal bond yields were assumed to be 7.25 %. The carrying charge rate was 8.41 % for nuclear units and 7.81 % for other generating types. The discount rate was 6 %.

b. Synthetic Utility Characteristics. Characteristics of the synthetic utilities shown in Table 5-2 were developed after a statistical analysis of small utilities of the United States. Small utilities were defined as grid-connected utilities in the contiguous United States having a 1974 peak demand between 0.5 and 500 MWe. The development of the synthetic utilities is explained in Reference 5-6.

Table 5-2. Characteristics of Synthetic Utilities

1974 Peak Demand (MW)	System Description	Peak Load Season	Annual Load Factor ( )	1974 Power Resources: Total Generation Capacity	Coal Steam	Oil Steam	Combustion Turbine	Diesel
[illegible]	Municipal With Coal-Fired Generation	Summer	45	40 MW	(2) 5 MW (1) 20 MW	-	(1) 10 MW	
[illegible]	Municipal With Oil-Fired Generation	Winter	[illegible]	24 MW		(1) 5 MW (1) 10 MW	-	(3) 3 MW

Difference between total generation capacity and peak demand is met through purchased power

c. PFDR Characteristics. The characteristics of the PFDR system used in the study are summarized in Table 5-3. The system consists of a parabolic dish concentrator, receiver, and heat-engine-generator located at the focal point. Each system, or module, produces about 15 kWe. Modules are interconnected electrically to achieve higher power levels. The capital cost estimate in Table 5-3 includes the cost of the PFDR subsystem (collector, transport, and conversion), the storage subsystem, and balance of plant costs (land, site development, water supply, buildings, electrical connections, and overhead items). Interest during construction is not included. The capital cost estimate is shown as a range, which can be broken down into three figures as follows:

(1) The low cost figure ($508/kWe) assumes low costs for plant equipment and balance-of-plant.

(2) An intermediate cost figure ($969/kWe) assumes the same costs for plant equipment but standard balance-of-plant costs per unit area normally associated with fossil-fired units.

(3) The high cost figure ($1281/kWe) assumes high costs for plant equipment and standard balance-of-plant costs. (The difference between the $1821/kWe figure determined for municipals and the $1848/kWe in Table 5-3 determined for cooperatives, is due to the higher cost of capital to cooperatives.)

Table 5-3. PFDR System Characteristics Used in Burns and McDonnell Study

Plant size (rated capacity, MW)	10
Commercial Availability	1985
Cost Characteristics (1975 $)	
Capital Cost ($/kW)	508-1,848
Operation & Maintenance	
Fixed ($/kW-yr)	2-14
Variable (mills/kWh)	1-4
Other Characteristics	
Average Plant Efficiency	.28
Equipment Forced Outage Rate	.01
Annual Maintenance (weeks/yr)	0.1
Storage	
Capacity Rating (MW)	10.0
Energy Rating (MWh)	20.0
Receiver Design Insolation Value (kW/m^2)	0.9
Collector Area (km^2)	0.040
Land Area (km^2)	0.133
Solar Multiple	1.0
Lifetime (years)	30.0

d. Impact of Solar Penetration on Utility Costs. At the high cost, solar thermal plants were not able to reduce the revenue requirements of the utilities. Five percent solar penetration between 1990 and 2000 in the oil-fired utility increased revenue requirements 2.0% for the 1980-2000 period.

At the intermediate cost, a 5% penetration of solar thermal plants reduced revenue requirements for the oil-fired utility by .88% but did not reduce costs for the coal-fired utility.

At the low cost, a 5% pentration of solar thermal plants reduced costs 2.25% in the oil-fired utility and 0.5% in the coal-fired utility.

e. Impact of Fuel Price Escalation Rate on Expansion Plan Costs. In the oil-fired utility, the solar plant (5% penetration) became more economical than the conventional plan at a differential fuel price escalation rate of about 1%. In the coal-fired utility, the cross-over point occurred at a differential fuel price escalation rate of 4%.

f. Breakeven Capital Cost. The breakeven capital cost is that value of solar thermal plant capital cost which results in the present worth of all future revenue requirements (PWAFRR) for the solar expansion plan equalling the PWAFRR for the conventional plan.

The breakeven capital cost is a convenient measure of the economic value of a solar thermal power plant to a user. It depends on the type and quantity of fuel and capacity displaced and on the output characteristics of the solar plant.

Breakeven capital costs in 1975 dollars calculated for the PFDR system were $716/kWe and $1139/kWe for the coal-fired and oil-fired utilities, respectively, based on 10% solar penetration.

g. Impact of South Central Insolation. The PWAFRR of solar expansion plans for the oil-fired municipal in the South Central region, simulated by Fort Worth, Texas insolation, were found to be higher than for the Southwest region by one to approximately two percentage points for solar penetration of 5% to 20%. Thus, the breakeven capital cost decreased from $1139/kWe to about $1117/kWe for the oil-fired municipal. The intermediate cost estimate for a PFDR plant increased from $969/kWe to $1017/kWe, primarily because of the larger collector area required.

The increase in revenue requirements is also a function of reduced energy output per unit of rated capacity. This is reflected in reduced capacity factor and capacity credit. (Capacity factor is the ratio of the average load on a generating unit over time to the capacity rating of the unit.)

Capacity credit is the expected capability of the solar thermal plant to reduce the peak demand while maintaining the same level of system reliability as that associated with conventional generating capacity.

Capacity credit and capacity factor for the PFDR system with 2 MWh/MW storage as a function of solar mix and insolation (siting) are shown in Table 5-4.

h. Operation of a PFDR Plant in a Small Utility. In the Burns and McDonnell study, a solar thermal power plant was dispatched in one of two ways: sun-following or peak-shaving. The difference is one of storage utilization.

Table 5-4. Capacity Credit and Capacity Factor For PFDR Plants With 2 MWh/MW Storage Using Southwest and South Central Insolation

Solar Penetration %	Capacity Credit SW	Capacity Credit SC	Capacity Factor SW	Capacity Factor SC
02	75	55	36	30
05	65	45	36	30
10	50	35	36	30
20	35	25	36	30
40	20	15	36	30
60	15	10	35	29
80	10	05	32	28

The objective of sun-following dispatch is to maximize the energy output of the plant. Energy is dispatched directly to meet demand but can be sent to storage if the available receiver power exceeds either the rated electrical capacity of the solar thermal power system or the user's demand. Energy from storage is then made available to the utility system at the end of solar plant daytime operation.

In peak-shaving dispatch, the objective is to lower the daily peak demand as much as possible. If the daily peak is broad, stretching over many daytime hours, as is the case in most utilities, the problem is difficult because less time is available for collecting the energy for storage prior to its required utilization, more energy is needed to decrease the peak a given amount, and the energy losses in the storage device significantly reduce the net output of the plant (compared to direct, sun-following dispatch to the utility sub-transmission system).

Whether or not a solar thermal power system should be dispatched to peak-shave or to follow-the-sun depends on the breadth of the peak, the cost differential between on-peak and off-peak power (both purchased and self-generated), and the timing of the peak. These issues were beyond the scope of the Burns and McDonnell study, but warrant further investigation. Generally speaking, utility peaks a.e too broad to warrant peak-shaving dispatch by solar plants.

Whether or not a solar thermal power system can be dispatched in peak-shaving or sun-following mode in a particular application depends on the application and the type of storage. The Burns and McDonnell study reported that thermal storage would permit sun-following dispatch but inhibit peak-shaving dispatch in small utilities connected to the grid. Battery storage had the reverse effect. It should be noted that hybrid systems and plants without storage can be dispatched in the sun-following mode.

1) Sun-following Dispatch in Small Utilities. Consider a solar thermal power system with central generation and thermal storage. Stored thermal energy is converted to electric energy in the same turbine-generator as is used to convert thermal energy transported directly from the receiver. The capacity of the turbine generator is limited, so the utilization of the stored thermal energy must be postponed until later in the day. During the day, if insolation is such that the thermal design point of the receiver is exceeded, the excess thermal energy can be removed from the receiver and transported to the storage device. To ensure that the thermal design point of the receiver is met or exceeded, a large number of days per year, the collector field is sized at 1.5 to 2.0 times the minimum necessary. The ratio is called the solar multiple.

2) Peak-shaving Dispatch in Small Utilities. The situation is different in a solar thermal power system with distributed generation and battery storage. The thermal energy in the receiver can be allowed to increase very little above design point because the only cooling mechanism is the transport of heat to the heat engine, which is fixed in capacity and in its ability to dissipate heat. There is no thermal transport to storage. Consequently, the dish concentrator, receiver, and engine must be sized for near-peak insolation conditions, and the solar multiple is close to 1.0. There is essentially no electrical energy being generated during the day which can be transported to battery storage without decreasing the energy dispatched directly to the utility subtransmission system, unless a number of the PFDR systems in the plant are dedicated to providing energy to storage. However, it is highly unlikely that a small community utility would dedicate PFDR systems to providing energy to storage because the energy stored in the batteries could be supplied by any plant in the utility system, including baseload plants operating at low-load, nighttime conditions. Battery storage is not likely to be economical in PFDR plants until energy from PFDR plants can compete with the lowest cost baseload energy available to small utilities. (Notice that this is independent of the battery cost.) The two remaining PFDR plant configurations, no-storage and hybrid, should be considered in near-term small utility applications. The next two sections discuss where each is most appropriate.

i. Small Community Utility Market. The small community utility market is summarized in Table 5-5. The data is from the Burns and McDonnell small utility data base for 1974. DRI projections of market growth rates were utilized from 1974 to 2000 and averaged 2.79% per year (Reference 5-7). The expected growth in peak demand (MW/yr) in 1990 is shown for both municipals and cooperatives by region.

The total market is 1347 MW/yr in 1990. Sixty percent is in municipals; 40% is in cooperatives. The largest municipal market (177 MW/yr) is in the north central. The large cooperative markets are in the Great Lakes (195 MW/yr) and Southeast (102 MW/yr).

j. Ranking of Small Utility Applications. Small community utility applications should be ranked for two reasons:

Table 5-5. Small Community Utility Market

Region	Municipal Utilities' Peak Demand Growth in 1990 (MW/yr)	Cooperatives' Annual Peak Demand Growth in 1990 (MW/yr)	Approximate Required Firm Capacity (Regional Totals) (MW/yr)	Index of Economic Feasibility
SW	142	28	170	47.0
SC	69	99	168	29.5
SE	135	102	237	30.0
NW	82	23	105	12.9
NC	177	70	247	39.6
NE	41	28	69	36.2
GL*	157	195	352	29.6
	802	545	1347	

Table 5-6. Small Utility Non-Firm Capacity Market in 1990

Region	Reserve Margin in 1990	Approximate Minimum Acceptable Reserve Margin 1990	Maximum Acceptable Amount of Non-Firm Capacity in 1990 Municipals	Cooperatives
SW	0.26	0.17	12	18
SC	0.19	0.17	1.4	14
SE	0.15	0.17	0	0
NW	0.15	0.17	0	0
NC	0.16	0.17	0	0
NE	0.16	0.17	0	0
GL	0.20	0.17	4.7	3
			18.1	35

Table 5-7. Higher Ranking Small Utility Applications

$\sqrt{MS^2 + EF^2}$ **	Rank	Application	Preferred Plant Type
1.40	1	Great Lakes Cooperative	Hybrid
1.24	2	Southwest Municipal	Hybrid
1.24	3	North Central Municipal	Hybrid
1.03	4	Great Lakes Municipal	Hybrid
1.01	5	Southwest Cooperative	Hybrid

*Great Lakes

**The square root of the sum of the squares of normalized market size (MS) and economic feasibility (EF).

(1) To limit the number of applications to be studied in order to better understand the sensitivity of PFDR system factors to changes in application factors found to be of critical importance.

(2) Identify those applications which may be appropriate for early engineering experiments.

Important considerations in ranking small utility applications are as follows:

(1) What is the growth in load or required generating capacity projected for each region and utility type? Load growth (MW/yr) has already been discussed and is shown in Table 5-5.

(2) What is the direct insolation in the region?

(3) What is the price of electricity in the region? Direct insolation and electricity cost can be multiplied to produce an index of general economic feasibility as shown by SAI, in section 2c. The economic index for each region is shown in Table 5-5.

(4) Is the solar thermal plant required to be firm or non-firm generating capacity? If the solar plant is a combustion fuel hybrid, its rated capacity is firm. Otherwise, it is not*. Firm capacity contributes to meeting the utility's capacity requirement while non-firm capacity contributes only to meeting the energy requirement. A non-firm capacity plant is a fuel saver only. If the application is in a grid with projected inadequate reserve margin, firm capacity would probably be preferred to non-firm capacity. Regional reserve margins for 1990 are shown in Table 5-6 based on projections by DRI (Reference 5-7). The maximum acceptable amount of non-firm capacity in 1990 can be found by multiplying the total capacity required for each region by the difference between the expected reserve margin in 1990 and the minimum acceptable reserve margin, as shown in Table 5-6. (The minimum acceptable reserve margin was estimated by JPL.) Using this procedure, the total non-firm capacity market is 18 MW/yr in 1990, compared to 1347 MW/yr of firm capacity, which underscores the importance of hybrid systems.

* In areas of very high insolation, high summer peak loads, and adequate reserve margin, such as the southwest, calculated capacity credits (such as those in Table 5-4) may be accepted by some utilities at low solar penetrations, but will be suspect in other regions and at significant higher penetrations.

Applying the above criteria, the preferred applications were found to be Great Lakes cooperatives, Southwest municipals, North Central municipals, Great Lakes municipals, and Southwest cooperatives, as shown in Table 5-7.

The ranking shown in Table 5-7 is based on market size (MS) and economic feasibility (EF). For each combination of utility type and region an ordering value was found equal to $(MS^2 + EF^2)^{1/2}$. MS and EF can be thought of as two axes defining application space with the highest ranked system being the one furthest from the origin. (Both MS and EF were normalized prior to calculating the ordering value.) The preferred plant configuration is also shown in Table 5-7 for each combination of utility type and region. In each case, dispatching is presently envisioned to be sun-following, which implies daytime utilization only, with early assignment in the daily economic commitment schedule. This is equivalent to daytime intermediate operation.

As shown earlier in Figure 5-2, the predominant fuel used by a utility is an important factor in determining the breakeven capital cost. Within each of the five preferred applications, oil-fired utilities would be expected to have higher breakeven capital costs than coal-fired utilities, and, thus, would tend to represent earlier market opportunities and greater potential for displacing oil. Oil-fired utilities and those purchasing power from oil-fired utilities would be preferred applications in each subcategory.

k. <u>Experiment Definitions.</u> The role of experiments in bringing PFDR technology to the point of commercial readiness is pivotal. Engineering experiments are essential to establishing the system feasibility of the PFDR concept in the minds of potential users, developers, manufacturers, and sponsors.

In this application category, one of the most attractive applications, Southwest Municipals, is superior in market size, economic feasibility, insolation, and favorability of climatic conditions. It is unlikely that all small utilities, for example, North Central Municipals, will accept Southwest Municipal experiment results as proof of the system feasibility of the PFDR system in their application under their climatic conditions. More than one experiment will probably be needed to prove system feasibility in all of the higher ranking small utility aplications.

The first small community utility experiment should therefore focus on the technical quality of the hardware and its operation in a relatively benign environment. Market considerations, while very important overall, are less constraining for the first experiment because the most important consideration is initial technical success. Only when this issue is settled favorably may a system be considered for applications in more severe environments. Consequently, a series of experiments addressing the small community sector would appear to have considerable merit. Experiments beyond the first SCSE will be planned to consider regional and utility needs as well as a progression of technological maturity.

In summary, small utility applications have been and will continue to be analyzed in order to ensure that the Small Community Experiment Series is relevant to the broadest possible cross-section of potential users.

These experiments will also serve as relatively low cost scale models of PFDR plants in larger, more complex utility applications, which are described in the next section.

2. Utility, Industrial, and Military Installation Applications

SAI is currently under contract to perform a comprehensive impact analysis and requirements definition of solar thermal small power plants, 1-10 MWe each in capacity, installed in a utility system or serving a non-utility load in the United States. The study encompasses the period from 1985 to 2000 but emphasizes the period from 1985 to 1989 and treats utility and non-utility applications as equally important. The study consists of 10 tasks. Tasks 1 through 3, completed in FY1979, were concerned primarily with developing an extensive data base on solar thermal power system configurations, potential applications, and regional characteristics essential to completion of the impacts analysis and requirements definition in Tasks 4 through 10. The results presented here are for electric-only applications.

a. Task 1. Solar Thermal Electric Plant Data Base. The subsystem alternatives evaluated in this study consisted of:

(1) Collector (Concentrator/Receiver) Subsystem

- Point Focusing Distributed Receiver
- Heliostat/Central Receiver
- Fixed Mirror Distributed Focus (FMDF)
- Line Focusing - Parabolic Troughs

(2) Energy Conversion Subsystem/Thermodynamic Cycle

- Rankine
- Rankine through Storage
- Open Brayton
- Closed Brayton
- Stirling
- Combined Cycles

(3) Storage/Hybrid Configurations

- No Hybrid, No Storage
- Hybrid, No Storage

- No Hybrid, Storage

- Hybrid, Storage

(4) Energy Transport

- Thermal Central Generation

- Chemical Central Generation

- Electrical Distributed Generation

For these subsystem options there were 96 possible configurations for each mode of generation (distributed, central). To reduce the number of potential systems, a set of selection criteria was established, which included an analysis of the technical feasibility and component availability during the 1985-2000 period.

The review of heat engine component availability to be used in near-term (1985-1990) systems yielded the following:

- Open Brayton Cycle. Seventeen models rated from 22.5-22,500kW (30 to 30,000 hp) (approximately 20 kW to 20 MW equivalent electrical output allowing for losses) are available from nine manufacturers. Delivery is generally 6 to 12 months.

- Closed Brayton Cycle. There is no domestic production and only one manufacturer (Garrett AiResearch Corporation) has built a prototype. There are many closed cycle Brayton engines in Germany that have been installed. Professor Bammert of Hanover University in Germany has been the leading force in their installation and while these machines are in commercial use they are not what is termed "commercially available."

- Organic Rankine Cycle. Many manufacturers have built prototype engines rated up to 600 kW. At least two have achieved what SAI considered commercial production; Sundstrand Corporation of USA and Ormat Turbines Limited of Israel. The Ormat unit is 1 kW and has a very low efficiency (5%-6%). The Sundstrand 4-22 kW machine was considered available. Delivery is estimated at 12 to 18 months.

- Steam Rankine Cycle. Several manufacturers have machines in the 1-10 MWe range. While small units exist, their performance is usually low because they are designed to use waste heat and their low initial cost, not their efficiency, has been the driving factor in their development. Small research engines exist. For the 1-10 MWe range, a delivery time of 18 to 24 months is estimated.

- Stirling Cycle. Prototype models have been made by eight manufacturers from a few watts to 1210 W/275 hp ratings. Delivery schedule estimated by vendors is 2 to 3 years from receipt of a production order.

- Combined Cycle. Five models are available in the range from 3.5 to 11 MWe. Delivery schedule from the two manufacturers is 8 to 18 months.

The performance and cost of these available components formed a baseline from which SAI projected reasonable improvements by 1985 to 1989.

Information on the commercial availability of solar collector subsystems was obtained from published reports and established performance/cost goals of the DOE for solar systems components.

On the basis of extensive evaluation of the available technical data performed by SAI, the solar thermal electric plant configurations to be analyzed initially in Tasks 4-10 will emphasize point-focus distributed receiver (PFDR) technology. The PFDR system was selected for these initial analyses primarily on the basis of collector efficiency. The rationale is discussed in Reference 5-8.

Two basic configurations will be analyzed: 1) PFDR with distributed generation (focal-mounted turbine/generator); and 2) PFDR with central generation (thermal energy transport to a central turbine/generator). Initially, Brayton, Stirling and combined cycles will be considered for the distributed generation mode, possibly with hybrid and electrical storage. Only Rankine cycles will be considered for the central generation mode, because large heat losses are typically associated with the thermal transport, and Rankine turbines are more efficient in the larger sizes. Chemical transport will not be treated in the initial analysis because it is in an early stage of testing and technology development. In addition, thermal storage will be considered for the central generation mode. These systems will be simulated by a computerized model, QAG, which was developed by SAI and its subcontractor, Black and Veatch (B&V). The model simulates the performance of solar thermal power plants using hourly meteorological data and subsystem parameters as inputs. The performance of each subsystem is specified by its efficiency which is defined as the ratio of the output energy to the input energy to the subsystem. The interface between two interacting subsystems is characterized by linking factors which generally depend on the characteristics of the interacting subsystems. The off-design efficiency of each subsystem is expressed as a function of the energy input to it. The product of subsystem efficiencies and linking factors define the performance of the entire power plant.

b. Task 2. Selection and Formulation of Application Models. A broad range of potential applications were investigated in detail, including manufacturing and industrial business, military installations, large and small utility systems, agricultural and irrigation applications, national parks, and minerals and mining industries. In addition, a comprehensive data base was developed which provides electrical load profiles, electrical consumption and cost data, and geographic distribution data required for the impacts analysis. Extensive information was also gathered concerning thermal energy requirements, but was not analyzed within the scope of this study. Applications will be discussed individually under Task 3b.

c. Task 3. Regional Characterization, and Selection of Combinations of Systems, Applications, and Regions for Initial Analysis.

1) Task 3a. Regional Characterization. Any division of the United States into a small number of regions is certain to result in a degree of nonhomogeneity within some, if not all regions. The annual average direct insolation by state in the contiguous United States varies by a factor of 2.2:1, and the cost of electricity by a factor of 8:1. Water resources vary from plentiful to virtually non-existent. Fortunately, there is some degree of geographical correlation among the most important parameters. A workable regionalization having seven major regions and ten subregions has been developed by SAI on the basis of average annual direct insolation, the cost of electricity for industrial use, the adequacy of water resource availability, air temperature and humidity factors, wind, barometric pressure, and seismic factors. A measure was devised that incorporates both the average yearly direct insolation and the cost of electricity for industrial use. This measure is:

$$U = S \times C$$

where:

S = average yearly direct insolation (kWh/m^2yr)

C = cost of industrial electricity ($/kWh)

therefore:

$$U = (kWh/m^2yr) \times (\$/kWh)$$

$$= \$/m^2yr$$

This measure, in units of dollars per square meter year, is a measure proportional to the value of a reflecting surface used to produce electricity for industrial use. As such, the cost effectiveness of solar systems is proportional to this measure. The parameter U and the average daily direct insolation were the primary quantities used to define the geographic regions. The cost effectiveness measure was evaluated for each state. The regionalization is shown in Figure 5-2 and discussed below.

a) Region 1. Region 1 which includes New Hampshire, Massachusetts, Connecticut, Rhode Island and New Jersey is characterized by low insolation levels and high industrial electrical energy costs. Water resources are adequate in a quantitative sense, but the entire region suffers from severe thermal pollution. Boston is approximately in the center of the region, and detailed data for Boston may be used for a first order approximation of system performance.

b) Region 2. Region 2 spans the latitudes from Maine to Florida and includes climatic zones ranging from humid cool summer to tropical Savanna. Despite the geographical diversity, the region is relatively homogenous with regard to direct insolation and electrical energy costs.

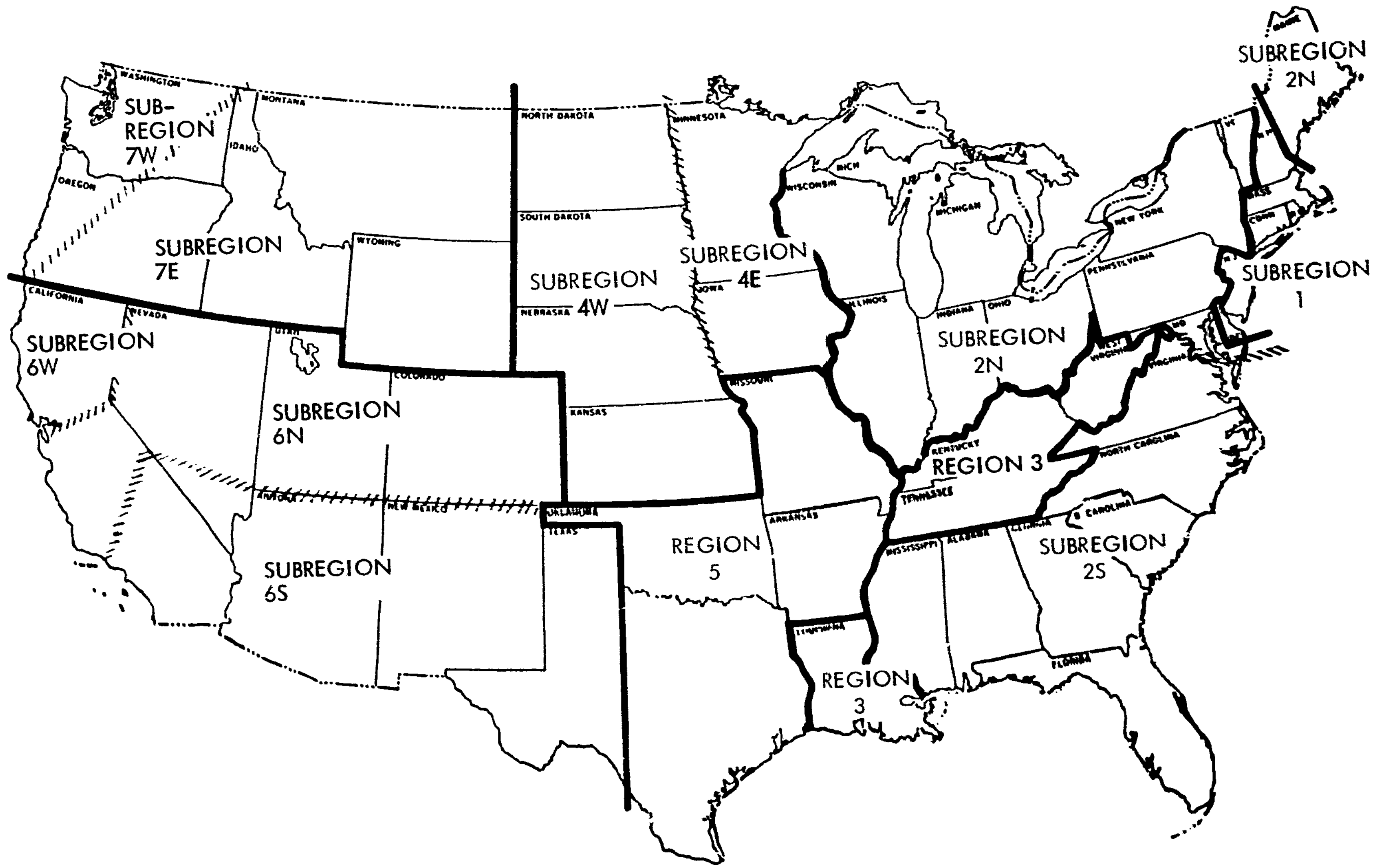


Figure 5-2. Regionalization of the United States by SAI

The entire region is characterized by adequate water resources but the Northern portion suffers from severe and major thermal pollution. (In the Great Lakes drainage basin, total water use is 120% of total runoff, although consumptive use is only 4% of total runoff).

This region has been divided into northern and southern subregions (2N and 2S), with the boundary along the southern border of Maryland. This reduces the range of annual daytime average temperature to 10°C for each subregion. All of 2N is characterized by severe or major thermal pollution while only a small portion of 2S (mostly in Northern Virginia) bears such a classification. Four typical meteorological year (TMY) meterological records - Caribou, Maine, New York, Washington, D.C., and Madison, Wisconsin are available for the northern subregion, but they represent the extreme limits of the area. A fifth record, designated 2N has been prepared by SAI which is representative of the central portion of the subregion (approximately through the center of Ohio, Indiana, and Illinois).

Four TMY meterological records - Cape Hatteras, Apalachicola, Miami and Charleston are available for the southern subregion. All are coastal stations and the Miami data is atypical of the region except for the southern extremity of Florida. A fifth record, designated "2S" has been prepared by SAI and is representative of the central portion of the sub-region (approximately through the centers of Mississippi, Alabama, Georgia and the western portion of South Carolina.

c) Region 3. Region 3 includes West Virginia, Kentucky, Tennessee, and Louisiana. It is characterized by low to moderate insolation levels and low electrical energy costs. Water resources are generally adequate, but virtually all of West Virginia and Kentucky and much of Tennessee are in the Ohio drainage basin which suffers from major thermal pollution. The western portion of Louisiana is in the Arkansas-Red-White and Texas-Gulf drainage basins which are classified as marginal and inadequate, respectively. However, the portion of these basins within Louisiana receive adequate precipitation throughout the year and are underlain by major aquifers.

Because of the low cost effectiveness index, significant market penetration is not a likely prospect in this region.

There are two TMY meteorological records for Region 3: Nashville, Tennessee; and Lake Charles, Louisiana. The former is typical of West Virginia, Kentucky and Tennessee and the latter of Louisiana.

d) Region 4. Minnesota, Iowa, the Dakotas, Nebraska and Kansas comprise Region 4. Insolation varies from about 4 $kW/m^2/day$ in Eastern Minnesota to 6 $kW/m^2/day$ in Southwestern Kansas. Water resources are generally inadequate to marginal. Major parts of Iowa and Minnesota are in the upper Mississippi drainage basin which combines adequate surface water and major thermal pollution.

Because of the relatively large difference in insolation, Iowa and Minnesota have been designated as sub-region 4E, and the balance as sub-region 4W. Further, water resources in 4E are predominately adequate, but in 4W are generally inadequate.

There are three TMY records for the region: Bismarck, North Dakota; Omaha, Nebraska; and Dodge City, Kansas. The Omaha data are generally applicable to region 4E.

e) Region 5. Missouri, Arkansas, Oklahoma and Texas (east of the 100th meridian) comprise Region 5. The region is relatively homogenous with regard to insolation and industrial electrical energy costs. With the exception of the areas adjacent to the Mississippi River, water resources are inadequate to marginal.

There are three TMY meterological records for Region 5: Columbia, Missouri; Fort Worth, Texas; and Brownsville, Texas.

f) Region 6. Region 6 is the largest in the country and, in many respects the most diverse. It includes the sun belt and the high insolation areas immediately to the north. Water resources are classified predominantly as inadequate. Ground water availability is a site-specific parameter.

It has been divided into three sub-regions. Sub-region 6S is the sun belt which includes West Texas, New Mexico, Arizona, Southern Nevada, and Southern California. Sub-region 6W includes only Northern California. Sub-region 6N includes Colorado, Utah, Northern Nevada, and Central California. These three sub-regions differ significantly in insolation and water resources to warrant separate treatment.

Industrial electric energy rates are generally moderate in the region, but the high insolation levels result in a high cost-effectiveness index.

There are four TMY meterologic records for region 6S and their distribution provides a good representation of the climatology. They are: El Paso, Texas; Albuquerque, New Mexico; Phoenix, Arizona; and Santa Maria, California.

There are two TMY meterological records for sub-region 6N: Ely, Nevada; and Fresno, California. The data for Ely is generally applicable for sub-region 6N east of California and that for Fresno to the Central Valley of California.

TMY meteorological records for sub-region 6W and those from adjacent areas are not directly applicable. The area is mountainous and a marked difference in climate occurs over short distances.

g) Region 7. Region 7 is diverse in topography and climatology. However, it is homogenous with respect to the cost-effectiveness index for solar collectors. The region has the lowest industrial electricity rates in the U.S., and consequently, the lowest cost-effectiveness index.

The Pacific Coastal portion defined by an arbitrary straight line from the SW corner of Oregon to the NE corner of Washington, differs markedly from the rest of the region in terms of average insolation and water resources. It has been designated sub-region 7W and is characterized by adequate water resources, relatively low insolation levels, and an extreme range of variations in insolation over the year. (The July to December ratios of average daily direct insolation for Seattle, Washington, and Medford, Oregon, are 9:1 and 10.8:1 respectively.)

Isotherms for annual average daytime temperature could not be derived from available data. The rugged topography makes temperature a site specific parameter.

There are three TMY meterological records for the region, two in 7W (Seattle and Medford) and one in 7E (Great Falls, Montana).

For all regions and sub-regions, detailed data is contained in the SAI Task Summary Report, Reference 5-8.

2) Task 3b. Selection of System, Application, and Region for Initial Analysis.

a) Utility Applications. Already-developed synthetic utility models with typical load profiles, generation mixes, and transmission networks for use in technology assessment studies have been obtained by SAI from the Electric Power Research Institute and form the baseline utility systems to be used in subsequent analysis, as specified in the Contract Statement of Work. For convenience, the characteristics of the EPRI large synthetic utilities are shown in Table 5-8. Differences represented among the model systems allow study of the sensitivity of technology improvements, equipment characteristics, fuel scenarios, etc., to these different characteristics.

The EPRI synthetic large utilities range from about 20 to 55 GW and are a reasonable size for making reliability assessment studies. However, the cost of dispatching these large scenarios for power production and cost studies may be excessive. Thus, a generation system scaled down to between 10,000 and 11,000 MW, maintaining approximately the same ratio of generation types, is also included for each of the six synthetic utilities.

Small utility models to be utilized will be those developed by Burns & McDonnell for EPRI and JPL and presented in last years Annual Technical Report (Reference 5-12).

The utility market for the United States is summarized in Table 5-9. DRI projections (Reference 5-7) were preferred by JPL because they were more conservative, i.e., showed a lower growth rate than those of the National Electric Reliability Council. As in the small utility case, JPL estimated the amount of non-firm capacity which a particular grid might be able to accept, subject to limitations imposed by reserve margin agreements among utilities, by multiplying the growth in load, or required capacity, by the difference between the projected reserve margin and the minimum acceptable reserve margin.

Table 5-8. Summary of Synthetic System Characteristics

Scenario	Generation (MW)	Load (MW)	Transmission (MI)*	Comments
A	[illegible],500	44,000	24,955km (15,500)	Summer Peaking - Mid-range 345, 230, 138 kV network - some 500 and 765 kV - coal, nuclear
B	46,000	38,000	33,810km (21,000)	Winter Peaking; High Summer Peaks - Dispersed 500, 230 kV network - some 345, and 138 kV - hydro, oil, coal
C	22,000	16,500	21,735km (13,500)	Summer Peaking - Highly dispersed 345, 230, 138 kV network - coal, nuclear
D	32,000	26,000	8,050km (5,000)	Summer Peaking - Mid-range 345, 138 kV network - some 500 and 230 kV - gas, coal, nuclear
E	45,000	37,000	20,125km (12,500)	Summer Peaking - Mid-range 345, 138 kV network - some 500 and 230 kV - gas, coal, nuclear
F	32,000	26,000	20,930km (13,000)	Summer Peaking; High Winter Peaks - Mid-range 500, 230, 138 kV network - oil, nuclear

*Approximate circuit miles

The results, presented in Table 5-9, show that the firm capacity market will be 70 times larger than the non-firm capacity market. It should also be noted that every near-term cancellation of a nuclear or coal plant decreases the non-firm capacity market of the future and increases the firm capacity market. The results in Table 5-9 do not include recent plant cancellations.

In Task 3b, three of the EPRI synthetic utility systems were selected by SAI for initial analysis based primarily on regional considerations and utility generating capacity type. System F with mostly oil and nuclear generation, high winter and summer peaks, and medium transmission line lengths is appropriate for the Northeast area. System B is recommended for the West, with its significant hydroelectric generation in addition to coal and oil and long average transmission lines which may affect dispersed generation. Initial sensitivity analyses will also investigate System E and the 35 MW Municipal Utility for the South Central (Texas) area, with predominantly gas generation and some new coal and nuclear typical of that region.

b) Industrial Applications Analysis. A detailed analysis of potential industrial applications was performed based on energy consumption, electricity costs, load shapes, insolation, and representative solar system performance and costs. For each 3-digit SIC code and state, the profitability of solar investment was calculated, and the resulting energy displaced was estimated based on user load shapes and conservative system sizing (turbine/generator output no more than average daytime demand). As expected, specific industry-state combinations look attractive because of high electricity costs and/or high insolation, with total market size also playing an important role. Land availability, which is also a key factor, was not addressed in this analysis because of insufficient data. Nominal land costs were used in the economic analysis.

Table 5-10 lists those industry/state combinations with the highest profitability (shortest payback) for investment in solar thermal electric power. These applications are characterized by high energy costs and/or high insolation and may represent potential near-term applications. The highest ranked application, for example, is sawmills and planing mills in New Hampshire.

This is because electricity costs averaged above 10¢/kWh, based on Bureau of the Census data. Favorable locations for near-term applications include: California, Hawaii, southwest states, south central states (high insolation and energy costs); and New England and New Jersey (high energy costs).

Table 5-9. Characteristics of the U.S. Utility Market in 1990

FERC Region	1990 Reserve Margin	Approximate Adequate Reserve Margin	1990 Average Capacity Addition (MW/yr)	Non-firm Capacity Market Size (MW/yr)
New England	.16	.17	1,410	0
Middle Atlantic	.17	.17	2,130	0
South Atlantic	.15	.17	4,500	0
E. North Central	.20	.17	2,310	69
W. North Central	.17	.17	2,210	0
E. South Central	.17	.17	2,580	0
W. South Central	.21	.17	1,550	62
Mountain 1	.26	.17	130	12
Mountain 2	.13	.17	810	0
Mountain 3	.43	.17	480	125
Pacific	.15	.17	1,550	0
			19,660	268

Table 5-10. Industry/State Combinations With Highest Profitability

Order	SIC Code	Industry Group	State	External ROI (payback-1)
1	234	Sawmills and Planning Mills	NH	.622
2	254	Partitions and Fixtures	NJ	.529
3	245	Wood Buildings and Mobile Homes	IA	.522
4	249	Miscellaneous Wood Products	WV	.317
5	27	Printing and Publishing	AZ	.371
6	203	Preserved Fruits and Vegetables	MA	.348
7	245	Wood Buildings and Mobile Homes	OK	.346
8	396	Costume Jewelry and Notions	CA	.345
9	239	Misc. Fabricated Textile Products	UT	.333
10	347	Metal Services	WI	.327
11	209	Misc. Foods, Kindred Products	CT	.325
12	208	Beverages	AZ	.321
13	358	Refrigeration and Service Mach.	CT	.319
14	249	Miscellaneous Wood Products	WV	.317
15	204	Grain Mill Products	HI	.315
16	306	Fabricated Rubber Products	NJ	.304

Table 5-11 lists the industries with largest potential overall energy displacement. These industries are characterized by large annual electricity consumption correlated with high energy costs and/or insolation. As such, they represent the largest potential for solar applications in the 1990 to 2000 time frame. The solar thermal electric system costs were assumed to be around 600 $\$/m^2$ collector, resulting in some solar market penetration in a large number of industries.

Table 5-12 shows those states with the largest overall energy displacement. These states are characterized by significant industry concentration coupled with high insolation and energy costs.

It should be emphasized that the results of the industrial applications analysis do not apply to specific users of a solar thermal electric plant. The analysis is based on average values for each industry/state combination in conjunction with a statistical representation of the many user-specific factors which affect the economics for a solar installation. Key factors which were not addressed in the analysis include cost of capital, specifics of the user financial status, differences in investment criteria, site-specific insolation and energy costs, differences in solar thermal electric plant design/performance/cost, and many intangibles such as user assumptions about the future, risk avoidance, innovativeness, willingness to support renewable energy sources, and competition from alternative energy sources. (The financial factors mentioned above will be dealt with in FY1980 through individual case studies using the JPL Alternative Power System Economic Analysis Model described in Section D4. Consumer behavior is presently being addressed by General Electric through a comprehensive market survey explained in Section D3).

For the industrial baseline applications analysis, a 24-hour base-load profile will be analyzed (characteristic of large industries) together with an 8-hour single shift load for comparison. These two load types are well represented by the Research Triangle Institute (RTI) load profiles for primary metal industries (SIC 33) and for wood and lumber products (SIC 24) demands, respectively (Reference 5-8). Moreover, these two applications placed high in the Task 2 ranking in terms of both cost effectiveness and total market size, and they have a geographic distribution consistent with the baseline regional selections. It should be noted that these applications will be analyzed in the context of the utilities defined earlier, so that both of the on-site and utility impacts of solar plants will be investigated. Other potential applications and load characteristics will be evaluated in subsequent analysis.

c) Military Installations and National Parks. Military installations are also expected to be a potential application of PFDR systems because of: the availability of funding if mission requirements are met; the orientation towards long-term economics; the desire to be independent of utility outages; and the availability of manpower for operation and maintenance.

The criteria for judging the applicability of these applications is discussed below.

Total Market Potential--There were 134 Naval stations, 133 Air Force bases, and 127 Army posts accounted for in this analysis.

Table 5-11. Industries with Largest Nationwide Energy Displacement

Order	SIC Code	Industry Group	Energy Displaced, MkWh/yr
1	372	Aircraft and Parts	256.9
2	331	Blast Furnace, Basic Steel Products	205.8
3	307	Miscellaneous Plastics Products	182.5
4	291	Petroleum Refining	177.8
5	371	Motor Vehicles and Equipment	157.3
6	376	Guided Missiles, Space Vehicles	143.1
7	206	Sugar, Confectionery Products	125.9
8	281	Industrial Inorganic Chemicals	112.8
9	324	Cement, Hydraulic	112.3
10	366	Communication Equipment	112.2
11	242	Sawmills and Planning Mills	109.0
12	329	Misc. Nonmetallic Mineral Products	105.2
13	332	Iron and Steel Foundries	99.7
14	344	Fabricated Struc. Metal Products	93.4
15	327	Concrete, Gypsum, Plaster Products	92.9
16	203	Preserved Fruits and Vegetables	86.3
17	367	Electronic Components, Accessories	84.8
18	335	Nonferrous Rolling and Drawing	85.2
19	357	Office and Computing Machines	84.4
20	202	Dairy Products	79.5
21	208	Beverages	77.2
22	201	Meat Products	70.5
23	209	Misc. Foods, Kindred Products	70.2
24	347	Metal Services	68.7
25	275	Commercial Printing	65.4
26	356	General Industrial Machinery	65.3
27	346	Metal Forgings and Stampings	65.0
28	204	Grain Mill Products	64.0
29	263	Paperboard Mills	63.9
30	262	Papermills, Exc. Building Paper	63.7
31	265	Paperboard Containers and Boxes	61.6

Table 5-12. States with Largest Energy Displacement

Order	State	Energy Displaced, MkWh/yr
1	California	5,382.77
2	Massachusetts	651.42
3	Arizona	472.19
4	New Jersey	452.15
5	Michigan	328.48
6	Texas	299.03
7	Illinois	266.22
8	Pennsylvania	265.27
9	Connecticut	262.36
10	Florida	254.41
11	Ohio	220.35
12	Hawaii	191.70
13	Missouri	181.34
14	New York	149.94
15	Kansas	130.92
16	Wisconsin	127.98
17	Iowa	122.70
18	Georgia	106.63
19	Minnesota	95.40
20	Indiana	92.78
21	Arkansas	87.81
22	Colorado	80.36
23	Rhode Island	71.45
24	Mississippi	62.50
25	North Carolina	57.06
26	Maryland	56.16*
27	Nebraska	44.54
28	Nevada	44.45
29	Alabama	41.59
30	Virginia	36.52
31	Oklahoma	35.56
32	South Carolina	34.62
33	Tennessee	33.57
34	Utah	27.82
35	Delaware	19.76
36	Kentucky	19.49
37	New Hampshire	19.15
38	New Mexico	14.90
39	Lousiana	14.18
40	West Virginia	10.70
41	Maine	9.86
42	South Dakota	6.27
43	Vermont	5.40
44	North Dakota	3.42
45	Oregon	2.39
46	Idaho	1.70
47	Alaska	.89
48	Montana	.69
49	Washington	.67
50	Wyoming	.07

*Includes District of Columbia

The total electric power consumed by these 394 installations is approximately 22.8 x 10^6 MWh annually, which represents about 0.74% of the total power consumed in the United States. This would appear to represent an adequate market potential. There are 320 National Parks Service locations, which would appear to be a sufficiently large number to represent an attractive applications category. However, the total electricity consumption for the 209 parks reporting was only 0.106 x 10^6 MWh. If we assume a figure of approximately 0.16 x 10^6 MWh for all 320 parks, this represents only 0.005% of U.S. consumption, and a judgmental rating of fair is thus given.

Total Electrical Energy Consumption per Installation -- The vast majority of the 394 military installations have annual consumption levels at or above the output of a 1 MWe PFDR system, whereas only a few of the parks do.

Self-Generated Electricity -- Only a small fraction of military installations generate their own power, and most of these also purchase power. During the Eisenhower administration, the DOD directed military installations located in the U.S. to purchase all their power from local utilities unless a clear cost savings could be shown or mission imperatives dictated self-generation. As a result, very few installations generate more power than they purchase. Only Guantanamo Bay, Cuba, and Adak, Alaska, produce all their own electricity. These, however, do not represent attractive applications for solar electricity from the Navy point of view, because they both consume vast amounts of fuel for ship servicing, and the fuel that would be saved by solar generation would be a small percentage of the overall base consumption.

A study conducted for the National Park Service (NPS) by Lincoln Laboratory identified four sites within three parks that generated all their own power, but all four of these have power consumption levels below that of a 1 MWe system. If smaller power systems are to be considered in the future, then NPS sites could be a viable applications category, but it will take considerable effort to assemble comprehensive data on self-generated power in all the NPS installations.

Electricity Costs -- The median cost of electricity for Army and Navy bases lies around 29 mills/kWh, below the U.S. average of approximately 32mills/kWh. Many of those installations paying higher costs lie outside the continental United States or reported only small amounts of electricity consumed. The large majority of installations are thus presently experiencing electricity costs which are low or moderate, and this criterion does not, of itself, yield readily apparent near-term applications for solar electric power generation.

Geographic Location -- The applications categories of military bases and national parks span the U.S. and have ample installations in each of the Task 3 regions.

Availability of Data -- Sufficient data existed and were obtained to identify military bases as attractive applications categories. No load profiles were available for the NPS, and data on self-generation of power had to be inferred from reported diesel fuel consumption.

Only 209 of the 320 parks reported data, and of the parks reporting, only total electricity consumption data, along with steam, diesel, and fuel oil data, were useful for this analysis. If solar thermal electric systems of less than 1 MWe are to be addressed at some future time, then the NPS sites could represent an attractive application category. In that case, additional NPS data would have to be obtained, probably through extensive telephone canvasing and personal visits to individual sites.

Thermal Generation -- Thermal energy generated in the four applications categories was examined. The values for the NPS were inferred from reported steam and fuel oil consumption. For comparison, the waste heat from a 1 MWe solar thermal electric generating system would be on the order of 2931 MW/yr (10^{10} Btu/yr). The military installations generate significant quantities of heat, and thus present the possibility of utilization of waste heat from solar thermal electric systems. The data from NPS shows that of the 15 parks which consume 1 MWe-level power annually, all but one generate thermal. The utilization of waste heat for local site purposes would appear to be a possibility, but additional analysis of the NPS installations would have to be performed on an individual site basis to determine this with certainty.

Thermal Costs -- The conclusion to be drawn regarding thermal energy costs for Army and Navy installations is identical to that which applies to the cost of electricity at these installations; namely, no large group of installations emerge as suffering from exorbitant costs for thermal energy.

d) Agricultural Applications. Total energy consumed for direct use in U.S. agricultural production was about 1.3 quadrillion Btu in 1974, with an additional 0.7 quadrillion Btu consumed indirectly by fertilizers and pesticides. While this represents only about 3% of U.S. energy consumption, agriculture plays a critical role in the U.S. economy. In addition, about 13% of U.S. energy is consumed in the processing, distribution, and preparation of food. Only on-farm energy consumption is treated in this section; fertilizer production and food processing are treated in the industrial and manufacturing applications analysis.

Direct energy consumption for crop production is about five times greater than that for livestock, even after subtracting the indirect energy content of fertilizers and pesticides. Major crop production activities include mobile field operations (land preparation, planting, cultivation, application of fertilizers and pesticides, and harvesting), transport, irrigation, frost protection, grain handling, lighting, and crop drying. For this study, battery-powered tractors and trucks were not considered practical or cost-effective because of the mobility and extremely high power requirements. Small battery powered vehicles (i.e., for waste removal in livestock operations) might be feasible, but initial investigations indicate that fossil fuel will have to become much more expensive before battery-powered farm vehicles become cost-effective. Of the remaining crop production activities, irrigation represents by far the largest energy demand, both for fossil fuel and for electricity.

For this reason, irrigation has been investigated separately and will be discussed in the next section, as a potential application of solar thermal electric power systems. The remaining crop production operations on typical farms tend to be either very small (i.e., lighting) or seasonal (i.e., crop drying which must be performed within several weeks after harvest to prevent spoilage).

Crop production activities are inherently seasonal, which presents problems in effectively using solar power systems (this is discussed in more detail for irrigation). Livestock operations, however, generally provide a better year-round match with available insolation. Ventilation, for example, has high electrical demands (20 kW in summer for a 30,000-layer egg farm) that are larger in summer than in winter and are primarily daytime loads. Other potential livestock applications include lighting, water supply, feed handling, milk cooling, milking, brooding, egg handling and washing, and water heating, with ventilation being the largest electrical load. However, total livestock energy consumption is small on a national scale, and energy demands on a single farm or even several farms are not sufficiently large to be suitable for one 10 MWe power system. For example, a high density enclosed 30,000-layer egg farm requires about 150 MWh/yr for the overall operation, including ventilation, feeding, lighting, egg collection, egg cleaning, water supply, and egg cooling. For this reason, additional analysis of agricultural applications for solar thermal electric power was not performed in this study, except for irrigation.

An extensive data base is available for analysis of smaller-scale solar systems in agriculture should it be decided to lower the 1 MWe plant limitation. The 1974 Agricultural Energy Data Base provides on magnetic tape a detailed breakdown of agricultural energy consumption by individual state, month, functional operation, and fuel type. An updated version will be available from the Economic Research Service in 1979. In addition, hourly load profiles for a range of representative farms were developed in a recent study of photovoltaic applications in agriculture.

e) <u>Irrigation.</u> Farm production requires about 2.4 quadrillion Btu annually, about 3% of the nation's total energy consumption. Of this, over 10%, 0.26 quadrillion Btu is used for irrigation. Irrigated land contributes over 20% of total U.S. crop production, with about 52% of this acreage in Texas, Nebraska, and California. Currently, electricity and natural gas supply about 85% of the irrigation needs.

The energy consumed for irrigation of crops is small in terms of national use (about 0.3%), but nevertheless plays an important economic role in the agricultural economic sector, particularly in arid regions such as the Southwest. Because of increases in fuel prices and energy shortages (particularly natural gas) irrigation potentially represents a near-term market for solar thermal electric power systems. Other favorable factors for solar systems include the negative impacts on utilities resulting from generally poor load factors in heavily irrigated areas, the uncertainties in generation cost and expansion planning for irrigation loads that vary considerably from year to year, and the cost of electric transmission and distribution facilities for grid isolated areas.

In addition, the potential availability of used land within farming communities may reduce siting problems, and the irrigation pumps can potentially be operated during the daytime. The non-critical nature of irrigation demands on any given day (resulting from the water storage implicit in soil and plants) reduces the impacts of cloudy days, particularly because cloudy days have reduced irrigation requirements resulting from reduced ground evaporation and plant evapotranspiration.

A wide range of plant configurations would be suitable for solar powered irrigation. However, seasonal variations are inherent in crop irrigation demands and impose stringent requirements on solar plant design. If the solar system is sized to meet peak summer loads, then it is oversized for the remainder of the year, even if excess power is used to supply other crop farming needs (which, except possibly for 1 month of crop drying, are generally much smaller than irrigation needs). This dictates the need for smaller system sizes, in conjunction with backup power (utility or on-site generation) and either seasonal storage in the form of water ponds, or sellback to utility during winter months. Systems with neither seasonal storage nor sellback would have a significant amount of unused energy during the off-season, which would result in much higher costs (double for a typical 6-month season) for the useful solar energy.

Seasonal water storage, however, has several disadvantages including additional capital costs of the storage reservoir, significant evaporation losses, and added area requirements for the reservoir. Sellback of power to the utilities during winter months would have to overcome utility attitudes and pricing structures, particularly in light of the backup power required during summer months and the poor load factors already associated with irrigation. It is possible that solar power generation during peak irrigation demands could reduce the utilities' need for capacity expansion to meet peak loads. Nevertheless, the limited annual operating cycle of irrigation systems, coupled with the high energy demands (which make it difficult to match with other on-farm applications) are a major problem in achieving cost-effectiveness for solar irrigation systems. The possible exception is of year-round, four-season, early-harvest vegetable farms in a few areas of the southwest and California.

Capital investment requirements and the financial resources available to farmers are a major consideration affecting the potential for solar irrigation, even assuming life cycle cost-effectiveness. The high initial investment for solar would have a significant impact on the already low debt-to-asset ratios of many farmers. Moreover, farmers are currently realizing relatively low returns on the value of their assets, making it difficult to obtain the large financing required for solar systems. The higher cash outflows during the initial years of operation could seriously affect the already strained annual operating budget of most farmers, even though the annual costs of conventional fuel would eventually be higher. In addition, the fixed annual costs of solar financing would not have the operating flexibility of fuel costs, which can be reduced or eliminated in the event of crop failure or a bad season. These factors, coupled with the high costs of solar, make it unlikely that irrigation would provide a large market for solar thermal electric power systems unless heavily subsidized by government financing.

Solar irrigation nevertheless has many advantages, as described previously in the beginning of this section. These factors, coupled with the high visibility and good public relations of providing water for irrigation systems, have inspired DOE to fund several irrigation projects, ranging from the 23 kW Mead Experiment in Nebraska, utilizing photovoltaics, to the 150 kW deep wells (122m, 400 ft) in Coolidge, Arizona, utilizing parabolic troughs and an organic Rankine turbine.

f) Mining and Mineral Industries. Mining and mineral industries account for about 2% of total U.S. energy consumption, including a significant amount of self-generated electricity.

Most electricity consumption occurs in oil and gas extraction and in coal mining. The major states are Texas, California, Pennsylvania, Arizona, and West Virginia. Although these states include high insolation areas, it is not expected that mining operations will constitute a promising market for solar thermal electric power systems even for remote operations. One reason is the availability of inexpensive fossil fuel resources because they are being directly mined by the various industries. In addition, the amount of energy that solar electric systems could displace is quite small relative to the fossil fuel energy available directly from on-site mining operations. (This may not be true for solar thermal systems application in enhanced oil recovery which will be studied by JPL in FY1980.) In addition, mining industries generally require portability for on-site generation equipment so that it can be transported to new locations when local ore deposits are exhausted. Such a requirement makes solar systems in the 1-10 MWe size range impractical. Finally, the mineral industries generally expect an extremely fast payback (2-3 years) for their investments, reflecting the unreliable and transient nature of mining operations. This is not compatible with the long-term financial commitments inherent in solar power systems. It should be noted that these limitations apply mainly to fossil fuel mining operations. Non-fuel operations having large, permanent mine-mouth processing plants may be attractive applications.

In summary, the data base development tasks of the SAI study have been completed. In FY1980, the impact analysis will be accomplished.

3. Workshop for Potential Users of Small Solar Thermal Power Systems

A Workshop for Potential Military and Civil Users of Small Solar Thermal Electric Power Technologies was held September 11-14, 1979, at the BDM Corporation in McLean, Virginia. Major addresses were made by Martin Adams, Deputy Program Director for Solar, Geothermal, Electric and Storage Systems, U.S. Department of Energy; George Marienthal, Deputy Assistant Secretary of Defense for Energy, Environment and Safety; and Senator Pete V. Domenici (R, New Mexico). There were 65 attendees representing the military, industry, JPL, and state and federal government.

The purpose of the workshop was to bring together potential users, system developers and decision makers involved in developing solar thermal power technologies to meet military and related civil power requirements.

The objectives were to: 1) examine the economics of military and related civil near-term applications for solar thermal power; 2) determine what institutional implementation is prerequisite for effective military and commercial application of solar thermal electric power technologies; and 3) define military and related civil applications which can be met by small solar thermal electric power technologies.

a. Military Applications. Five military applications were identified:

(1) Tactical

(2) Theatre

(3) Remote

(4) Emergency

(5) Facilities and Installations.

1) Tactical. Tactical systems are mobile electric systems in the 0.5 to 750 kW range assigned to troop units at the division level and below. Critical requirements are:

(a) Size range: .025-.042m^3/kW (0.9-1.5 ft^3/kW).

(b) Weight: 8.16-11.34 kg/kW (18-25 lb/kW).

(c) Emissions (non-detectable noise at 100m, minimum possible infrared emissions, and camouflageable for low visible spectrum emissions).

(d) Hardness, operate after 305mm (12 in drop) and 45 minute vibration at 7-500Hz (7-500 cycles) per second).

(e) Start time: 15 minutes under all weather conditions.

(f) RAM (reliability, availability, maintainability, 95% reliability over 24 hours, 97% combat ready availability, 600 hours mean time between overhaul, 250 hours between scheduled maintenance).

(g) Fuel types (multifuel).

(h) Fuel supply: .59-1.27kg (1.3-2.8 lb/kWh).

(i) Mobility (moved on a daily or weekly basis).

Tactical systems have the most stringent operational requirements of any of the five application areas. The general consensus of the workshop was that the use of solar energy systems in tactical applications would therefore be limited to garrison and special peacetime applications.

The military inventory of heat engine-generator sets (gen-sets) in the 15-750 kW size range is approximately 650 MW. The annual replacement rate is 80 MW. BDM estimated that up to 16 MW/yr of small (15 kW) gen-set capacity could cost-effectively utilize a standard solarization kit consisting of hybrid receiver and a portable fold-out concentrator. Cost goals for PFDR systems were calculated by BDM to be 120-210 mills/kWh, depending on application size and location of deployment. This corresponds to $2700/kW, assuming 1825 hours per year of direct operation from solar radiation.

Colonel A. G. Rowe, U.S. Army, Program Manager, Mobile Electric Power, and other workshop participants discussed the commonality of the small multi-fuel gen-set in the PFDR system and the advanced tactical military gen-set which the Army has a requirement to develop. It was noted that significant cost savings to the Departments of Defense and Energy could be realized through a common development effort and higher volume production of a standard engine-generator.

Civil applications were found to have less severe but similar requirements. A hybrid system with a solar option has similar potential for retailers and renters of portable power systems (i.e., the basic heat engine could meet most power requirements) while solar kits could realistically be utilized for some substantial fraction of applications.

2) Theatre. Theatre systems are transportable prime power systems greater than 750 kW assigned to engineer units to provide power at temporary facilities. Critical requirements are:

(a) Size: .064-.168m^3/kW (2.3-6 ft^3/kW).

(b) Weight: 26.3-59kg/kW (58-130 lb/kW).

(c) RAM (10,000 hours mean time between overhaul).

(d) Fuel supply: .285/day (.075-.084 gallons/day).

(e) Fuel type: multiple fuel preferred but not required.

(f) Duty cycle: 24 hours/day during deployment; 20-35% deployed in peacetime

(g) Mobility: transportable by sea or air to a theatre of operations or emergency.

BDM determined that the total military theatre inventory was 340 MW and the annual replacement rate was 17 MW/yr of which up to 7 MW/yr may be met with PFDR systems. Cost goals were calculated to be 120 mills/kWh and $2700/kW at 1825 hr/yr of operation direct from solar radiation. The minimum time of deployment to a theatre for cost effective operation was found to be 120 days. This "logistics payback period" was based on a 750 kW system, which would occupy a volume equivalent to that of 600 hours of fuel supply.

3) Remote. Remote systems are used at permanent installations which generate their own power. They are typically small (15-1000 kW) and geographically isolated. Critical requirements are:

(a) RAM (maximum of 53 minutes unscheduled down-time/yr).

(b) Hardness (protection from harsh environments).

(c) Duty cycle (usually continuous, occasional peaks due to operational stimulus).

BDM determined that the inventory consisted of 220 MW the annual procurement rate is 11 MW/yr, of which up to 10 MW could be met with PFDR systems. Plant requirements dictate hybrid systems. Cost goals were found to be 125-220 mills/kWh corresponding to $2700/kW at 1825 hours/year. Of course, as the number of hours of operation increase, the breakeven cost increases.

4) Emergency. Emergency systems are fixed or portable power systems which function when prime power fails. These are primarily back-up units, providing full duplicate capacity, and operate very few hours per year. Critical requirements are:

(a) Duty cycle (tested once per week plus sporadic, short operations).

(b) Start time (immediate response required).

The duty cycle is such that PFDR systems were not considered as appropriate for this application.

5) Facilities and Installations. All non-remote U.S. military installations purchase power. Cost is the critical requirement. BDM calculated cost goals to be approximately 86-90 mills/kWh. If DOD were to require energy self-sufficiency for mission-critical facilities, the annual procurement rate would be about 30 MW/yr.

The general consensus of the workshop regarding PFDR technology implementation was that a program similar to the Federal Photovoltaic Utilization Program (FPUP) should be initiated. A 10-12 year development time frame would then be assured and, in this way, the procurement of solar thermal technology may occur in less than the usual 20 year time period. This would allow DOD engineers and scientists to collect data on the operation and maintenance of systems necessary to establish their suitability to meet DOD requirements.

In addition to these applications, terrestrial energy for the MX missile facilities is also being analyzed by JPL. In FY1980 the Air Force may award 25 to 30 conceptual design contracts. About half of these will be chosen for FY1981 demonstrations. A decision will be made in FY1982 as to which systems will be procured for 1986 in-service operating capability. Up to 5,000 shelters will require 20 kW each, and a support base for 35,000 personnel will require 45 MW.

b. Civilian Applications. Two civilian applications have been identified within the framework of the Burns and McDonnell and SAI contracts: 1) isolated small community utilities; and 2) isolated industrial loads, respectively.

1) Isolated Small Utilities. Burns and McDonnell studied electrically isolated small utilities in the 0.5 - 500 MW range in Alaska and Hawaii (grouped together by FERC region) and projected load growth in 1990 to be 138 MW/yr for the region. While this is not a large market, it is significant. Due to high electricity costs and excellent insolation (for Hawaii) the index of economic feasibility for Hawaii, calculated by SAI, was the highest of all the states in the U.S. (Conversations with representatives of utilities on Pacific Islands reveal that fuel costs early in 1979 were $18.50/barrel and diesel generator installed costs were $600/kWe. With appropriate economic assumptions, levelized BBEC was calculated to be 120 mills/kWhr in the first quarter of 1979.) It is expected that isolated utilities on U.S. islands will constitute an important, early market for PFDR systems. The DOE Division of Central Solar Technology estimates that total load growth in 1990 in Hawaii will be 110 MW/yr (Reference 5-9). Because reserve margins will be low, possibly 15%, PFDR systems installed in this application would probably be hybrid systems.

2) Isolated Industrial Loads. SAI has identified grain mill products (SIC 204) in Hawaii as an industry/state combination application with high profitability (Table 5-11). Grain mill products were one of six industries in Table 5-11 which also could be included among the industries with the largest nationwide energy displacement (Table 5-12). In FY1980, JPL will be studying isolated industrial loads from both a thermal and electrical perspective. Among those to be studied will be grain mill products and enhanced oil recovery.

C. SUPPLY ANALYSIS AND INDUSTRIAL DEVELOPMENT

1. Industrial Engineering and Costing of PFDR Components and Production Facilities

Arthur D. Little, Incorporated, is conducting a study to investigate the means by which industry could produce and install PFDR systems at minimum cost and to characterize the factors, issues and problems inherent in the transfer of this technology to the industrial sector. The approach is to analyze one PFDR system concept in depth in order to obtain definitive information on the overall process of industrialization and the potential for cost reductions in the production and installation of a typical PFDR system.

A preliminary draft report, "Comparative Industrialization Needs of Three Types of Solar Engines," was prepared (Reference 5-10). The engines evaluated were Steam Rankine, Open Brayton Cycle and Free Piston Stirling. The report concluded that the engine options will require differing amounts of new capital equipment for their fabrication.

The reciprocating steam engines can be made today with in-place capacity in other industries while the Stirling engine may require specialized facilities both for subassembly manufacture and assembly. The analysis indicates that it is possible for some types of these engines to be made with capacity already in place, should that be the desired approach in order to minimize investment risk. It is assumed that for low production of 1000 units/year (which is only 4 units/day), the work will, in large part, be done by job shop subcontractors. If component manufacturing capability is in question, it is assumed that some combination of facilities, second shifts, job shops, etc., could be instituted to cover the production of these components.

For production quantities of 10,00C units/yr, the report estimates that the component fabrication capital requirements for the steam Rankine engine are $3,000,000 and for the Stirling Engine, $6,000,000. For production quantities of 100,000 units/yr the capital costs are $7,000,000 for the steam Rankine engine and $18,000,000 for the Stirling engine. Facility and capital requirements for component fabrication of the five engines are summarized in Tables 5-13 and 5-14, respectively.

A preliminary draft report, "Process Analysis for Manufacturing Cellular Glass for the JPL Conceptual Design Concentrating Collector," was prepared. The report analyzed in detail all of the items required to produce cellular glass such as raw materials, processes and costs. The report estimates that the fixed capital investment for a "Foamglass" (as produced by Pittsburgh Corning Corporation) panel production facility capable of making 50,000 units/year is $22.7 million. A facility capable of producing 500,000 units/yr would cost $108 million.

2. Industrial Engineering and Costing of Brayton and Stirling Engines

A thorough cost analysis of the individual parts of the subject engines in production quantities of 100,000 units/yr was accomplished by JPL and the results are shown in Table 5-15.

Estimated costs for production quantities of 1,000, 25,000, and 400,000 units/yr will be completed in FY1980.

The major differences between the JPL figure in Table 5-15 and the ADL figures in Table 5-14 arise from differences in assumptions regarding infrastructure: ADL assumed the existing manufacturing infrastructure could support 100,000/yr while JPL assumed new manufacturing capabilities would be required.

Table 5-13. Component Fabrication Facility Requirements

Solar Engine Production, Units/Year			
Engine	1,000	10,000	100,000
Foster Miller Steam Rankine Engine	Assembly Only	Assembly Only	Assembly Only
Jay Carter Steam Rankine Engine	Assembly Only	Assembly Only	Assembly Only
Sundstrand Steam Rankine Engine	Assembly Only	Precision Casting & Light Machinery	Automated precision costing and machinery
AiResearch Brayton Engine	Assembly Only	Assembly Only	Assembly Only
MTI Stirling Engine	Clean Room Assembly Only	Precision Casting with exotic metals, provision machining of large diameter	Automated precision w/exotic metals, automated precision machining of large diameter

Table 5-14. Component Fabrication Capital Requirements

Solar Engine Production, Units/Year			
Engine	1,000	10,000	100,000
Foster Miller Steam Rankine Engine	N/A	N/A	N/A
Jay Carter Steam Rankine Engine	N/A	N/A	N/A
Sundstrand Steam Rankine Engine	N/A	$3,000,000	$7,000,000
AiResearch Brayton Engine	N/A	N/A	N/A
MTI Stirling Engine	N/A	$6,000,000	$18,000,000

Table 5-15. Results of Cost Analysis of Brayton and Stirling Engines (100,000 units/year)

	Brayton (20kW)	Stirling (30kW)
Raw material and/or purchased parts	$1318	$1056
Labor hours	12.53	12.12
Labor cost @ $8.00/hr	$125	$121
Miscellaneous		$30
Total engine cost per unit (Labor & Material)	$1443	$1207
Capital Equipment	$20,775,575	$70,565,000
Tooling	$ 9,081,800	$22,229,000
Total Capital Equipment & Tooling	$29,857,375	$92,794,000

D. DEMAND ANALYSIS AND MARKET DEVELOPMENT

The technological developments and cost estimates described in previous sections include a large amount of uncertainty. This section turns from supply concerns to the problems of demand and market estimation. For these issues, the uncertainty involved is greater. Willingness of consumers to purchase or use solar thermal devices depends upon a large number of regulatory, institutional, and financial factors. These factors were explored in a study by RPA (Reference 5-11), which is summarized in the next section.

By making a number of assumptions about these technical, social, and economic factors, it may be possible to arrive at a rough estimate of future demand for solar thermal energy. Subsection 2 outlines the results of existing market penetration models: their strengths and weaknesses are discussed. Given the problems that many models have, the PFTEA program has developed some alternative tools. The results of a contract on market penetration analysis are developed in Subsection 3, and Subsection 4 describes a model developed at JPL to handle investment analyses. The models outlined in these two subsections attempt to clarify the interactions and uncertainties within the factors that affect market demand for solar thermal systems. This will be a first step toward understanding how well the technologies being developed will compete in the market for energy.

I. Barriers and Incentives to Commercialization of Small Solar Thermal Power Systems

The commercialization of small solar thermal electric power systems will not be an automatic or inevitable process following research and development. Technological and institutional barriers will affect the innovation of small power systems. The timely success of small power systems will require a thorough understanding of these barriers and appropriate incentives.

A broad perspective of the process leading to the eventual market penetration of small systems was undertaken by Resource Planning Associates (RPA) to provide a long-range overview of the major problem areas facing these systems. The overview (Reference 5-11) was to be used to develop strategies for accelerating the development, transfer and widespread adoption of the technology.

This contract provided early insight into issues facing small power systems in the future and guidelines to project management on the best strategy for conducting the RD&D process in a way that would maximize the benefits and minimize the constraints to successful industrialization and commercialization of these systems. The issues facing small power systems will be discussed first in terms of barriers and incentives. Then the guidelines to project management will be presented.

RPA found that the major barriers to near-term commercialization result from the following perceptions:

(1) Lack of proven technical feasibility: potential users wish to see several years of reliable system operation in a climatic region and application similar to their own before they will buy the systems. They are particularly concerned about the effects of daily and seasonal solar and weather patterns on the supply of energy.

(2) Lack of proven economic feasibility: potential users stress that the costs of energy supplied by the systems must be shown to be similar to or lower than the many alternatives before significant markets will develop. The non-economic benefits of using small solar power systems will generally not affect the decision until the relative life-cycle costs are very close to that of other systems.

(3) Lack of a viable manufacturing and distribution infrastructure: potential manufacturers are unwilling to invest in the mass production machinery necessary to lower the small solar power system costs to competitive levels until the substantial uncertainties about markets, technologies, and federal policies are resolved.

Even after the small power systems are technically proven, become economical in some applications, and have an established manufacturing infrastructure, barriers to their widespread use in long-term markets will include:

(a) Non-competitive within the conventional utility grid: grid-connected small generating units are being used less frequently, so the small solar power units must be competitive within a large utility grid to provide significant energy savings.

(b) Doubts about specific local system requirements: problems caused by insolation variation, land, manpower, and health and safety requirements, which must be evaluated on a site-by-site basis, may reduce market penetration.

(c) Negative economic factors: foreign financing and development priorities, utility charges for supplemental and buyback rates, and military purchasing and budgeting procedures may reduce the potential markets for small solar power systems.

Short-term and long-term barriers and incentives are summarized in Tables 5-16 and 5-17.

The major types of economic incentives that directly lower the costs of the solar systems are financing incentives and tax incentives. Financing incentives aim at reducing the initial capital investment in the solar power system and at reducing the cost of capital by using direct capital subsidies and credit subsidies. Direct capital subsidies for the initial investment, which would finance a part of all of the solar power system purchase, were the most popular option among the potential users and manufacturers interviewed. Subsidies appear particularly effective for tax-exempt sectors such as municipal utilities. In addition, in foreign applications, direct grants are considered to be the only method that will be effective in encouraging foreign purchases of the small solar power systems. These foreign countries typically have severe balance-of-payment problems, a lack of investment capital, and other development priorities (i.e., food, health, and education) that rank higher than electrification.

Credit subsidies are aimed at making capital available to borrowers who would otherwise not qualify, reducing the cost of capital needed for investing in the systems. These usually take the form of direct government loans (usually at low interest) or government guarantees of interest or principal. RPA interviewees felt that these incentives would be significantly less effective than direct cash grants, particularly during the early years of commercialization when the systems are far from being economically competitive. In addition, the problems of inadequate capital availability at which they are directed are not felt to be major. Private and municipal utilities and industrial organizations generally have adequate access to capital markets to finance the solar system investments. Rural electric cooperatives have Rural Electrification Administration (REA) loans for the entire load requirement at low interest rates. Some foreign countries may have short-term financing problems, but normally the World Bank and other agencies will eventually finance such projects at subsidized or market interest rates if the technology costs are competitive.

Tax incentives are only effective in the private-sector markets, such as private utilities and industrial and agricultural applications. The major types of tax incentives that may affect a decision to invest in solar thermal power systems include: tax credits, in which a portion of the initial investment is deducted from the recipient's tax bill; accelerated depreciation allowances, which increase the net cash flow during the early years; and tax-free bond financing, which lowers the effective capital costs. These incentives can be translated into an equivalent cash subsidy, based on the recipient's tax situation and discount rate. Previous surveys and our interviews have in fact revealed no overall preference among users and manufacturers between tax and cash subsidies having equivalent net present values.

Based on a survey of the literature and interviews with potential manufacturers and users of the solar technology, the RPA report revealed specific problems with the PFTEA program as perceived by the private sector. A 1-10 MWe system is a difficult size to market: too small for some (most utilities including small ones now prefer large units operated through a consortium); and too large for others (a 100 kWe system is large for many small users).

The studies also confirmed that a large experiment (10 MWe) initially was probably unwise and a series of small experiments would be more beneficial.

The study pointed to the lack of information and knowledge in the private sector on solar energy in general, but less so on small power systems. Public information activities were undertaken as a result.

Five broad guidelines were suggested for the PFTEA program:

1. Identify Major Market and Market Requirements. A good technology without a market is doomed to failure. Due to the newness of the technology, a continuous assessment of markets is required to:

(a) Identify the major potential market sector requirements.

(b) Identify important factors affecting the sector market demand.

(c) Inform private manufacturers of results.

(d) Develop Federal strategies to stimulate the development and marketing of the technology.

2. Develop Systems that Meet Market Requirements. Market conditions and requirements change rapidly. Realistic assessment of the markets and small power system technology must be made to assure a continuing and interim match during the technology development itself, i.e., use of hybrid systems instead of dedicated solar.

Table 5-16. Summary of Short-Term Barriers and Incentives

Barrier	Implications for JPL Program	Suggested Incentives
No Proof of Technical Performance		
• Confusion over system configurations	• Delay in market acceptance	• Narrow system choices before major market development efforts
• Doubts about dependability	• Perception of unreliable service or unreasonable system costs	• Conduct demonstration programs • Develop hybrid systems • Develop utility planning models • Organize users consulting group
Lack of Proof of Economic Performance		
• High near-term systems costs	• Subsidies may be necessary to stimulate early markets - Financing subsidies - Tax subsidies	• Review fossil fuel pricing - Remove existing subsidies - Use world market prices - Incorporate social costs
	• Noneconomic benefits are not reflected in prices of other energy sources	• Evaluate impacts of new pollution regulations
Lack of Manufacturing Infrastructure		
• No viable near-term markets	• Manufacturers will not adopt and develop technologies on their own	• Organize a manufacturers consulting group
• Uncertainty about federal roles	• Manufacturers are reluctant to participate in federal programs	• Perform market analyses
- Patent policies - Research policies - Cost of participating in federal programs	• Development and marketing of economically competitive systems will be delayed	• Define patent policies • Finance federal purchases • Provide testing facilities

SOURCE: Resource Planning Associates, Inc.

Table 5-17. Summary of Long-Term Barriers and Incentives

Barrier	Implications for JPL Program	Suggested Actions
Expansion of Conventional Power Grids	• Remote and small generating unit applications may level off or decline	• Market assessments - Establish long-term cost goals - Define market sectors - Develop utility planning models
System Performance and Requirements		
• Insolation variation	• Systems may be underused	• Evaluate backup and hybrid systems • Develop utility planning models and interfaces
• Land requirements	• Land may be available	• Consult land use planning officials
• Manpower requirements	• Systems may not be purchased or properly maintained	• Evaluate costs of alternative ownership models • Develop training courses for operation and maintenance of systems
• Health and safety effects	• Regulations may reduce market potential	• Evaluate environmental impacts of alternative systems
Economic and Financing Factors		
• Foreign financing problems and development priorities	• Export potential is reduced	• Involve development banks • Investigate local manufacture
• Supplemental and payback rates	• High standby rates may make system uneconomical	• Develop utility planning models • Relate cogeneration system energy pricing techniques to small solar power systems
• Military purchasing and budgeting procedures	• Military may not buy the systems even if they are economical	• Investigate alternative ownership options

SOURCE: Resource Planning Associates, Inc.

3. Convince Manufacturers to Produce Systems. Stimulate manufacturer interest by increasing the number of subsystem development contracts, and increase manufacturer participation in RD&D decisions through use of advisory groups, industry review of R&D results and general industry participation in the program. The more initiative given to industry, the greater their support and response to manufacture when conditions are right.

4. Convince Users to Purchase and Operate the Systems. Involve users early in the technology development process. The users will have a greater propensity to plan earlier for future use of the technology.

5. Create Federal Policies to Support and Accelerate Market Development. Until markets for the technology develop, the government must support those marketing and development activities which would not otherwise be undertaken by the private sector. Activities should include: assessment of social costs and benefits of small power systems; coordination of the PFTEA program with other related solar programs and offices; evaluation of options for accelerating industrialization; and maintenance of consistent federal policies and procedures.

These recommendations have been implemented to the extent possible by JPL and will aid market penetration by solar thermal systems. It is also necessary to be able to estimate the rate of market penetration. This issue is the topic of the next three subsections.

2. Existing Market Penetration Models

R&D funding decisions, which can be crucial to a solar energy technology's development, are usually based on an evaluation of its market potential in comparison with other conventional and solar energy technologies. Therefore, it is important to understand the nature of solar energy market penetration models in use now.

The mathematical structure of solar energy market penetration models gives the impression of mathematical rigor and accuracy. Although the mathematical structure of several models has a rigorous foundation, implicit assumptions underlying this foundation can severely restrict their applicability. Further, some solar energy market penetration models attempt to emulate the rigorously developed models without providing a reasonable foundation. The resulting misuse of market penetration methodology is not science but number mysticism.

Solar energy market penetration models can be considered to be composed of six distinct components as shown in Figure 5-3. Of these six components, the analyses of the actual market penetration by a solar energy technology is the weakest component. Therefore, JPL's analyses concentrated on this component. The market penetration analyses used in solar energy market penetration models come divided into two groups: 1) those based on an elementary diffusion process; and 2) those based on ad hoc market penetration analyses.

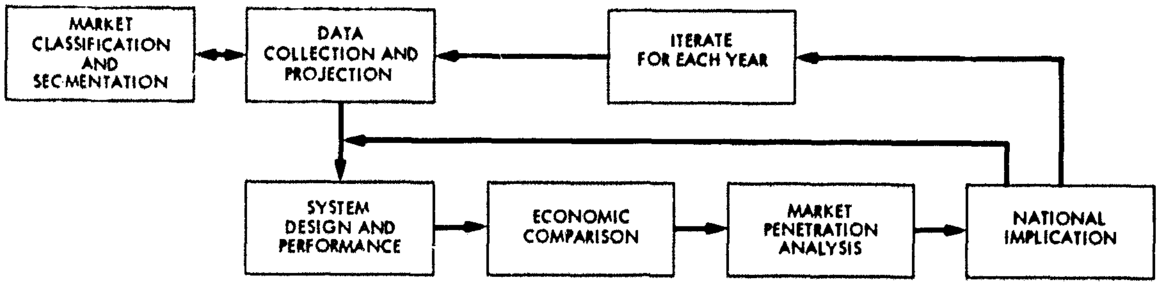


Figure 5-3. Market Penetration Model Components

It was the general conclusion of JPL's analysis that, in their present form, solar energy market penetration models are not science but number mysticism. The primary defect is that market penetration analyses are based on a very simple behavioral theory. Thus, the structure of the models themselves cannot be tested. Because of this lack of basis in behavioral theory, these analyses are limited to explaining behavior not predicting it. Finally, the one claim to legitimacy of these analyses is a foundation based on well developed models of diffusion processes. However, the applicability of diffusion models is limited by implicit assumptions. The more prominent and distinct solar energy market penetration models abandon this final claim to legitimacy by resorting to ad hoc procedures without rigorous foundations.

Despite the limitations of current solar energy market penetration models, JPL is not proposing their use be abandoned. Rather, caution is recommended until reasonable models can be developed. In order to be able to place reasonable confidence in the result of solar energy market penetration models, a market penetration analysis based on behavioral relationships must be developed. Admittedly, such a model will be complex and hence expensive to develop. Also, it could not be developed, tested and available for some time. However, such a model is a prerequisite for solar energy market penetration modeling to leave the realm of numerology.

3. Market Penetration Analysis

A chief shortcoming of existing market penetration analysis is its limited use of behavioral relationships. One of the current activities of the PFTEA program has been to incorporate behavioral relationships into a market model. General Electric, Space Division, was awarded the contract, "The Effects of Systems Factors on the Economics of and Demand for Small Solar Thermal Power Systems." The goals of the study are to estimate the rate of market penetration for solar thermal technology in selected market sectors as a function of time, solar power system factors, and market/economic considerations, and to develop cost-effective strategies for accelerating the rate of market penetration in the more promising near-term markets. The study program consists of three major tasks:

Market Analysis -- Task 1

Market Penetration Sensitivity Analysis -- Task 2

Commercialization Strategy Formulation and Evaluation -- Task 3

Task 1 was accomplished by using a survey, taking advantage of General Electric's extensive experience in similar studies for new technology product concepts and of the numerous contacts General Electric enjoys through its Power Systems Sales Operation, Apparatus and Distribution Sales Division, Industrial Sales Division, and International Sales Division. The objective of the survey activities was to identify and measure attitudes, reactions, and intentions of prospective users of solar thermal technology and to size the potential market for solar thermal small power systems. The market survey implementation process involved identifying potential users, segmenting the market, determining proper sample sizes for valid statistical analysis, and developing survey materials and survey methods. The survey methods included personal interviews by the Industrial Sales Division and by Electric Utility Sales Division Field Sales Engineers, personal and telephone interviews by project personnel, and a mail survey.

For the mail survey, questionnaires and background materials on solar thermal technology were sent to 200 industrial firms and 150 utilities. Included in the sample were representatives from all states, all major SIC codes, and all utility ownership classes.

The questionnaires were structured to determine application-user specific data on land costs, present and projected energy prices, conventional power generation equipment cost projections, estimates of future demand, criteria utilized to evaluate alternative investments, and the social, political, and institutional factors impacting the adoption of solar thermal technology.

Task 2 involves the development of a market penetration computer model for solar thermal small power systems. This model will be used to perform market penetration sensitivity analyses. The basic structure and logic of the demand model has been finalized. The market analysis survey work and the demand model development have been coordinated so as to insure that the output of the market survey is consistent with the input requirements of the demand model. In addition, other sources of demand model input, such as historical data on related product introductions, have been identified.

Preliminary results of the mail survey are as follows:

(1) The largest projected increase over the next 10 years in industrial electrical requirements is expected to occur in the Southwestern United States.

(2) Industries expect the availability of oil and gas in 1990 to range from partially to severely limited.

(3) The predominant criteria listed by industrial respondents as impacting the solar system capital investment decision were: initial price/kW; the availability of loan guarantees and other mechanisms to reduce the risk; and the availability and cost of land.

(4) Solar systems were viewed by industrial respondents as valuable insofar as they provide protection against fuel price escalation and fuel curtailment; they provide a means and a justification for repowering of existing plants.

(5) Based on company needs, solar system benefits and limitations, 47% of the industrial respondents and 49% of utility respondents stated that a solar system would be an option that their company would consider in the 1990 time period.

An important reason for the high interest in solar energy expressed by industrial rather than utility companies can be gleaned from an analysis done by GE for JPL of the relative value of the thermal and electrical output of a solar thermal plant. GE found that the value of thermal output is from 2 to 4 times the value of electrical output based on the average price of industrial electricity.

Arriving at this conclusion regarding the relative value of electric and thermal output, GE analyzed steam Rankine systems with supply conditions of 538°C (1000°F), 900 PSIA with 6.35mmHg (.25 in Hg) exhaust pressure for electric only operation and 100 PSIA exhaust for cogeneration of process steam. Based on assumed current values of 3¢/kWh for electricity and $3/million Btu for fuel (3:1 price ratio) and energy price escalation rates of 2% over inflation, specific findings were as follows:

(1) Collector field (concentrator, receiver, thermal transport, and controls) value, as a thermal energy supplier, is $18/m^2 ($18/ft^2 based on 46,500m^2 (500,000ft^2) delivering 29.31MW (100 million Btu/hr, peak) at an annual capacity factor of 0.3.

(2) Adding cogeneration to the above field results in a breakeven power conversion (PCS) value of 310 $/kW $18/M^2 (at 18/ft^2 field cost). Current estimates of incremental PCS cost for conventional cogenerating steam turbine systems are in the 350 $/kW range.

(3) Fossil firing of the cogeneration system during periods of low insolation and at night raises the PCS breakeven value directly with capacity factor. At CF=.9 breakeven PCS value is .9/.3 (310) or 930 $/kW.

(4) For the electric-only systems, 310 $/kW PCS value could be achieved only at very low solar collector field costs $8/m^2 ($0.8/ft^2).

(5) Fossil firing of the electric-only system did not enhance the PCS value, since the incremental cost of fossil firing was higher than the purchased electricity cost for all turbine efficiencies.

(6) PCS breakeven cost in $/kW is independent of turbine efficiency. High efficiency turbines showed no more value on a $/kW basis than lower efficiency units, and could actually have a reduced $/kW value if the high efficiency is obtained at the expense of non-recoverable losses such as gearbox and generator inefficiencies.

GE concluded that cogenerating solar power systems offer substantial advantages over pure solar electric systems, including:

(1) Greatly enhanced economics leading to earlier commercialization potential.

(2) Ability to economically fossil fire the systems during periods of low insolation and at night, to achieve high capacity factors and resultant higher system value.

(3) No need for high performance, high cost power conversion systems. Lower efficiency, technologically mature power conversion systems can be advantageously used with no loss in system savings. More important than high efficiency are the capabilities to fossil fire the PCS and efficiently utilize waste energy. This point is summarized in Figure 5-4.

During FY 1980, JPL will be concentrating on industrial thermal and combined thermal and electric applications.

4. The Alternative Power System Economic Analysis Model

The Alternative Power System Economic Analysis Model was developed by JPL with the help of Energy Services Consulting Corporation as an interactive computer model which can be applied in three ways:

(1) The model projects the annual, after-tax costs of capital investment in various conventional and non-conventional energy technologies for each year in the investment time horizon. (In total, these costs are termed "lifecycle costs".)

(2) The model serves as an investment analysis tool.

(3) The model serves as a policy analysis tool, to investigate the effects of policies on specific investors.

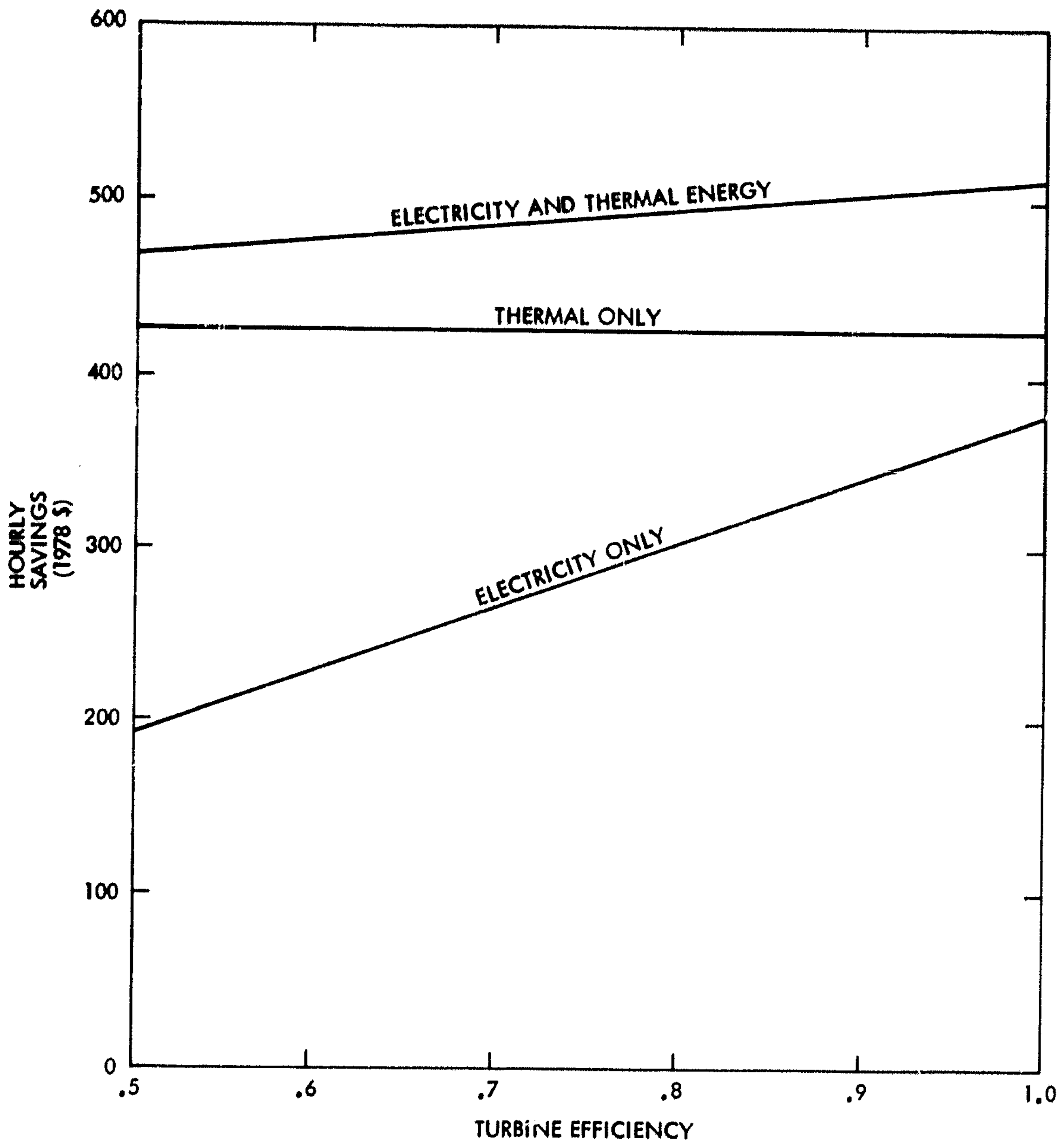


Figure 5-4. Hourly Savings in Various Modes

a. Cash Flow Model. The basic model premise is that the evaluation of investment alternatives should be based upon a "lifecycle cost" perspective. The relative worth of the various investment alternatives in conventional and non-conventional energy technologies is particularly difficult to judge when the various cost elements associated with the investment alternatives change at varying rates over the time horizon of interest. For example, an investment in a fossil-fueled system could have low initial costs, yet be extremely expensive in the long run if there were a rapid escalation in the cost of the fuel necessary to operate that system. The needed "lifecycle cost" perspective is obtained through use of a cash flow methodology. In a cash flow model, detailed cash flow information is projected for each investment alternative for each year in the investment time horizon. Within the APSEAM model, this annual cash flow information is aggregated to produce various measures of the lifecycle costs of each of the investment alternatives. The model can be used to quantify the effects of variations in technology cost (capital costs and operations and maintenance costs), general economic conditions, investor-specific financial conditions, the method of financing of the capital investment, the resource (i.e., solar insolation levels), technology performance over time, supply and demand matching, incremental plant start-up, and component replacement scenarios. A flow diagram of the model is shown in Figure 5-5.

b. Investment Analysis Tool. The Model also functions as an investment analysis tool. As such, it seeks to answer the question, "What is the relative worth of different investment alternatives to a specific investor?" This question is much broader than the question, "What are the life cycle costs of different investment alternatives?", for it takes into account a specific investor's financial environment (for example, his ability to absorb those costs, his cost of capital, etc.) as well as the specific investment alternatives available to that investor. As applied to energy system investments, the investment alternatives can include:

(1) Capital investments in various energy technologies (conventional or non-conventional) to meet specified energy requirements (electrical and/or thermal).

(2) Purchase of all energy needs (electrical energy from the utility grid, thermal energy from combustion of purchased fossil fuel in fossil-fired boilers).

(3) Cessation of those activities which create energy needs -- investment in some alternative with no creative demands.

The model aggregates the projected cash flow information to produce an investor-specific "investment profile" for each investment alternative, a set of figures of merit which enable that investor to make an informed decision.

c. Policy Analysis Tool. In addition to functioning as a lifecycle cost model and as an investment analysis tool, the model also functions as a policy analysis tool. As such, it seeks to answer the question, "What is the impact of various governmental actions on the perception of specific private sector investors concerning the relative worth of various investment alternatives?"

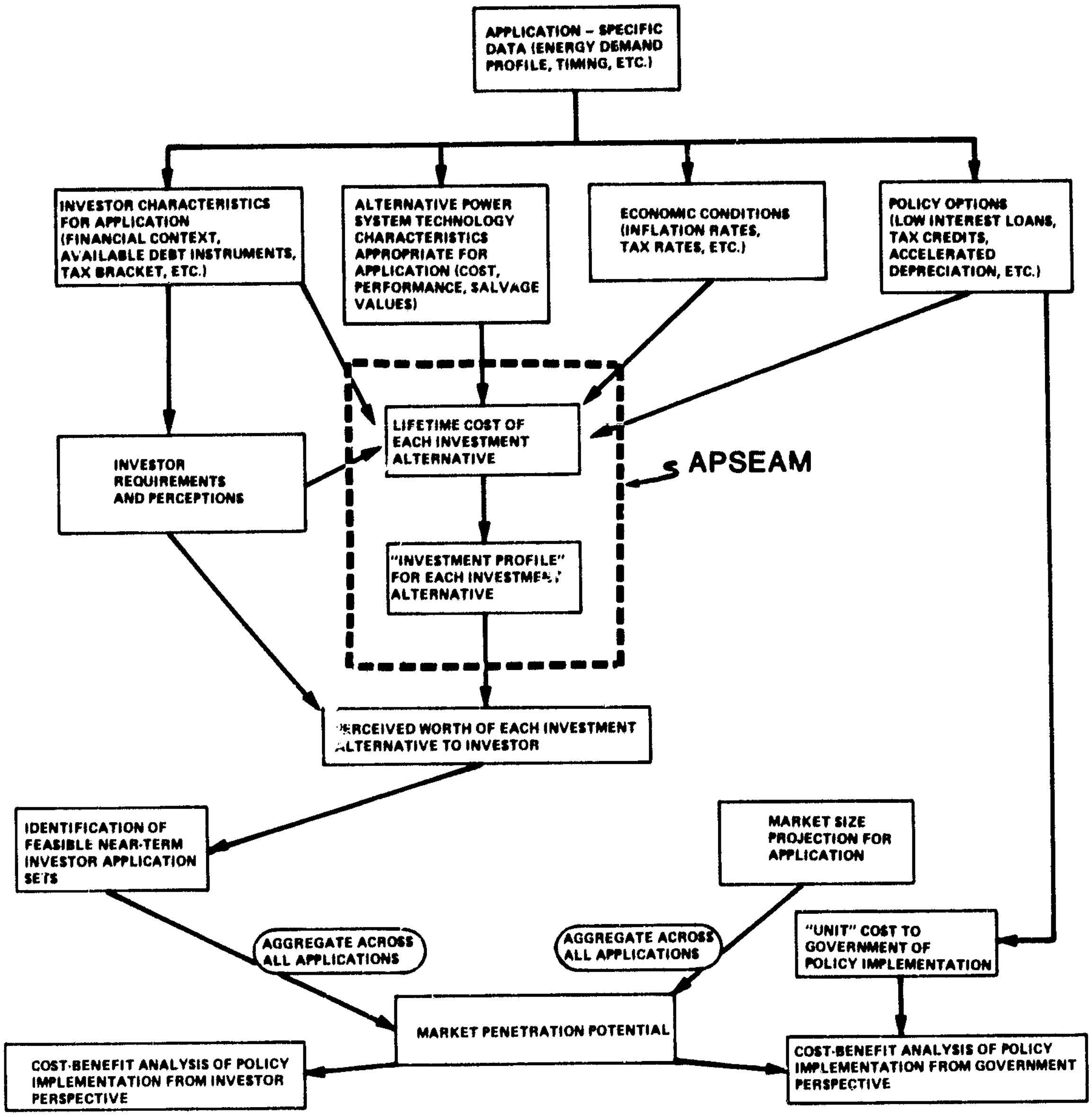


Figure 5-5. Alternative Power System Economic Analysis Model

The model enables the impact of specific state and federal actions on the perception of specific private sector investors concerning the economic viability of the various investment alternatives to be quantified. For example, the model can quantify the implications of utilizing various methods of depreciation accounting, various provisions for tax credits, various rules concerning the carry-back and carry-forward of tax credits, and/or operating losses. Insofar as the model is a year-specific cash flow model, these governmental actions can be year-specific. Thus, time-phased incentive strategies can be evaluated.

This is an important model feature insofar as the government will likely use time-based strategies to encourage the use of alternative, non-conventional energy systems large incentives in the near-term, with a tapering off of the incentive size as the desired energy technologies penetrate the marketplace by natural mechanisms.

d. Ownership Options. The specific investor types which can be treated include private utilities, municipal utilities, corporations, and individuals. In addition, various types of joint ventures and leasing arrangements can be evaluated.

e. Model Value: Use of Outputs. As an investment analysis tool, the model produces investor-application-specific projections of how specific investors are likely to perceive the worth of a particular investment alternative relative to others. This information, coupled with the market size potential which those specific investors represent, provides the basis for meaningful estimates of market penetration. Hence, model-derived information can serve as valuable input to macro-market penetration models. In like manner, as a policy analysis tool, the model specifies what is the impact of specific policy decisions on the perceptions of specific investors in specific applications concerning the relative worth of various investment alternatives. Aggregated, this information enables the effects of alternative governmental policies and incentive strategies on the market penetration potential of various energy technologies to be quantified. In this way, the costs and the expected benefits associated with alternative policy options can be related and optimal trade-offs identified, both from the standpoint of the government and of individual investors. The flow diagram shown in Figure 5-5 specifies the various categories of inputs to the model and how model output can serve an essential function in understanding the role of various energy technologies in the energy marketplace of the future.

E. SUMMARY

The Applications Analysis and Development Task has developed a strategy which is summarized in Figure 5-6.

Figure 5-6 has four important messages:

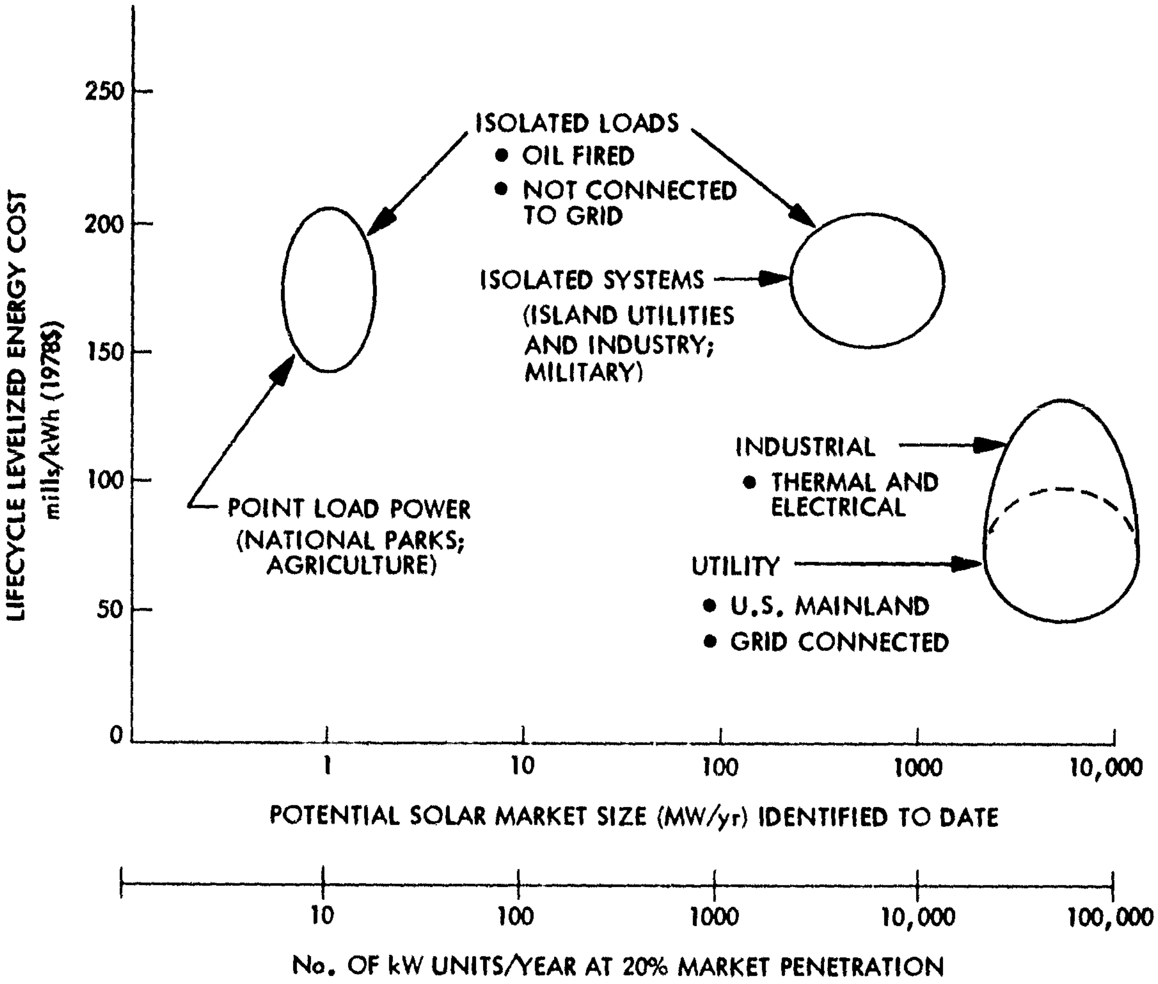


Figure 5-6. Partial Sampling of Energy Cost and Market Size In Three Application Categories for 1990-2000

(1) Dish collectors may be appropriate for the broadest possible range of applications: 1) isolated, 2) industrial and 3) utility. JPL will develop applications in all three market areas through studies, site visits, and engineering experiments.

(2) The ultimate market for dish collectors is the mainland U.S. utility market. It is the most difficult market to penetrate. However, early deployment of the same dish technology in isolated applications as is appropriate for mainland U.S. utilities will enable production volume to reach 10,000 units per year, a figure which appears to provide sufficient cost reduction for penetration of mainland U.S. utilities.

(3) The value of the energy in isolated applications is very high and is projected to increase due to a dependence on oil. Furthermore, isolated users located in areas with adequate insolation represent a substantial market. Consequently, isolated applications represent an appropriate early market for dispersed solar power plants, and the JPL strategy is to give high priority to these early applications.

(4) Industrial applications (i.e., industrial process heat and combined thermal and electric industrial loads) represent large potential markets and will be studied in depth in FY1980.

In summary, given the present projections for the price of oil, a partial sampling of possible markets indicates that sufficient markets will exist to sustain a parabolic dish industry as soon as mature, commercial systems can be made available. The JPL approach is to prove system feasibility in markets with the highest breakeven cost first in an attempt to generate and sustain production volume. Cost reduction through mass production will then permit penetration of the utility market.

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