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SOLAR THERMAL POWER SYSTEMS

Annual Technical Progress Report FY 1978

Prepared for the **U.S. Department of Energy**
Assistant Secretary for Energy Technology
Office of Solar, Geothermal, Electric and Storage Systems
Division of Central Solar Technology

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Overview

The Department of Energy Solar Thermal Power Systems Program has been funded over the past years as a major part of the national solar energy effort mandated by Congress. Progress has been made toward technical and economic readiness of high-temperature concentrator energy supply systems that was only hoped for, not assured, when the program was begun.

This report provides an accounting of the progress to date. Such an accounting is appropriate in light of the substantial Federal investment. Moreover, careful documentation of plans and activities is essential to increase the effectiveness with which program resources are applied in the future.

Specifically, the ultimate success of the solar thermal program depends on:

- An awareness of the state-of-the-art high-temperature concentrator system technology by potential users and their active involvement in the on-going R&D programs;
- Our ability to bring to bear the full capacity of American industry, universities, and national research centers; and
- A full and accurate understanding of program status, content, and prospects by those whose decisions affect its progress.

Several distinct technology development efforts are moving rapidly from concept definition through an orderly sequence of materials, components, subsystems, and system development and verification. In one form or another, the basic solar heat source technology can be applied to all major sectors of the national energy market.

This diversity and the rapid evolution of individual subprograms requires special attention to technology transfer. This report, the program multiyear plan, the annual program summary, and the detailed spending procurement and operating plans for the current year comprise a solid basis in documentation for this purpose.

In general, authority for implementation of specific subprograms has been delegated to national technical centers and DOE field offices. Appropriately, program managers so charged have provided an assessment of the key accomplishments of the past year and are responsible for the technical content of this report. Their accomplishments and fine efforts in support of this report reflect high credit on their organizations.

Gerald W. Braun
Assistant Director for
Solar Thermal Power Systems

Acknowledgments

The information contained in this Solar Thermal Power Systems Annual Technical Progress Report was provided by the various organizations responsible for the technical management of the respective portions of the program, as follows:

- Midtemperature Solar Systems Test Facility - Sandia Laboratories, Albuquerque
- Midtemperature Component and Subsystem Development - Sandia Laboratories, Albuquerque
- Total Energy Systems
  - Applications Analysis - Oak Ridge National Laboratory and Sandia Laboratories, Albuquerque
  - Fort Hood Project - DOE, Albuquerque Operations Office
  - Mississippi County Community College - DOE, Oak Ridge Operations Office
  - Shenandoah, Georgia, Knitwear Plant - Sandia Laboratories, Albuquerque
- Small Community Systems
  - System Applications Project - Jet Propulsion Laboratory
  - Crosbyton: Fixed Mirror, Distributed Focus - Sandia Laboratories, Albuquerque
  - Point-Focusing Distributed Receiver Development - Jet Propulsion Laboratory
- Remote (Irrigation) Systems - Sandia Laboratories, Albuquerque

- Technology Assessment
  - Assessment - Solar Energy Research Institute
  - New Applications - Jet Propulsion Laboratory
  - Test Facilities and Test Coordination - Solar Energy Research Institute
- New Components - Jet Propulsion Laboratory
- Materials Support - Solar Energy Research Institute
- Advanced Systems - Jet Propulsion Laboratory
- 10-MW_e Central Receiver Pilot Plant - DOE Solar Ten-Megawatt Project Office
- Large Power: Storage-Coupled, Repowered and Hybrid Systems - DOE, San Francisco Operations Office
- Large Power: Subsystems and Components Development - Sandia Laboratories, Livermore

The Aerospace Corporation, under a Management Support Contract, was charged with collecting, compiling, and editing these inputs and preparing the texts and graphics for the Department of Energy's Solar Thermal Power Program to publish the document.

Preface

The Solar Thermal Power Systems Program is an outgrowth of the response to the President's June 14, 1971, message calling for programs to ensure an adequate supply of clean energy in the years ahead. A Solar Energy Panel, formed in January 1972, identified the potential contribution of solar energy in meeting this goal, and on April 4, 1973, the National Science Foundation (NSF) was designated by the President to be the lead federal agency in coordinating solar energy research and technology.

On October 26, 1974, the Solar Energy Research, Development and Demonstration Act (Public Law 93-473) was signed into law, authorizing a vigorous federal program of research, development, and demonstration. Its goal was to provide the Nation with the option of using solar energy as a new source for meeting future requirements. This act authorized the new Energy Research and Development Administration (ERDA) to assume primary responsibilities for the Solar Thermal program from NSF on January 19, 1975. In response to the mandates of this act, major efforts were made within the Division of Solar Energy of ERDA to expeditiously develop and introduce economically competitive and environmentally acceptable solar energy systems.

Following the signing of the Department of Energy Organization Act (Public Law 95-91) on August 4, 1977, these responsibilities were transferred to the new U.S. Department of Energy (DOE) on October 1, 1977. Presently, DOE's solar energy activities are divided into three distinct organizational components.

- Division of Central Solar Technology

  - Ocean Systems Program
  - Solar Thermal Power Systems Programs

- Division of Distributed Solar Technology
  - Fuels from Biomass Program
  - Photovoltaics Program
  - Wind Energy Systems Program
- Division of Solar Applications
  - Heating and Cooling of Buildings Program
  - Agriculture and Industrial Process Heat Program
  - Technology Transfer Program

Both the Division of Central Solar Technology and the Division of Distributed Solar Technology come under the jurisdiction of the Office of the Assistant Secretary for Energy Technology (referred to as SOLAR/ET), while the Division of Solar Applications comes under the jurisdiction of the Office of the Assistant Secretary for Conservation and Solar Applications (referred to as SOLAR/CS).

Program planning continues under the guidelines established by PL 93-473 and by three other legislative acts passed by the 93rd Congress: The Solar Heating and Cooling Demonstration Act of 1974 (PL 93-409), the Energy Reorganization Act of 1974 (PL 93-438), and the Federal Nonnuclear Energy Research and Development Act of 1974 (PL 93-577). Together, these four laws grant DOE and other federal agencies the authority to pursue a research program aimed at effective solar energy use. Under this authority, SOLAR/CS and SOLAR/ET are working to develop solar energy technologies and to complement efforts in the private sector to develop solar energy resources.

This report is the first Annual Technical Progress Report for the Solar Thermal Power Systems Program. Two companion documents are available.

- The Program Summary, October 1978, which describes each of the contracts which were funded or in existence during FY 1978
- A Guide to the Solar Thermal Power Systems Program - FY 1979, which describes the continuing program and includes upcoming procurements and specific activities.

These three complementary reports document the implementation of the Solar Thermal Power Systems Program, provide an expanded insight into the significant current technical progress, and describe the future efforts toward meeting program objectives and cost goals set forth in the Multi-Year Program Plan (unpublished).

This technical progress report is structured along the lines of the current organization of the Solar Thermal Power Systems Program. Emphasis is on the technical progress of the projects rather than on activities and individual contractor efforts. Each project description indicates its place in the Solar Thermal Power Program; a brief history of each project prior to FY 1978 is given; the significant achievements and real progress of each project during FY 1978 are described; and future project activities as well as anticipated significant achievements for each project are forecast.

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Executive Summary

The Thermal Power Systems Program is unique among the solar programs in that this program provides a technology that can serve all sectors of the national energy economy. The program addresses the requirements of small and large power systems as remote or colocated energy sources for utilities, industries, institutions, small communities, and irrigation pumping. These systems collect and concentrate solar radiant energy to heat or vaporize fluids at high temperatures. The heat is then converted to electrical or mechanical power or applied directly to high-temperature processes. Systems such as these can be placed either at the point of energy use or at a central location from which energy is delivered to the user by the utility grid. These types of systems are expected to be commercially available in the 1980s. Beyond the 1980s, advanced high-temperature designs should be available to produce energy more efficiently and to produce transportable fuels and essential chemicals for energy use.

Two broad classes of concentrators encompass all of the possible solar energy system concepts: distributed receivers and central receivers. Distributed receivers integrate the heat absorber (receivers) with a concentrating element; this combined unit is also referred to as a distributed collector. Central receivers use a large number of concentrating tracking mirrors--heliostats--that are controlled to deliver reflected sunlight to a common, centrally located receiver. Numerous design concepts for both distributed collectors and central receivers are currently under development. The basic concept element is an individual mirror assembly ranging in output from 500 W to 500 kW_t. Systems can be assembled from these concentrator modules with capacities ranging from a few kilowatts to a few hundred megawatts. Because of differences in concentrating capability, efficiently produced temperatures vary over a range from a few hundred degrees Fahrenheit to 3000°F (1600°C).

The technical feasibility of such solar thermal power concentrator systems has long been established. The early systems, which were made by hand, were actually cost-effective until cheap oil and natural gas displaced them. The current solar technology development activities apply modern design and manufacturing techniques to these technically feasible concepts. Over $100 million was budgeted by DOE in FY 1978 toward the realization of these objectives, with significant progress resulting from these efforts.

This Annual Technical Progress Report presents descriptions of the various projects carried out under the DOE Solar Thermal Power Systems Program during FY 1978. The following summary highlights the FY 1978 accomplishments of these projects.

SMALL POWER SYSTEMS

Midtemperature Solar Systems Test Facility (MSSTF)

- Completed initial performance characterization
- Supplied electrical and thermal energy to the Solar Projects Building
- Initiated performance testing and operation of the Multitank High-Temperature Storage Subsystem

Midtemperature Component and Subsystem Development

Employed the MSSTF and laboratory facilities:

- Completed SOLTES (Simulator of Large Thermal Energy Systems) computer code documentation and sponsored workshop
- Demonstrated stable black-chrome selective coating in laboratory
- Completed figure-of-merit ranking of candidate reflector structural materials
- Prepared thin glass reflector laminate
- Procured collectors from Hexcel, Scientific-Atlanta, Solar Kinetics, and Polisolar
- Procured development receivers from GE and Itek
- Completed development of FMC and Del collectors
- Completed preliminary design of an engineering prototype advanced parabolic trough
- Completed silicone heat transfer oil testing to 1800 hours
- Completed trickle oil storage feasibility testing
- Completed preliminary design of a high-performance extraction steam turbine by MTI
- Prototype field laser ray trace instrument made operational
- Prototype portable reflectometer made operational

Total Energy Systems

- Determined the primary markets for these systems to be industrial applications; possible restricted markets for colleges and universities; and negligible commercial and residential market penetration until 2020
- Completed the Fort Hood Large Scale Experiment (LSE) functional system design and preliminary subsystem designs
- For the Mississippi County Community College (MCCC) project:
  - Completed purchases of concentrating photovoltaic cells and initiated purchases of concentrators
  - Completed design of an energy conservation building complex
  - Completed design of concentrator system and testing of prototype

- At the Shenandoah LSE:
  - Completed preliminary turbine design
  - Completed design for high efficiency turbine
  - Initiated definitive design
  - Dedicated the site

Small Community Systems

- Studies
  - Completed identification of (1) potential of small power systems in small utilities and (2) barriers and incentives for introduction of these small power systems
  - Initiated (1) comparisons of general power plants for small power systems and (2) Phase I competitive contracts for an experimental power plant

- Completed mirror, receiver, and wind tunnel tests

- Crosbyton-Fixed Mirror, Distributed Focus Project
  - Constructed test facilities at Texas Technical University and E-Systems
  - Initiated contracts for first-generation subsystem development

- Purchased one Omnium-G point-focus concentrating collector unit for test and evaluation and initiated cost studies

Remote (Irrigation) Systems

- Completed applications analysis of solar thermal systems for agricultural applications

- Demonstrated feasibility of the solar/electric hydride pump concept

- Initiated conceptual designs for novel pumping techniques

- Began operations at Willard, New Mexico, shallow well project and increased power output by:
  - Replacing collector receivers
  - Increasing collector field size
  - Modifying electrical generating system

- In the Coolidge, Arizona, deep well project:
  - Completed system design
  - Initiated power conversion system fabrication
  - Initiated site construction

- The Gila Bend project operation was assumed by DOE
  - Initiated operations
  - Transferred operational responsibility to DOE
  - Completed solar/electric hybrid pump modifications to include electric motor backup
  - Completed controls and receiver modifications

ADVANCED TECHNOLOGY DEVELOPMENT

Technology Assessment

- Conducted several technical workshops

- Established operational status of the Solar Thermal Test Facility Users Association (STTFUA)

- Initiated operations of the Georgia Institute of Technology Test Facility

- Initiated the Fuels and Chemicals project

- Purchased two Omnium-G units for performance evaluations

New Components

- Initiated testing of Brayton cycle

- Developed high-temperature ceramic air cooled receiver

- Investigated liquid metals for small power receivers

Materials Support

- Initiated research on black chrome and black cobalt

- Conducted high-temperature optical stability tests

Advanced Systems

- Initiated contracts for second-generation Stirling and Brayton cycle small heat engines

- Identified the potential of foam glass as low-cost structural material

LARGE POWER SYSTEMS

Systems and Applications Project

- 10-MW_e Central Receiver Pilot Plant
    - Selected McDonnell Douglas as Solar Facility Design Integrator
    - Completed site surveys and soil analysis
    - Met all federal, state, and local zoning and environmental requirements
    - Initiated procurement for heliostat production glass
    - Initiated design for Visitors Information Center
    - Selected McDonnell Douglas and Martin-Marietta as Phase I collector contractors
    - Initiated cloud measurement program at site

- Storage-Coupled Systems Evaluation
    - Completed liquid sodium and molten salt conceptual design studies for alternate central receivers
    - Neared completion of Brayton-cycle systems for advanced central receiver systems
    - Initiated Phase I utility scale line focus system concept design contracts

- Repowered Systems Analyses
    - Completed market and concept definition studies which indicated a potential for repowering capacity and developed cost-benefit analytical model
    - Completed 25-MW_e, 50-percent solar power system design for a specific plant site of a southwestern utility
    - Initiated "Venture Analysis" study at the Solar Energy Research Institute (SERI) to determine the optimum approach to commercialization

- Hybrid System Project

  - Awarded three Phase I conceptual design contracts
  - Initiated assessment analysis of various systems for application in the 1970s

Subsystem and Components Project

- Central Receiver Test Facility (CRTF) near Albuquerque, New Mexico

  - Completed construction and initiated testing operations
  - Achieved effective interaction with the STTFUA, an association of Solar Thermal Test Facility users

- Heliostat Development Project

  - Demonstrated second-generation heliostat conceptual designs with projected production costs near goals
  - Determined heliostat capital costs as function of reflectivity
  - Developed a computer model for the design and field performance of heliostats
  - Released "New Ideas" and Preproduction RFPs

- Receiver Development Project

  - Completed analysis indicating a Central Receiver Pilot Plant receiver lifetime of at least 30 years
  - Completed analytical model for direct absorber concept
  - Initiated Central Receiver Pilot Plant receiver panel tests
  - Studied advanced receivers for possible system cost reduction

- Storage Development Project

  - Conducted fluid maintenance, degradation, stability, and fouling tests
  - Initiated studies for advanced systems concept designs and procedures for testing high-temperature storage media

Most of these projects are continuing through FY 1979. The specific results of these analyses, tests, experiments, and demonstrations will provide the basis for and the extent of the effective realization of the program objectives to establish the technical readiness of cost-competitive solar thermal power systems for both small (under 10 MW_e or 100 MBtu/hr, thermal) and large (over 10 MW_e or 100 MBtu/hr, thermal) energy production applications by the mid-1980s.

Introduction

The Solar Thermal Power Systems Program is a key element in the national effort to establish solar conversion technologies within the major sectors of the national energy market.

The systems under development collect and concentrate solar radiant energy in order to heat or vaporize a fluid at high temperatures. The heat can then be converted to electrical or mechanical power, applied directly to high-temperature processes, or used in combination as in Total Energy Systems. Systems can be placed either at the point of energy use or at a central location from which energy is delivered to the user by the utility grid.

The major parts of a solar thermal energy conversion system consist of the following elements:

- Lenses or mirrors to collect and concentrate sunlight;
- Heat receivers to absorb the concentrated radiant energy;
- Energy transport systems (fluids and piping) to couple the collectors with the conversion and storage elements;
- Energy storage elements, e.g., tanks containing high-temperature fluid;
- Thermal conditioning or management equipment;
- Heat engines to drive generators; and
- Control systems to integrate and coordinate the operation of the other elements.

Two broad classes of concentrators encompass all of the possible solar energy system concepts: distributed receivers and central receivers. Distributed receivers (Figure 1) integrate the heat absorber (receiver) with the concentrating element; this combined unit is also referred to as a distributed collector. Central receivers (Figure 2) employ a large number of concentrating tracking mirrors--heliostats--that are controlled such that each delivers reflected sunlight to a common, centrally located receiver. Because the receiver is usually located on a tower, this is often referred to as the "power tower."

Numerous concentrator design concepts for both distributed collectors and central receivers are currently under development. The basic concept element is an individual mirror assembly ranging in output from 500 W to 500 kW. Systems can be assembled from concentrator modules with capacities ranging from a few kilowatts to a few

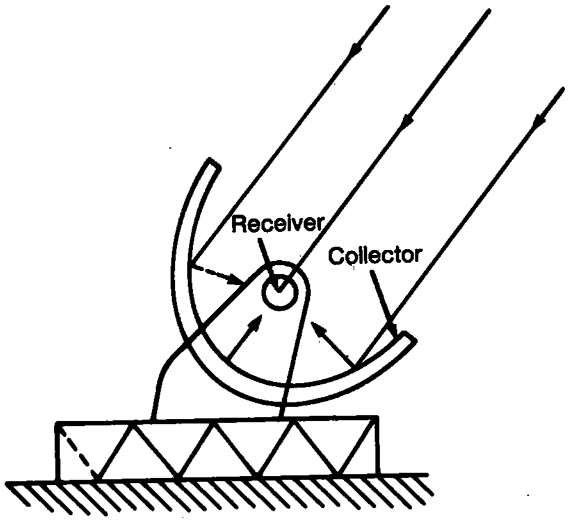


Figure 1. Distributed Receiver

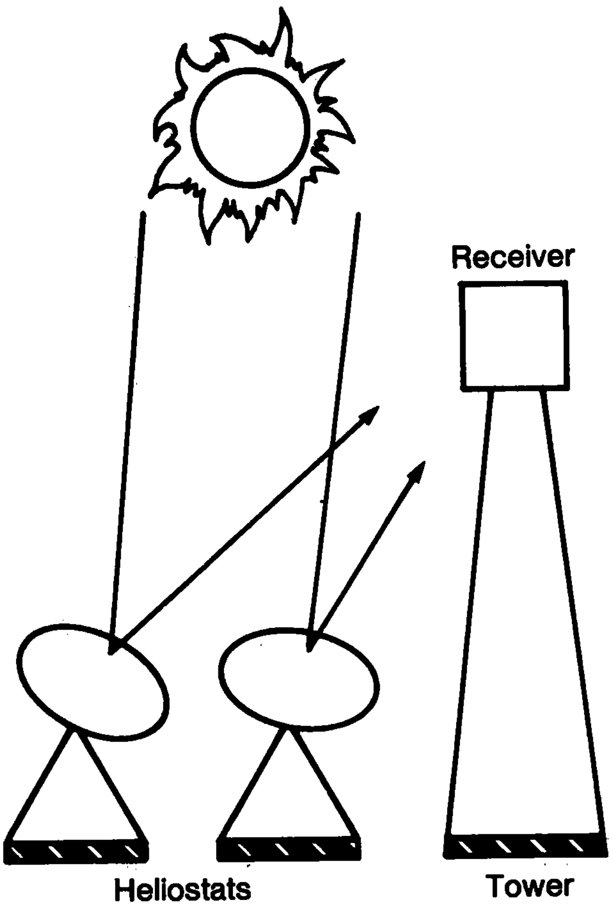


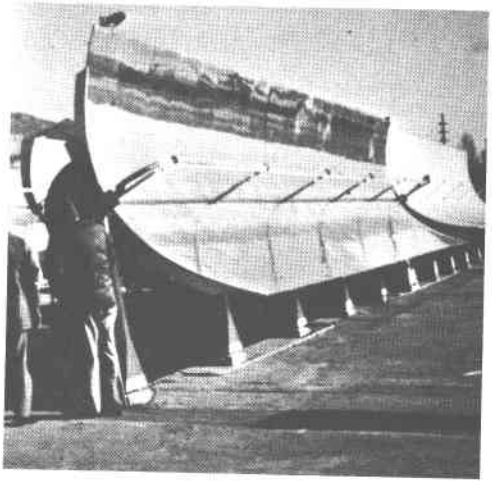
Figure 2. Central Receiver

hundred megawatts. Because of the differences in concentrating capability, efficiently produced temperatures vary over a range between a few hundred degrees Fahrenheit and 3000°F. Some components of these design concepts are shown in Figure 3.

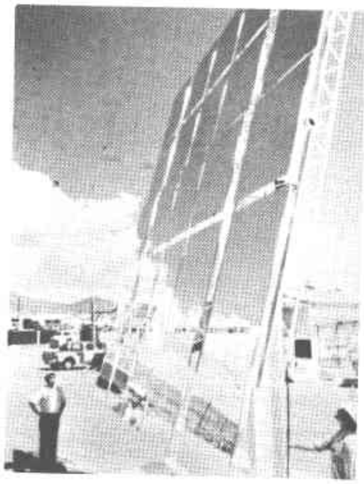
The technical feasibility of such concentrator systems has long been established. Early systems were constructed in the days before the first assembly line had its impact on industrial development and before low-cost oil and natural gas became mainstays of our energy economy. The current technology development program applies modern design and manufacturing techniques to the concepts long known to be technically feasible. Figure 4 illustrates clearly that current irrigation pumping systems and parabolic dishes recently placed in operation bear a striking resemblance to the systems built for the same purposes in the early 1900s.

Central receiver technology was also used in 1970 by the French for the 1-megawatt thermal (MW_t) solar furnace at Odeillo, France (Figure 5). This furnace is used for materials synthesis and metallurgy experiments. A modern system using a similar concept is being developed at a site of Southern California Edison Company near Barstow, California, for the purpose of generating 10 MW_e of electricity.

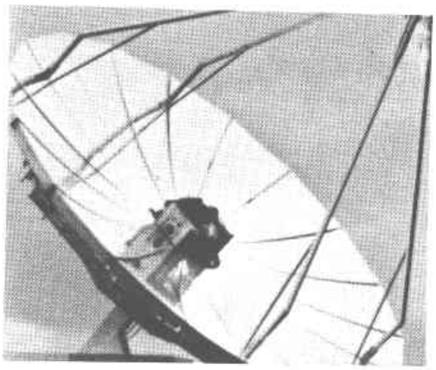
The overall objective of the Solar Thermal Power Systems Program is to establish the technical readiness of cost-competitive solar thermal power systems for both small (under 10 MW_e) and large (over 10 MW_e) energy production applications. Central receiver and distributed receiver technology development is being conducted for



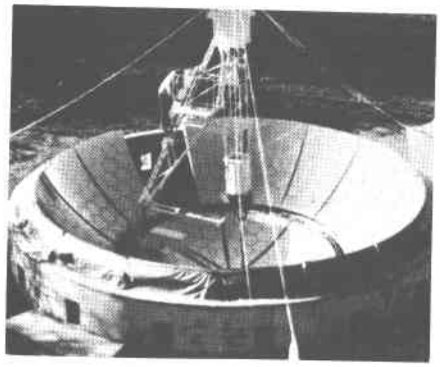
(a) Troughs, 500°-750°F, 0.5-5 kW'



(b) Heliostats, 600°-2500°F, 10-20 Kw



(c) Dishes, 750°-3000°F, 5-50 kW



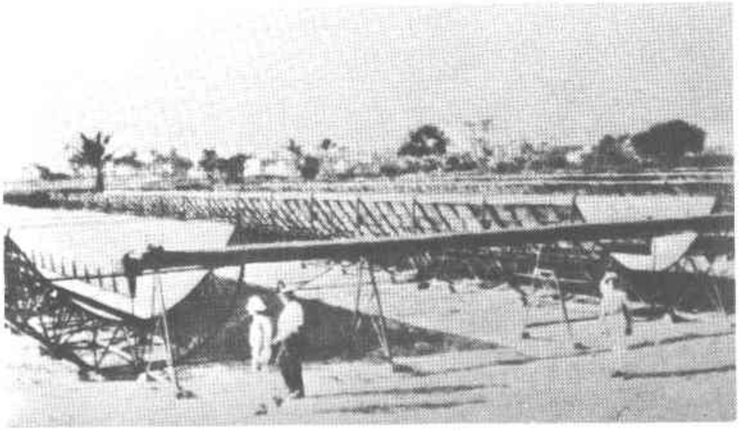
(d) Nontracking, 500°-1000°F, 50-500 kW

Figure 3. Design Concepts

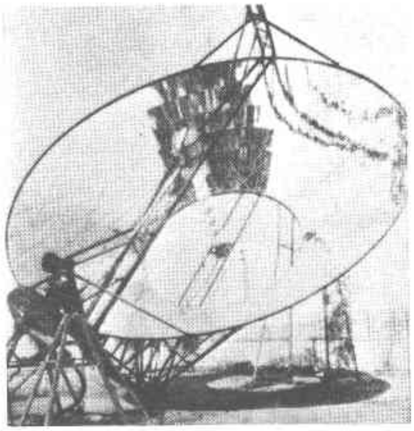
both large and small power applications. The technical readiness of a system technology is determined by its ability to perform reliably at required output levels with predictable durability characteristics. When the technology of these systems becomes cost-competitive, activities to support widespread commercialization will be initiated and coordinated with other appropriate organizations.

Initial commercialization can be defined as that time when a system is purchased in the open market without direct government support (e.g., subsidies, incentives, etc.).

- Small power applications--1983,
- Large power applications--1985, and

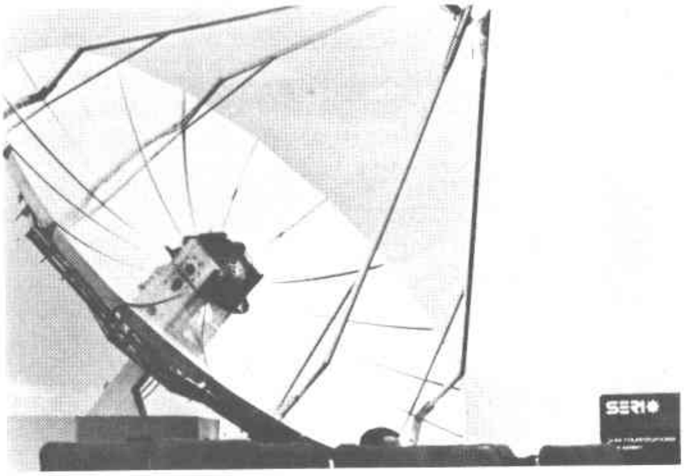


(a) 50-hp Solar Irrigation Pump at Meadi, Egypt (1913)



(b) 33-ft Parabolic Dish Cawston Ostrich Farm, Pasadena, California (1901)

(c) 25-hp Shallow Well Pump, Willard, New Mexico



(d) 37-ft Parabolic Dish "Omnium-G" SERI-Golden, Colorado

Figure 4. Comparison of Early 1900 Concepts to Current Applications

- High-temperature processing of fuels and chemicals from non-renewable feedstocks--1990.

To achieve the program's objectives, several time-phased system and subsystem cost goals have been defined in the Multi-Year Program Plan (unpublished). The long-term system cost goals, i.e., 1990, reflect values based on the average cost of conventionally generated energy displaced by the solar systems. The long-term subsystem cost goals are consistent and represent levels which will enable achievement of the systems-level cost goals.

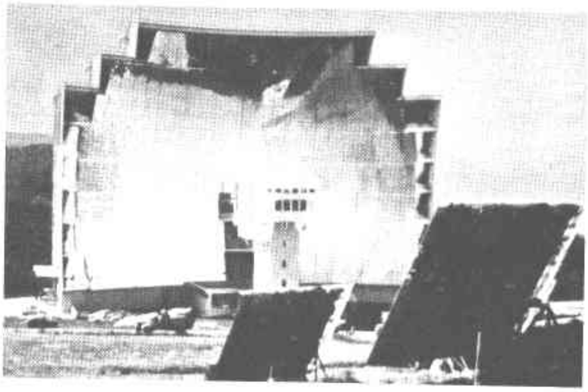


Figure 5. Solar Furnaces at Odeillo, France

Current indications are that the subsystem cost goals are achievable. For example, the 10-MW_e central receiver pilot plant heliostats are currently estimated at about $25/ft^2 compared to near-term cost goals of $20/ft^2. Prototype second-generation heliostat designs in the 44- to 55-m^2 size have been developed with costs projected as low as $7/ft^2 per unit reflectivity at production levels of 250,000 per year, which is lower than the long-term cost goals of $10/ft^2.

To achieve these objectives and goals, the program strategy directs system design efforts toward those applications having favorable conditions for early market penetration. For each key application, an orderly engineering development program is underway which includes the following:

- Concentrator and component evaluation and characterization,
- Subsystem design and performance verification,
- System integration experience via large- and small-scale experiments as appropriate, and
- Industrialization and cost-reduction initiatives as appropriate.

These engineering development programs are complemented and enhanced by a program of advanced technology development seeking performance improvements in the major subsystems and components.

The Solar Thermal Power Systems Program is structured around two key subprograms: Small Thermal Power Systems and Large Thermal Power Systems. Within these major divisions, there are a number of important potential applications with differing requirements for design, manufacturing, and marketing. The program organizes the technology development and related key applications in the following manner:

- Small Thermal Power Systems
  - Small Thermal Power Systems--Technology development and applications demonstrations for solar thermal systems under 10 MW_e (or 100 MBtu/hr, thermal) in size.
  - Advanced Technology--A supporting element established to identify and develop systems utilizing advanced technology concepts to enhance cost-effectiveness and to identify new applications for both small power and large power solar thermal systems.
- Large Thermal Power Systems --Solar thermal systems over 10 MW_e (or 100 MBtu/hr, thermal) in size.

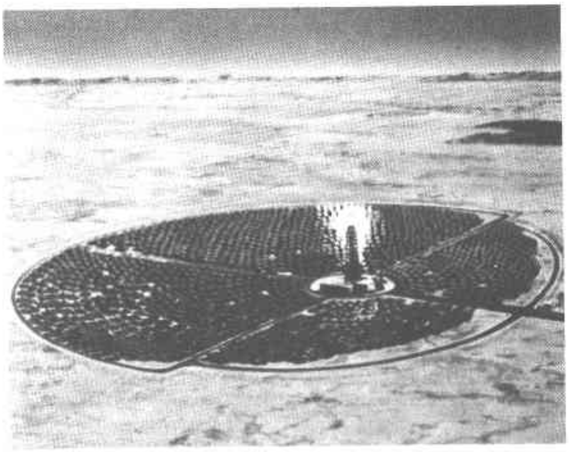
To streamline the development efforts and application programs, technical program management has been decentralized and is performed by DOE field offices, major engineering laboratories (including Sandia and the Jet Propulsion Laboratory), and the Solar Energy Research Institute (SERI). DOE field offices are expected to carry forward the major applications programs with the support of the engineering laboratories. Advanced development responsibilities are rapidly being transferred to SERI. Major experiments are phased with go/no-go decisions scheduled at key points with intermediate cost goals established as a frame of reference for these decisions.

In FY 1978 and 1979, the overall Solar Thermal Power Systems Program is funded at a level of roughly $100 million per year. The distribution of funding among the major programs is indicated in Table 1.

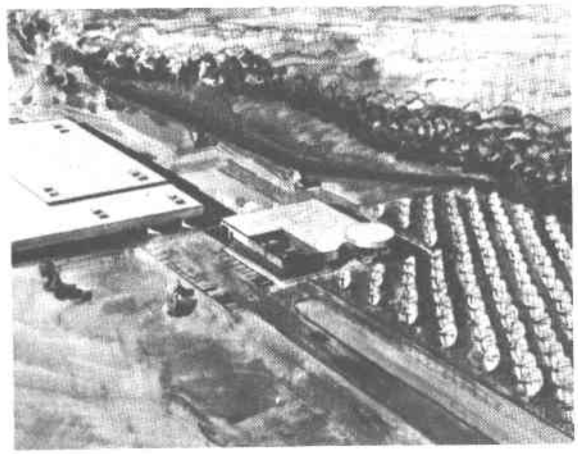
Table 1. Major Program Funding

Program	FY 1978	FY 1979
Small Power	$ 28,100,000	$ 31,000,000
Advanced Technology	10,200,000	13,500,000
Large Power	21,800,000	24,600,000
Barstow Pilot Plant	41,000,000	28,000,000
Capital Equipment	3,000,000	3,000,000
Total	$104,100,000	$100,100,000

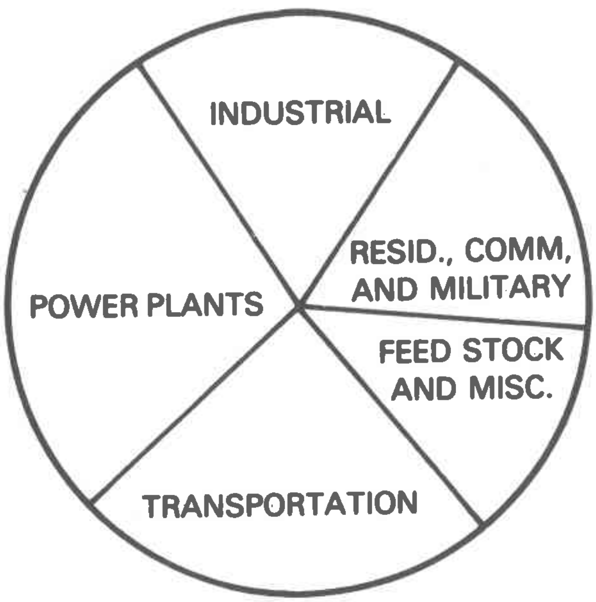
SOLAR THERMAL POWER DEVELOPMENT



Large Power Systems



Small Power Systems



Distribution of Primary Energy Usage (U.S. 1974)

Figure 6. Application Programs

Solar Thermal Power Development

As illustrated in Figure 6, the solar thermal power systems effort is unique among the solar programs in providing technology to serve all major sectors of the national energy economy. Both the large and small power applications around which the DOE Solar Thermal Power System Program is structured are expected to become commercially available in the 1980s. The large power program element includes production of electricity in central receiver power plants larger than 10 MW_e and other process heat applications of similar scale. The small power program element deals with systems smaller than 10 MW_e and with the industrial, commercial, residential, and institutional applications to which small systems based on distributed receiver collectors and small central receivers can be readily applied. Beyond the 1980s, it should be possible to apply the high-temperature capability of advanced design central receivers and of parabolic dish distributed receiver concentrators to processes for production of transportable fuels and essential chemicals. The Advanced Thermal Technology program element addresses this opportunity directly as well as appropriate materials, components, and process development for the entire program.

SMALL POWER SYSTEMS DEVELOPMENT

The Small Power Systems Program element is designed to extend solar technologies to small communities, commercial/industrial users, and rural or remote areas such as farms, in accordance with the program schedule indicated on Figure 7.

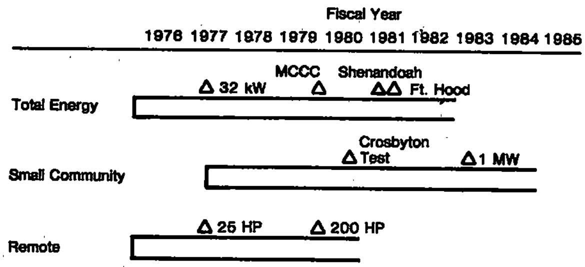


Figure 7. Program Schedule for Small Power Systems Program

The Small Power Systems Program consists of three subprograms: Solar Total Energy, Remote (Irrigation) Systems, and Small Community Power Systems. The long-range objective of each subprogram is to accelerate commercialization of solar energy systems through:

- Applied research to establish technical feasibility,
- Technology development to achieve a position of technical readiness, and
- Engineering development to a state of commercial readiness.

The program plan has been developed to achieve this objective by the design, construction, and operation of several field system projects based upon the results of applications analysis studies and a program of technology development.

The emphasis of the Small Power Systems Program is on the development of solar thermal technology in which the energy supply system can be integrated at the point of use. Such "on-site" systems are typically much smaller than those required for large utility power plant operations. Comparable conventional systems in current use rely heavily upon transportable fuels such as natural gas, propane, and oil.

Efforts in the Small Power Systems area include:

- Midtemperature Solar Systems Test Facility--Operates and maintains a collector module test facility for concentrating solar collectors and a system test facility to characterize performance and cost of solar energy components and subsystems and to accumulate operating and maintenance experience;
- Midtemperature Component and Subsystem Development--Develops components and subsystems and generates technical data in support of programs using distributed collectors;

- Total Energy Systems--For industry, commercial building complexes, agriculture, and small communities;
- Electric Power Systems--For small communities; and
- Remote (Irrigation) Systems --For applications in remote locations (essentially unattended) far from or inconvenient to an electrical grid.

Midtemperature Solar Systems Test Facility

The Midtemperature Solar Systems Test Facility (MSSTF) was developed at Sandia Laboratories in Albuquerque, New Mexico (Figure 132), in support of the national effort to develop solar energy technology for use in meeting projected demands for small power systems in the United States.

Candidate subsystems, components, and operational strategies for the small power system projects must be developed and evaluated. The MSSTF (Figure 8) was established to support the engineering evaluation of mid-temperature-range component and subsystem development for applications in the Small Power Systems Program. The MSSTF can test at both system and subsystem levels and is shared by the concentrating photovoltaic collectors test project.

The MSSTF consisting of the Collector Module Test Facility (CMTF) and the Systems Test Facility (STF) is used to evaluate candidate subsystems and components in common tests that are representative of projected operational conditions and provides experience in integrating components into a solar energy system. In the course of testing, expertise, which enhances conceptualization and design of improved components, is gained by all participants in the testing program, including test facility and program management personnel from private companies. In addition, the results and conclusions drawn from the testing program are widely distributed through formal reports, presentations, and technical interchanges with visitors to the MSSTF.

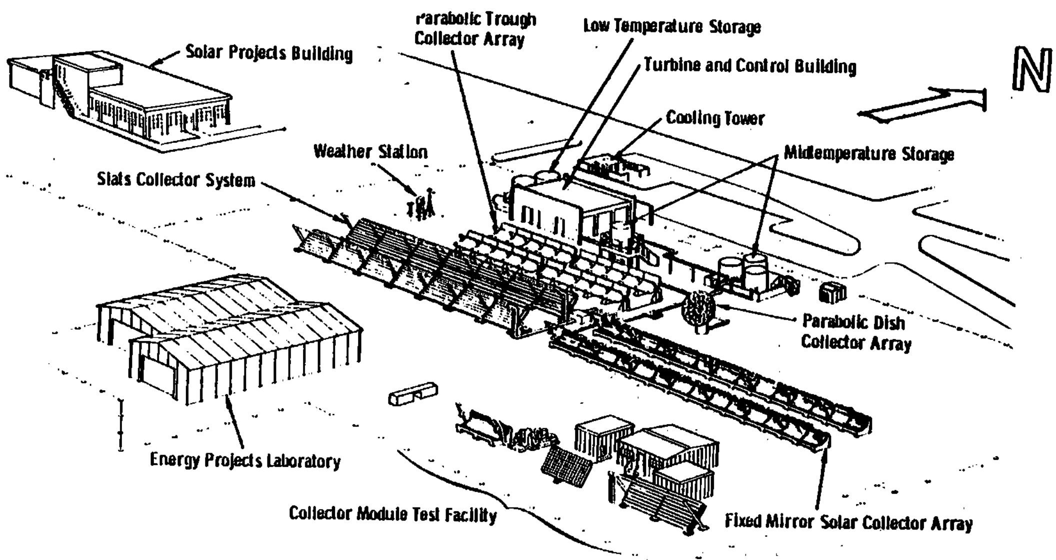
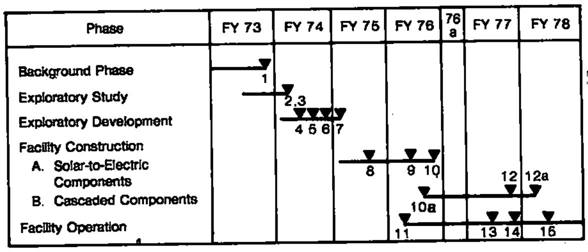


Figure 8. Midtemperature Solar Systems Test Facility

The operational goals for the MSSTF may be summarized as follows:

- Characterize, by representative engineering tests, candidate solar energy components and subsystems;
- Integrate experimental hardware into representative solar energy systems (i.e., systems large enough to encounter the problems of integrating full-scale components) to establish the feasibility of the solar total energy concept and to provide technical and cost data for dispersed power systems;
- Innovate through identifying potential improvements in component design and in system configuration and operation, and by encouraging such development in the private sector;
- Analyze the experimental data (from the MSSTF and other sources) to formulate conclusions helpful in designing systems for large-scale experiments, demonstrations, and commercial applications; and
- Disseminate the results and conclusions through reports, seminars, and conferences and through tours, briefings, and technical interchanges with visitors at the MSSTF.

The history of the MSSTF project is summarized in Figures 9 and 10. The design phase of the MSSTF began in 1973 and included extensive application



MILESTONES:

1. Completion of Phase 1
2. Preliminary System Design Complete
3. Economic Evaluation Complete
4. Collector Evaluation Facility Complete
5. System Analysis Program (SOLSYS) Operational
6. Baseline System Design Complete
7. Phase IV-A Proposal Submitted
8. Phase IV-A Design Freeze
9. Partial Collector Field, Storage, and Turbine/Generator Test Bed Complete—First Solar Energy Collection
10. Phase IV-A Complete, System 100 percent Operational

10a. Subcontracts for Collector Field Subsystems Placed

11. Initial Operation of Partial Solar Total Energy System Test Facility
12. Low-Temperature Components of Solar Total System Test Facility Installed

12a. Subcontracted Collector Field Subsystems Completed

13. System Analysis Program (SOLSYS) Refined and Revalidated
14. Demonstration of Solar Project Building
15. Operation of Complete Solar Total Energy System Test Facility

Figure 9. Midtemperature Solar Systems Test Facility Project Milestones

and systems analyses of the solar total energy concept and the development of systems computer programs, the best known of which were CYCLE* and SOLSYS.* The first hardware to be realized was the first test loop of the CMTF.

Construction of the "solar-to-electric" portion of the MSSTF was initiated late in 1974. This effort, called Phase IV-A to distinguish it from the expanded facility which had yet to be authorized, consisted of the fabrication, installation, and checkout of the 200-m^2 parabolic trough collector field quadrant, a high-temperature stratified storage tank, a 32-kW turbine/generator and Therminol-to-toluene heat exchanger, an instrumentation and control subsystem, a cooling tower, the

*Present upgraded versions of these codes are Cycle 2 and SOLTES.

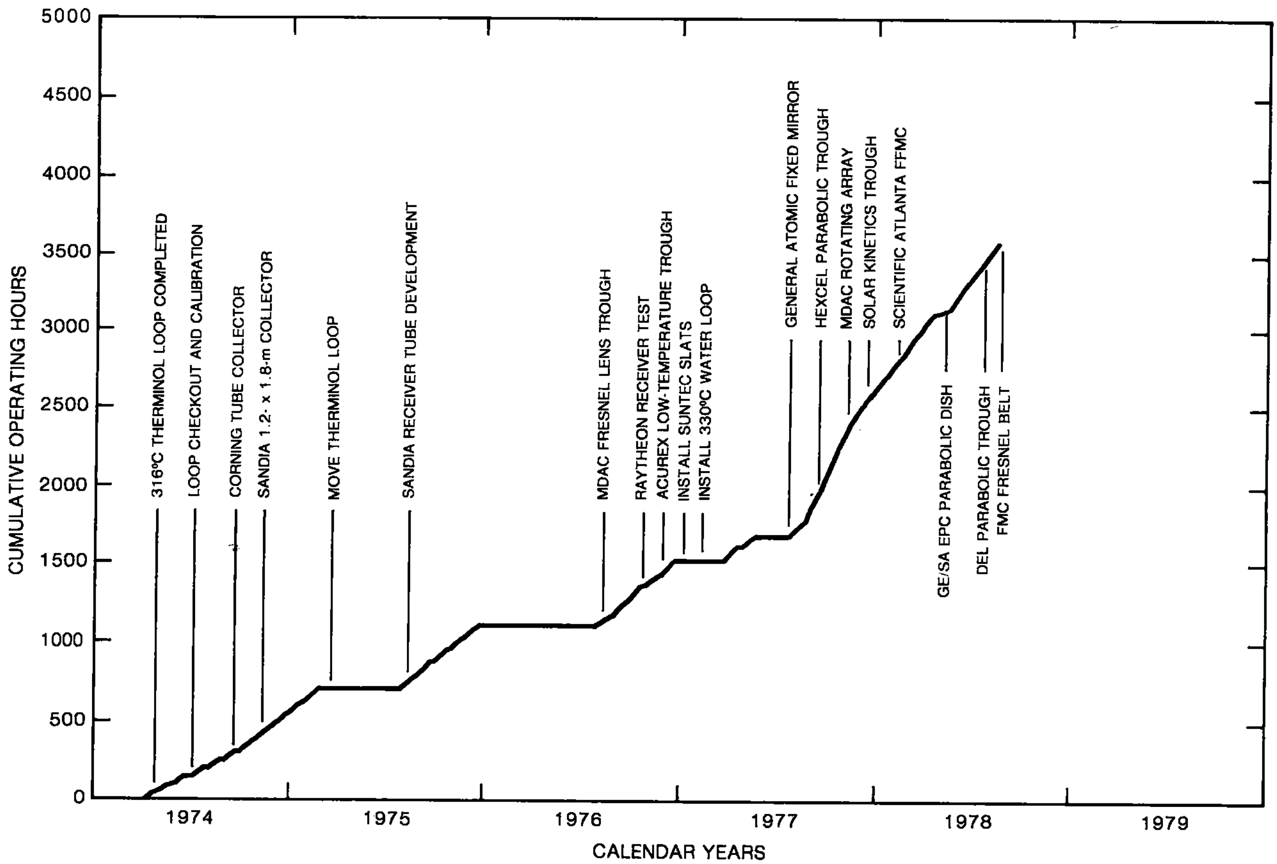


Figure 10. CMTF Operating History

turbine and control building, and all necessary pumps and fluid loops to interconnect these subsystems. The installation of the parabolic trough collector field was completed in December 1975. The balance of the installation was completed and all the components of the Phase IV-A system were operated together in April 1976.

Phase IV-B began in February 1976 and will continue as new subsystems are added to the facility and as other subsystems on which evaluation has been completed are removed. The initial goals of the Phase IV-B construction were to add a variety of collector fields to increase capability of collecting 2×10^6 kJ/day to a capacity of about 8×10^6 kJ/day and to achieve the capability of providing 32 kW for a full 11-hour operational day. High-temperature thermal storage capacity was increased from 30 minutes to 3.5 hours with the addition of a 24,000-l, multitank, sensible heat-storage system. In addition, the subsystem for low-temperature thermal energy storage, the LiBr absorption chiller, heating equipment, and all necessary additional sensors and controls were added to the facility. The project was demonstrated and a major project milestone marked in June 1977 when the Solar Projects Building was provided electrical power, heating, and cooling to become the world's first application of total solar energy to an actual load.

In FY 1978, two additional collector field subsystems were completed under Phase IV-B: (1) the Suntec SLATS and the General Atomic FMSC and (2) the Multitank High-Temperature Thermal Energy Storage Subsystem. Figure 11 shows the state of the facility as of the end of FY 1978. The Raytheon parabolic dish was installed in FY 1978 with its checkout tests scheduled for completion early in FY 1979. Another parabolic dish design, prototypical of the Shenandoah Large Scale Experiment provided by General Electric, will be installed in FY 1979. Procurement will be initiated for advanced high-temperature storage, prime mover, and parabolic trough collector field subsystems.

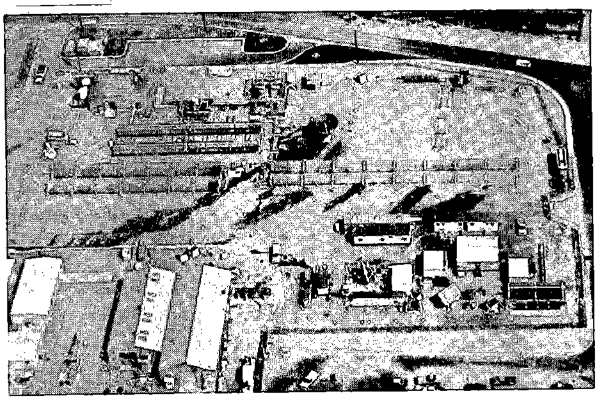


Figure 11. Aerial Photo of MSSTF

Phase V, overlapping Phase IV-A and concurrent with Phase IV-B, began in January 1976. It consists of operating the facility in accordance with a detailed test plan to provide performance data on all subsystems and to accumulate operations and management experience to form the design basis of large-scale experimental plants and future solar energy systems. Figures 12 and 13 show the accumulation of operating hours on some of the MSSTF subsystems. The operation of the system, including the supplying of electricity, heating, and cooling of the

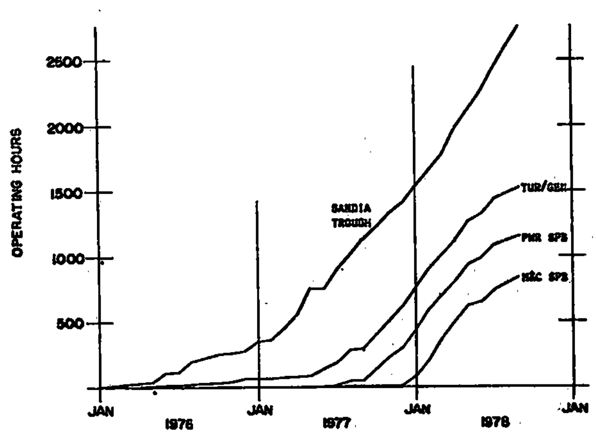


Figure 12. Subsystem Operating History

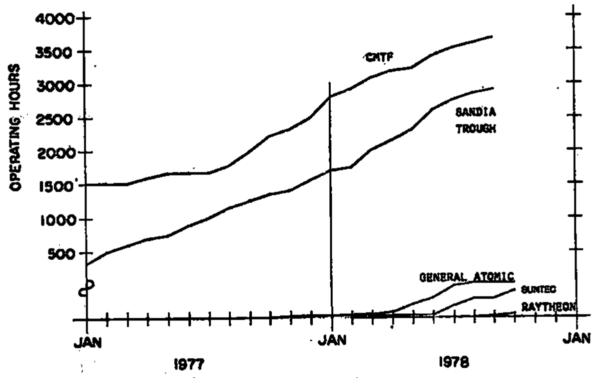


Figure 13. Collector Field Operating History

Solar Projects Building will continue in FY 1979.

Some of the more significant accomplishments during FY 1978 are categorized below according to the operational goals previously identified:

- Characterize--Test nine new collector modules. Figure 14 compares the performance of nine tested designs. This effort not only added to knowledge of solar collector design but also provided a means to encourage and fund private companies to develop advanced solar hardware systems. The initial performance characterization was completed for the

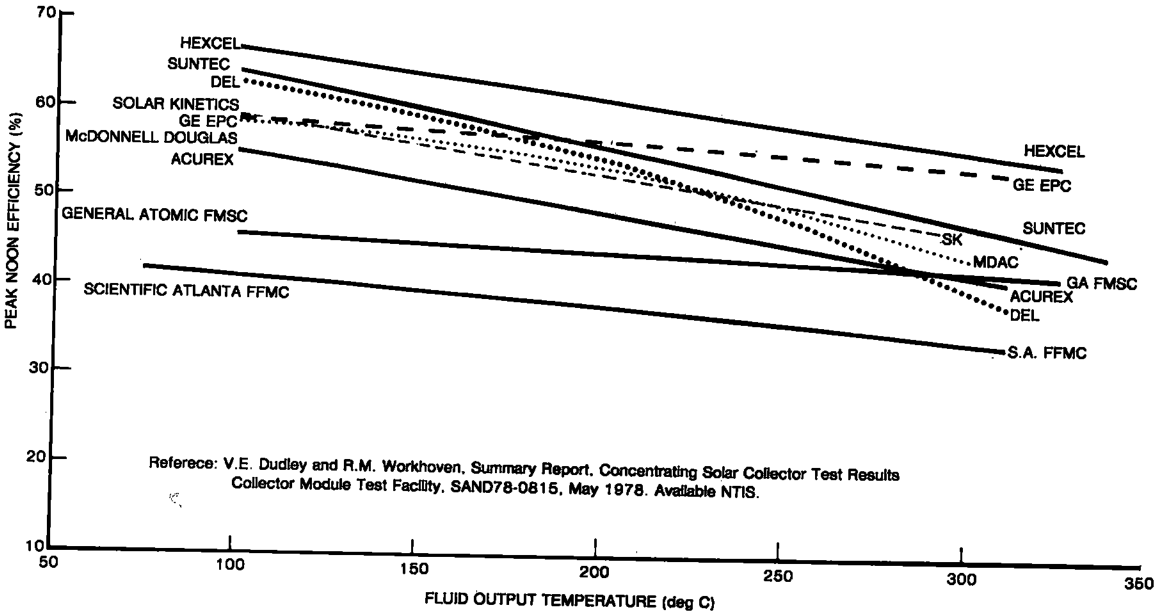


Figure 14. Comparison of Peak Collector Efficiency vs Output Temperature

Suntec SLATS and General Atomic FMSC Collector Field Subsystems and for the Multi-tank High-Temperature Thermal Energy Storage Subsystem.

- Integrate--The operation of the MSSTF as a solar total energy system supplying electricity and thermal energy to the Solar Projects Building was established as the standard mode of operation. Solar-specific operational strategies for the turbine, e.g., a "liquid-fired" boiler, seasonal variation of condenser temperature to match thermal demand, and automatic switching between solar and fuel were developed. The first systems-level tests involving all available subsystems in interactive operation were accomplished.

- Innovate--The Raytheon parabolic dish collector was installed and preliminary performance tests were initiated. A second parabolic dish collector, designed by General Electric for the Shenandoah Large Scale Experiment, was selected for a collector field subsystem at the MSSTF.

- Analyze--Figure 15, based upon data obtained from MSSTF operation, indicates degradation in the performance of the parabolic trough collector field subsystem. An advanced design for parabolic trough collectors that incorporates improvements suggested by the previous testing has been initiated. The data from the first 24-hour test indicate that during the test 63 percent of the collected solar energy was applied to the demands of the Solar Projects Building.

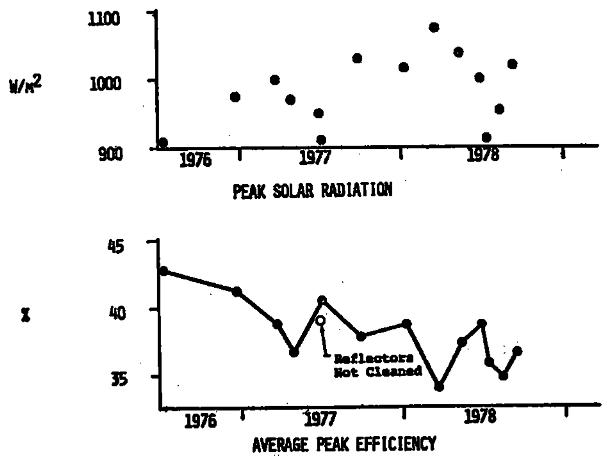


Figure 15. Parabolic Trough Collectors Performance History

- Disseminate--The transfer of information to industry by the Resident Engineer Project took an international flavor with the inclusion of Ormat Turbines, Ltd., in Israel. The MSSTF was visited by a total of 9337 visitors including 282 from foreign countries. The effort has also produced 34 conference presentations and 20 formal reports.

The MSSTF mission is primarily related to those goals identified in the Multi-Year Program Plan for total energy and distributed collectors, and appropriate operational goals have been defined for FY 1979 as summarized below.

- Characterize--Evaluate the Suntec SLATS, General Atomic FMSC, and Raytheon parabolic dish collector field subsystems and the Multitank High-Temperature Thermal Energy Storage Subsystem as operational components of the MSSTF. Install new test loop at the CMTF permitting the evaluation of collector modules to higher temperatures (up to 425°C).

- Integrate--Develop empirical information on maintenance and operation costs and procedures and identify other system operational considerations necessary for the implementation of small power systems.

- Innovate--Install the Shenandoah prototype dish collector field subsystem. Upgrade the existing parabolic trough collectors with hardware utilizing design improvements that have been identified in previous testing. Evaluate silvered glass reflector surfaces and improved black chrome absorber coatings in both the CMTF and the STF. Initiate procurement for second-generation subsystems. Evaluate five additional, previously identified, collector modules and procure and test several commercially available collectors.

- Analyze--Install an upgraded control and data acquisition system permitting more versatile testing techniques and improved analysis and reporting. Develop techniques for transferring test data analysis.

- Disseminate--Continue the technical dissemination program of conference presentations, formal and informal written reports, resident engineers, workshops, and the reception of visitors. Visitors are expected to average about 1000 per month in FY 1979.

Figure 16 shows a projected 5-year plan for planned and projected activities. Definitions of projected activities, indicated by the dashed lines, will evolve from program development. It is expected that the MSSTF will not grow substantially beyond its scope in FY 1979; subsequent subsystem installations will generally replace equipment that has been completely evaluated. One consideration in the decision relative to phasing out tested subsystems is the necessity of retaining a complete set of components for total system operation.

It is expected that the need for the test facility will extend through the mid to late 1980s. By that time, several large systems will be in operation, providing information from actual working conditions to be used in the design of subsequent systems. At that time, it may be possible to deemphasize the system aspects of the MSSTF and shape its role for the evaluation of innovative components, particularly collectors.

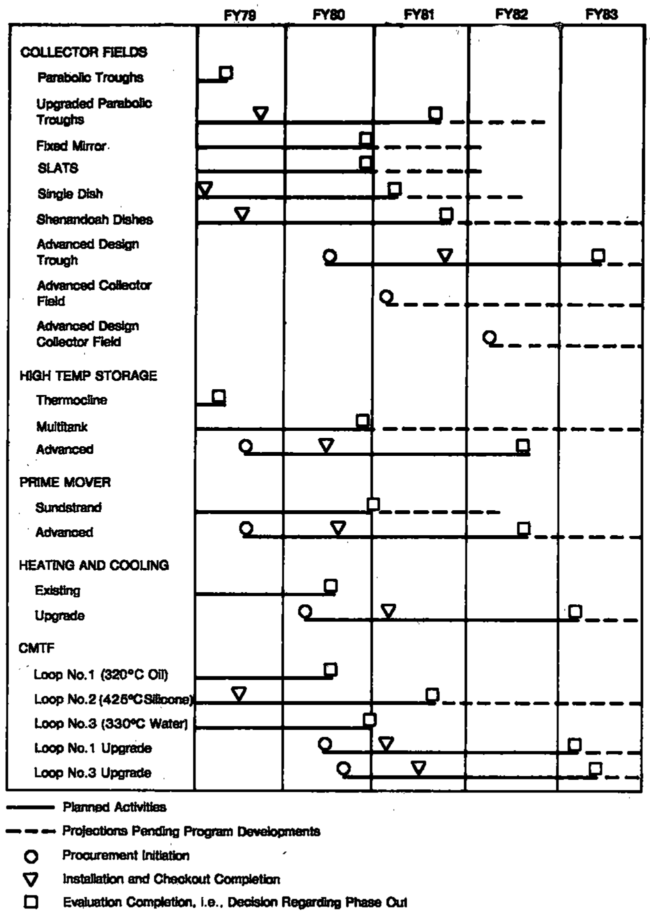


Figure 16. MSSTF 5-Year Plan

Midtemperature Component and Subsystem Development

Similar to the support provided by the Midtemperature Solar Systems Test Facility, the Midtemperature Component and Subsystem Development project at Sandia Laboratories, Albuquerque, New Mexico, supports the Small Power Systems program element. The objectives of this project are (1) to identify research and development areas that are unique to small solar power systems in the midtemperature range and (2) to perform technology development in these areas to ensure initial commercial implementation of the small power systems by the early 1980s. In this regard, this project provides materials as well as component and subsystem development support for the Total Energy, Small Community, and Remote (Irrigation) Systems as required in the areas of:

- Systems Engineering,
- Materials and Process Development,
- Collector Development,
- Storage Development,
- Prime Mover Development, and
- Operation and Maintenance Characterization.

Systems Engineering

To provide a computer code that simulates solar process heat, total energy, and power conversion systems, the first version of the SOLTES (Simulator of Large Thermal Energy Systems) code was written and debugged in FY 1978, employing some of the logic and thermal component models of a previous code (SOLSYS). It is a general code that can be used to simulate a variety of systems such as:

- Solar Power/Total Energy Systems,
- Fossil Fired Power Plants/Total Energy Systems,
- Solar Energy Heating and Cooling Systems,
- Solar Hot Water Sytems, and
- Solar Process Heat.

A load management capability allows SOLTES to simulate total energy systems which simultaneously follow power loads, power demands, heat demands, and heat loads. At the user's option, SOLTES automatically calculates system performance parameters and provides system energy transfer accounting.

A workshop was held with representatives of universities, small consulting firms, large companies, and national laboratories to explain and demonstrate SOLTES capabilities. A users manual was distributed to the attendees. During FY 1979, the present version will be distributed further; the program will be enhanced to increase the variety of simulator models and output capacity; and an IBM version will be prepared.

A Solar Systems Design Handbook for systems employing parabolic trough collectors was initiated. The handbook addresses the application of parabolic trough midtemperature solar technologies to process heat, on-site power, and total energy systems. It permits the design of these solar systems through the employment of parametric curves and tables and reduces the need for computer simulation. Performance curves are provided using Typical Meteorological Year (TMY) Weather tapes, appropriate trade-off evaluations between various subsystem options are treated, and component cost algorithms are included. Publication of the handbook is expected in FY 1979.

Four DOE study contracts evaluating the application of solar total energy systems to the industrial, commercial, residential, and institutional market sectors were completed. The industrial sector, characterized by fairly constant seasonal demands, high thermal-to-electric ratios, existing operation and maintenance experience, uncertainity of current energy sources, mitigated by typically short payback periods (3 to 7 years), and potentially restricted land availability, appears favorable for near-term market penetration. The commercial sector tends to be land limited and highly electric intensive while the institutional sector tends to have an unfavorable thermal-to-electric ratio. No markets for the residential sector were identified prior to the year 2000. A primary deterrent for the application of solar total energy to the residential sector is the high priority given this sector by the government in allocating fossil fuel energy resources. Areas identified for technology development included component reliability, improved turbine efficiencies and high-temperature heat transfer, and storage fluids.

Materials and Process Development

After degradation of the optical properties of black chrome-coated receiver tubes in use at the MSSTF was noted and confirmed by laboratory testing, efforts were initiated to improve the stability of these properties above 300°C in air. The standard bath and plating process produces coatings that are optically stable in air at 250°C but not at 300°C. Variations from the standard composition of the plating bath produced desired results at temperatures of 350°C to 400°C for extended test periods. These test results were independently verified by Honeywell Systems and Research Center. In support of the Coolidge, Arizona, project, a full-scale production plating with the new bath is planned for November 1978. During FY 1979, aging tests on black chrome-coated receiver tube sections will be continued in order to determine microscopic differences between stable and unstable coatings, critical process variables will be determined, and a detailed process handbook will be prepared by Honeywell Systems and Research Center.

The use of elastically deformed, thin (0.13- to 0.51-mm) silvered glass as a second surface reflector provides a method of forming trough concentrator shapes with advantages over conventional glass thickness (>1.5 mm). Feasibility analyses were conducted to optimize adhesive properties and backing materials to form a flat "reflector laminate" which is elastically deformed to the desired concentrating profile. Tests were conducted to confirm these analyses, to evaluate the fabrication processes, and to identify potential problems. New procedures for glass cutting and adhesive application as well as special fixtures for silvering were developed. Thermal cycling, thermal/ humidity cycling, bond strength, and reflectivity tests were conducted which indicate performance capabilities of the thin glass laminates. The first systems test will begin in March 1979 with the construction of a 6.1-m-long parabolic trough in the MSSTF collector field. System characterization and testing of the laminates will continue during FY 1979.

Early responses of major producers of sagged glass shapes indicated that existing technology was adequate for solar applications. However, early in FY 1978, responses to RFQs indicated that a variety of technological as well as facility problems still existed which included:

- High cost and uncertain availability of quality fixtures,
- Facility limitations that deter response for prototype parts,
- Mirror quality uncertainty and lack of standard quality control instrumentation, and
- Variations and uncertainties in deformation processes.

Much of the FY 1978 effort was devoted to solving these problems. Many companies were visited and some studies were funded to assess the performance of specific mold materials and the companies' capabilities to produce suitable prototype parts. These parts will be sent to the Sandia Laboratory Mirror Silvering facility (Figure 17) and then tested for uniformity and curvature. Studies at Sandia were initiated to evaluate ceramics for mold material as well as the possible use of microwave heating to sag the glass. These studies will continue through FY 1979.

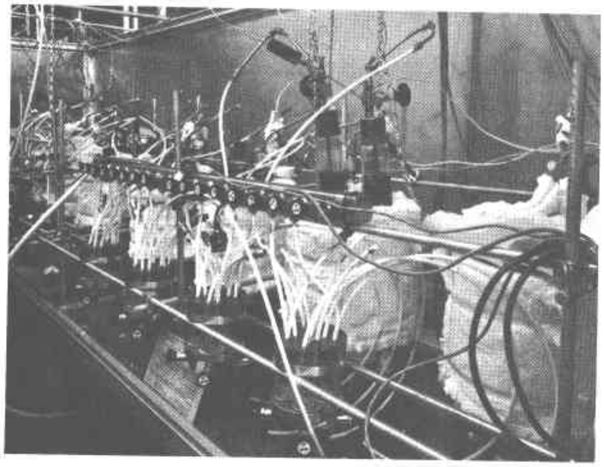


Figure 17. Sandia Laboratory Mirror Silvering Facility

Glass panels have been fabricated, silvered, and tested using a laser ray trace system. Figure 18 shows a pair of these glass sections mounted on a trough form. Two configurations of parabolic troughs are at stages where sagged glass will be required. Because tests have indicated that panels can be fabricated with acceptable accuracy, two contracts will be let in FY 1979 for fabrication of panels for a 2-m rim-to-rim advanced trough design and replacement for 9-ft rim-to-rim units. Costs of tooling, sagging, and subsequent silvering will be investigated for evaluating sagged glass potential for future mass production of collectors. The three-dimensional forming of large glass parts to long variable radii of curvature and to those dimensional tolerances for parabolic dish reflectors will require a development effort that is planned for early FY 1979.

In previous years, a variety of materials for concentrating collectors were experimentally evaluated. These

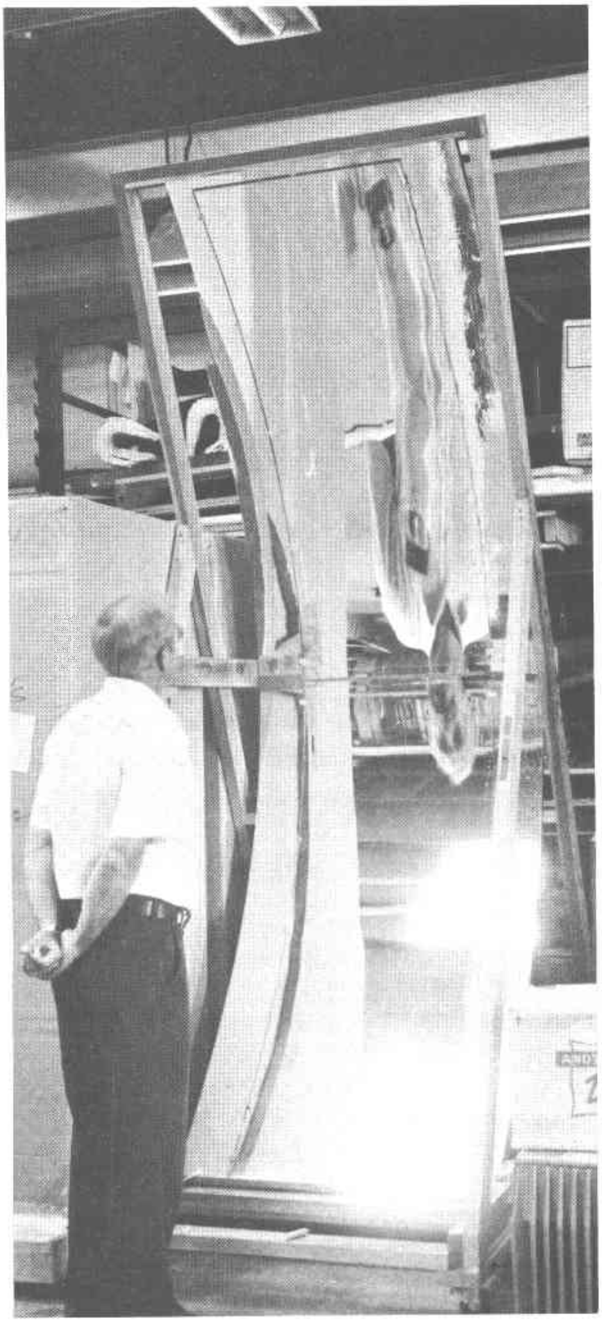


Figure 18. Sagged Glass Sections

data were supplemented in FY 1978 by design analyses that provided figure-of-merit ranking of candidate materials.

The criteria of weight, strength, and stiffness indicate the use of sandwich, ribbed, and monocoque structural forms. Material/design combinations were selected from the various candidates by performance, weight, and cost trade-offs as well as availability and mass production considerations. Testing of these selected candidates include:

- Laser ray trace inspection,
- Temperature-humidity cycling,
- Real-time environmental exposure, and
- Hail impact resistance (Figure 19).

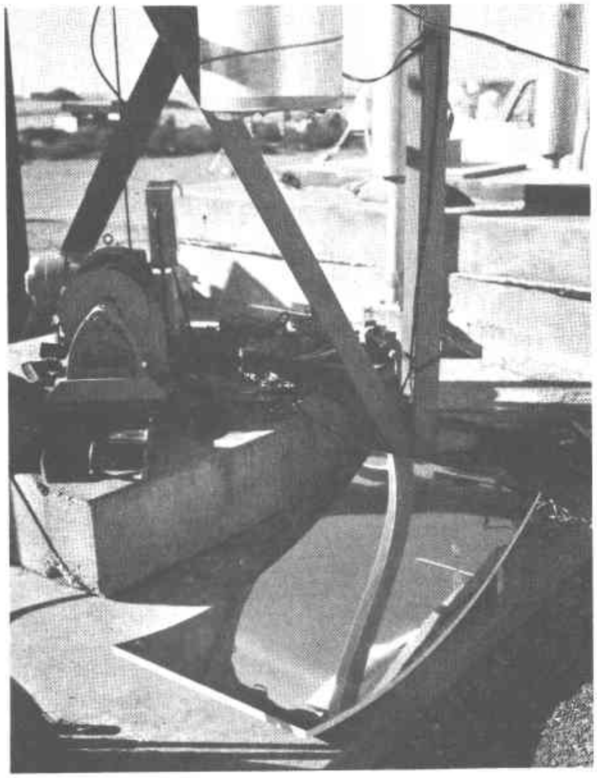


Figure 19. Sandia Hail Impact Gun

Each of these candidates will be evaluated with sagged, chemically strengthened, and thin glass reflector surfaces. In addition, four new materials programs were initiated:

- Modification of the laser ray trace to identify structural versus reflector surface changes during environmental cycling,
- Moisture diffusivity measurements in materials of structures,
- Chemical analysis of commercial products for degrading impurities, and
- Surface analysis of degraded mirrors.

During FY 1979, efforts will be directed toward optimizing material/design combinations and understanding the degradation mechanisms of materials and reflector surfaces.

Laboratory instruments and data analysis techniques were developed to characterize the specular properties of reflecting surfaces. It was determined that relatively small amounts of dust on a mirror cause a significant decrease in specular reflectance and experiments were conducted to determine the magnitude of this effect. Several new solar mirror materials were tested. The need was recognized for a portable reflectometer for obtaining field data and the development of such an instrument was completed (Figure 20). This instrument was designed to determine specular reflectance loss due to dirt and surface scratches on mirrors located in the field. During FY 1979, studies of the effects of dust accumulation will be continued, field calibration of the portable reflectometer will be conducted, and its use applied to curved surface mirrors and long-term mirror degradation tests will be studied.

Collector Development

A number of collector development contracts were awarded to establish a comparative range of performance capabilities of contemporary concentrating solar thermal collectors. During FY 1978, the collectors were delivered and tests were conducted in the Collector Module Test Facility (CMTF) at the MSSTF. A summary of the collector efficiency results for several of these collectors is shown in Figure 14.

The Hexcel collector (Figure 21) is a linear focus 72° rim-angle parabolic trough employing a black chrome-coated receiver tube enclosed in Pyrex glass.

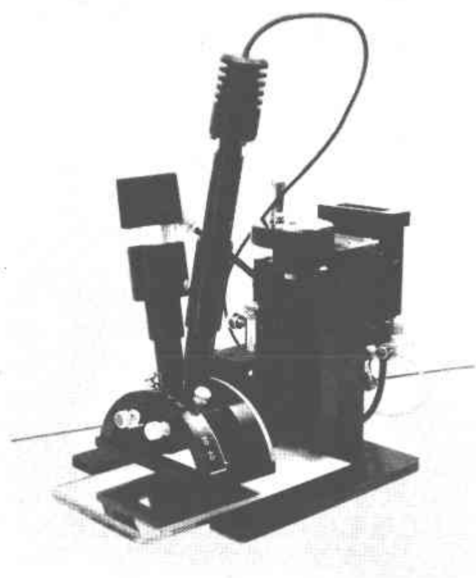


Figure 20. Portable Reflectometer for Specular Reflectance Measurements

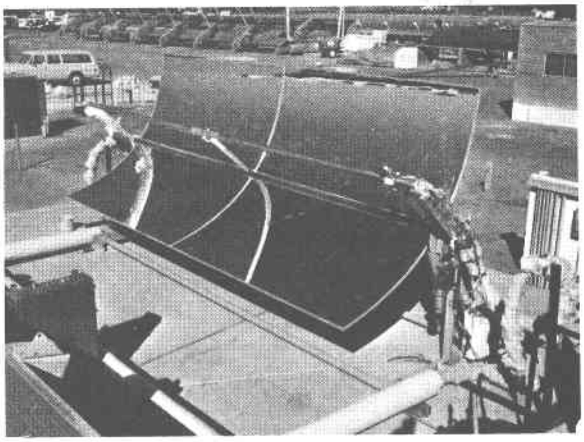


Figure 21. Hexcel Solar Collector

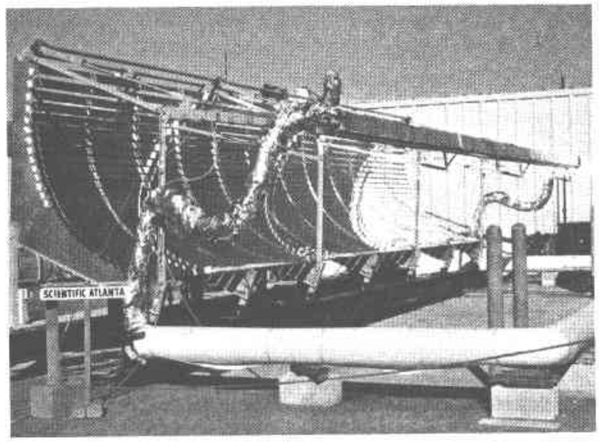


Figure 22. Scientific Atlantic Solar Collector

This collector exhibited the highest efficiency of any linear collector evaluated to date. The Scientific Atlanta collector (Figure 22) is a faceted fixed mirror concentrator utilizing sheet metal fabrication and construction techniques. The second surface mirror facets are formed from low iron glass, and the receiver is enclosed by a secondary reflector. The Solar Kinetics Collector (Figure 23) is a linear focus 90° rim-angle parabolic trough utilizing a black chrome-coated receiver tube enclosed in a Pyrex glass jacket. The Polisolar AG collector, obtained from Soltrax, Inc., (Figure 24) is a linear focus 120° rim-angle parabolic trough with sagged glass mirror surfaces and black chrome-coated receiver tube enclosed in a cylindrical glass jacket. This collector will be tested at CMTF in FY 1979.

The General Electric receiver (Figure 25) is an alternate design of a low rim angle receiver tailored to the Suntec SLATS (previously tested) requirements. The receiver has been installed on the Suntec module at CMTF and will be tested in FY 1979 to provide direct comparison with the Suntec and Itek receivers. The Itek receiver (Figure 26) is also an alternate design of a low rim angle receiver tailored to the Suntec requirements. It will be installed and tested in the Suntec module following the completion of the General Electric receiver tests. The FMC collector (Figure 27) utilizes a Fresnel belt reflector of narrow glass mirror strips mounted on a stainless steel belt that moves on a cylindrical path. The receiver tube is fixed at the center of the cylinder thus permitting rigid plumbing connections. This unit has been installed at CMTF. Testing is underway and will continue during FY 1979.

The Del Manufacturing collector (Figure 28) is a parabolic trough utilizing a sagged (pressed) glass reflective surface with a rim angle of ~110° that rotates about the fixed receiver tube. A series of hail tests were conducted that indicated this collector is highly resistant to 1/2- and 3/4-in. hail and also exhibited resistance to 1-in. hail.

Two preliminary design studies were conducted to stimulate the development

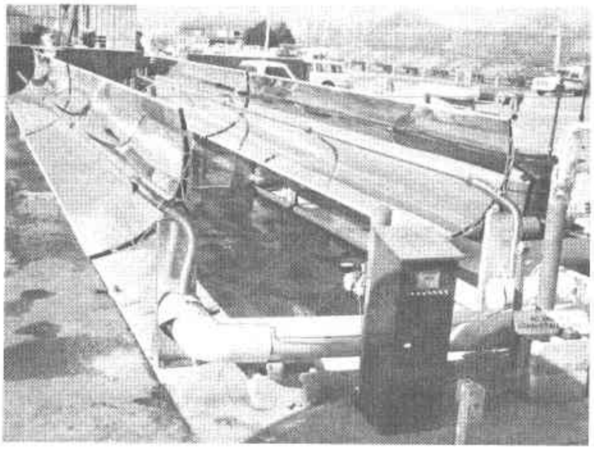


Figure 23. Solar Kinetics Solar Collector

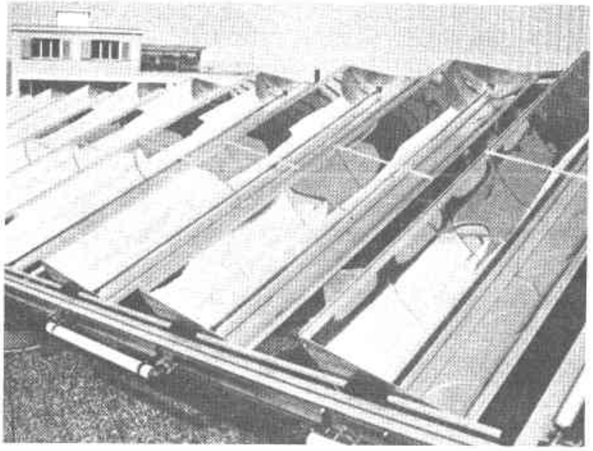


Figure 24. Soltrax Polisolar Parabolic Trough Collector

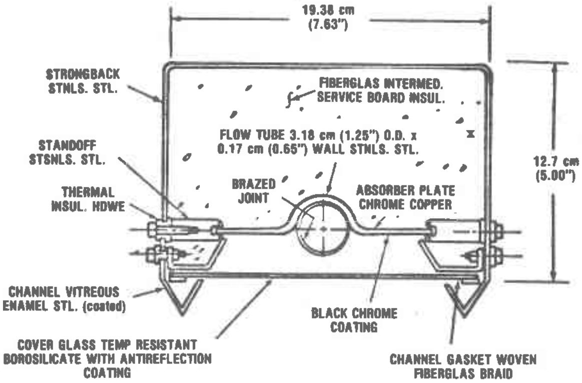


Figure 25. Section View of GE Wide-Aperture Receiver

and evaluation of new and novel designs for solar thermal collectors operating in the midtemperature (230°C to 330°C) range. One of the concepts (Figure 29) consists of an inflated cylinder of light weight plastic materials that provides a potential for low cost; however, the performance is relatively low. The other concept (Figure 30) is a point focusing system using a series of Fresnel lenses and disk receivers mounted on a pedestal. The cast acrylic lens system limits the optical efficiency to about 70 percent. Both studies were terminated at the end of the preliminary design phase.

Trough development efforts were initiated in 1978 to include in-house design and fabrication of an engineering prototype collector, design and demonstration of three different manufacturing concepts of parabolic trough collectors, and the technology transfer to industry of results and achievements. RFPs will be issued for collector fabrication. Tests and evaluations of these collectors will be conducted at CMTF, and efforts will be initiated to promote manufacturer utilization of the developed technology. Figure 31 presents the schedule for this effort.

A detailed program schedule/milestone chart breaking the Trough Development Project in 15 separate subtasks with a single individual responsible for each subtask has been prepared. The subtasks are Program Management, Engineering Prototype Collector, Receiver, Tracking, Drive, Foundations, Sheet Molding Compound Design Layout, Sheet Metal Design Layout, Sandwich Structure Design Layout, Glass Support, Stress Analyses, Thermal Analysis, Field Control, Materials Development, and Glass Development.

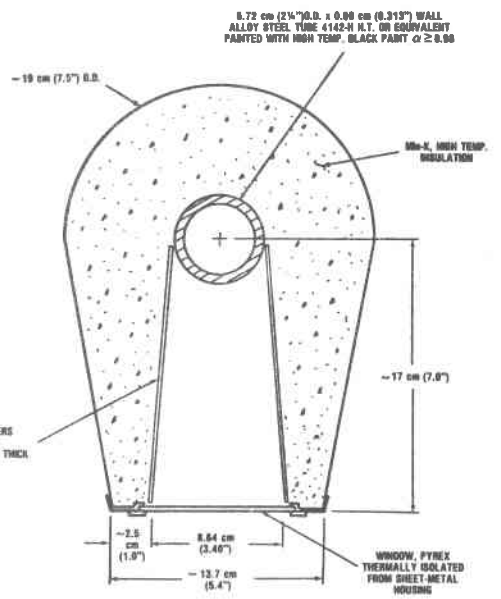


Figure 26. Section View of Itek Receiver

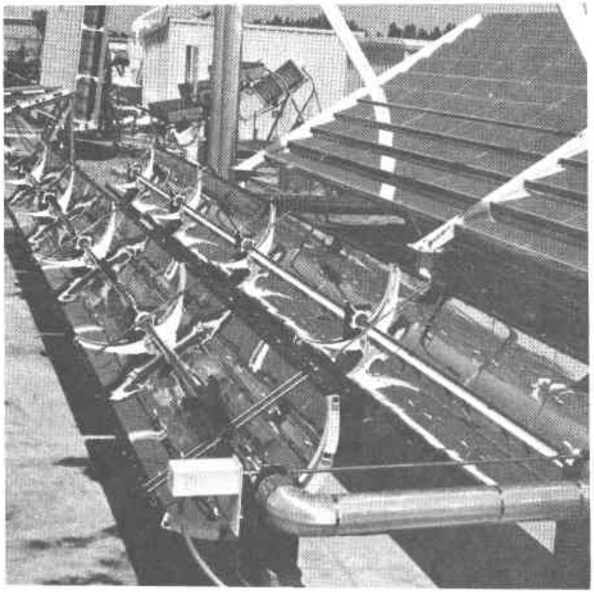


Figure 28. Del Solar Collector

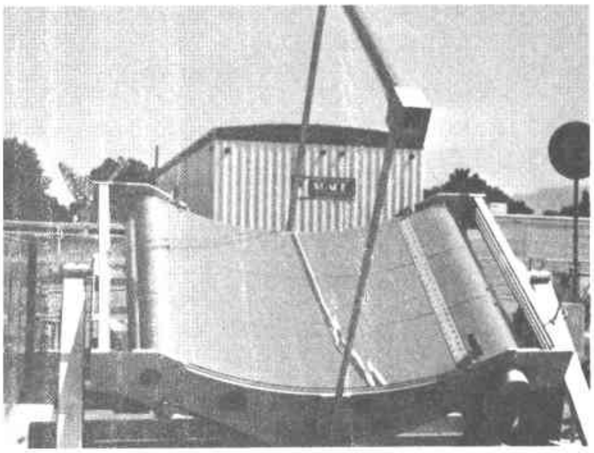


Figure 27. FMC Solar Collector

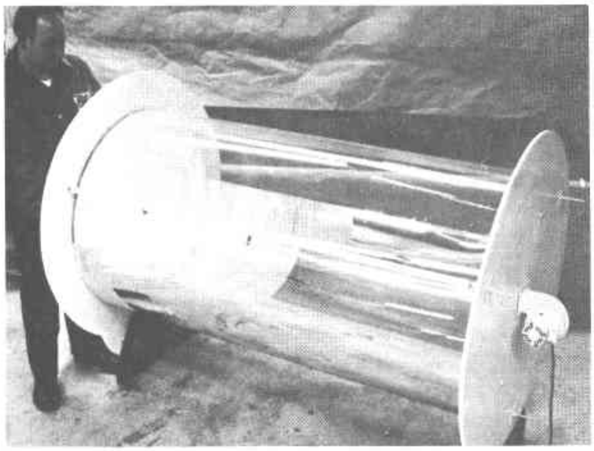


Figure 29. Air-Supported Collector Mockup (34 in. diameter x 5 ft)

Several significant program decisions have been made concerning wind loads, foundation requirements, and scope of the controls effort.

Refinements in the interpretation of the 90-mph wind survival requirements have been made to allow for, among other things, altitude scaling and wind fences. The sum total of all these new interpretations is to reduce aerodynamic forces by approximately 50 percent. The major effect of these new interpretations is that all new collector fields will require a wind fence of 50-percent porosity to survive 90-mph winds.

A foundations study has indicated that foundation costs can be safely re-

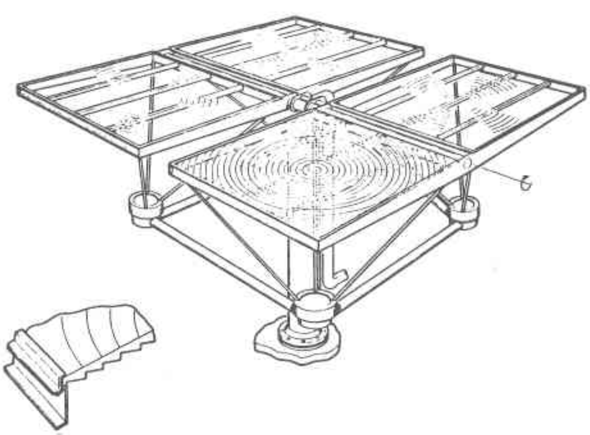


Figure 30. Large Circular Fresnel Lens Collector Assembly

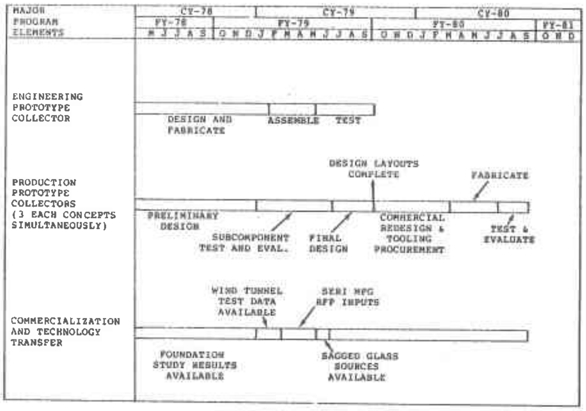


Figure 31. Trough Development Project Schedules

duced from present costs of over $3/ft^2$ of aperture area to less than $1/ft^2$ of aperture area.

The scope of the collector tracking effort has been expanded from controlling collector tracking to controlling the tracking and fluid control for a typical field of collectors. Present plans are to control tracking and fluid control from a single microprocessor system.

A test specification is being developed to provide definitive requirements for qualifying line-focus, parabolic trough thermal solar collectors. The specification uses ASHRAE 93-77, "Methods of Testing to Determine the Thermal Performance of Solar Collectors" for performance testing. In addition, tests are being developed to qualify collectors for environmental exposure and accelerated life and for acceptance and field inspection.

The objective of the Engineering Prototype Collector project is to demonstrate a high performance parabolic trough which has the potential for long life. Glass is being used for the reflector to meet this objective. Exotic technology such as high vacuum receivers will not be used to keep costs down.

Thin glass bonded to a steel backing sheet which is elastically deformed to the parabolic trough shape is the baseline design. The 2- x 6-m parabolic trough is a steel skin with aluminum core honeycomb structure. The honeycomb structures have a proven history of accurate surfaces and environmental stability from the structural materials evaluation project. Detailed finite element structural analysis shows the glass will survive 40-m/s wind loads and will have acceptable deflections during 14-m/s wind operate conditions. A contract for six trough structures was placed with Hexcel in September 1978.

Detailed all-day performance analysis has resulted in the selection of a 25.4-mm receiver tube enclosed in a 48-mm Pyrex glass tube with air in the annulus.

A microprocessor-controlled tracker using a fine wire flux sensor wrapped around the receiver tube will be evaluated on the prototype. Essential elements of the controller were breadboarded in the laboratory and the flux sensing wire was tested on the Solar Kinetics collector in the CMTF.

Detailed drawings of the support and drive system have been completed and quotes on piece parts are being obtained. It is anticipated that the collector will be assembled and ready for test in the CMTF by April 1979. The collector is expected to demonstrate a noontime efficiency of greater than 60 percent at 300°C.

Storage Development

The first series of silicone fluid tests in support of the Total Energy project at Shenandoah, Georgia, began in March 1978 employing 13 vessels containing various low cost filler materials (i.e., rock, iron). These tests were prematurely terminated due to problems in vessel design. Testing was resumed in June and a total of 12 materials have been evaluated for compatibility with Syltherm 800 at 3 temperature and 5 pressure combinations. To date, results have been gathered from over 41,000 vessel hours of testing. Results indicate a fairly reliable order ranking of acceptable solid filler material and methods to minimize fluid losses. Figures 32 and 33 show laboratory apparatus used to conduct these tests. Additional tests will be conducted to establish methods to accurately calculate fluid losses for any solid filler material used with Syltherm 800. A report will be published in 1979.

In order to assess the design concept for the high-temperature storage subsystem proposed for the Shenandoah project, a prototype subscale rock and trickle flow subsystem was designed and tested. The results confirmed concurrent studies that this concept produced an inhomogeneous three-phase, three-component operation which limited reliable scaling for physical size and energy transfer rate to full scale application.

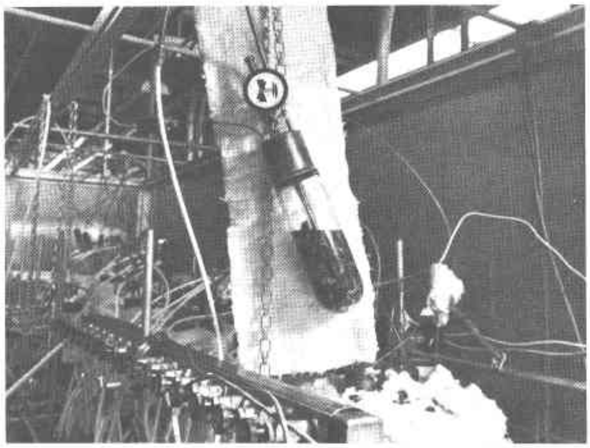


Figure 32. Silicone Fluid Test Equipment

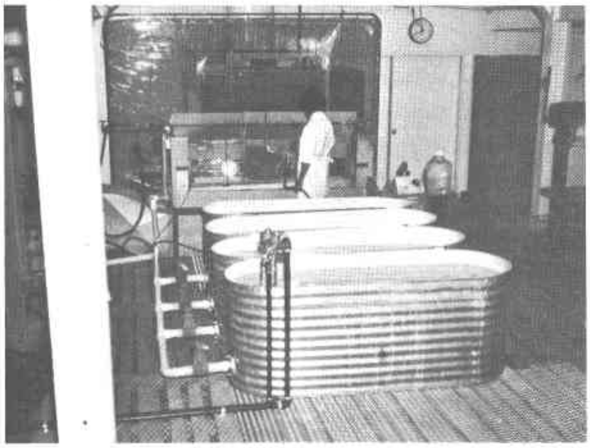


Figure 33. Silicone Fluid Test Equipment

Prime Mover Development

To obtain an extraction steam-turbine generator that would meet the requirements for the Total Energy

Project at Shenandoah, Georgia, RFQs were issued in March 1978 to 13 potential suppliers. A contract was signed in May; the detail design study was completed in August 1978; and detail design is currently underway for a four-stage pressure-compounded machine. Component fabrication and assembly will be completed by August 1979, testing by November, followed by shipment and installation at Shenandoah, Georgia.

Operation and Maintenance Characterization

Because specular reflectance is of primary importance in maintaining collector efficiency, it was necessary to investigate cleaning agents and techniques. During FY 1978, an investigation was initiated by McDonnell Douglas of conditions for geographical locations of the southwest desert region and the Atlanta, Georgia, region. This work is now underway with the installation of test mirrors at four locations. The tests will be completed in FY 1979.

Prior to FY 1978, a prototype Laser Ray Trace indoor system was in use that is capable of testing 2- by 4-ft parabolic troughs and a larger portable field system had been designed and construction initiated. During FY 1978, the prototype indoor system was modified (Figure 34) and used extensively. Currently, a larger, more general indoor system is being built and will be operational in December 1978. Also during FY 1978, the field system (Figure 35) was completed and put into operation at the MSSTF. An improved version of the field system is currently being designed and will be in use early in FY 1979.

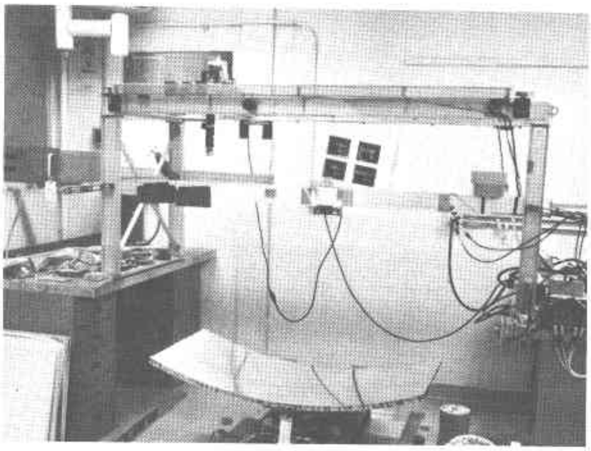


Figure 34. Sandia Indoor Laser Ray Trace Tester Prototype

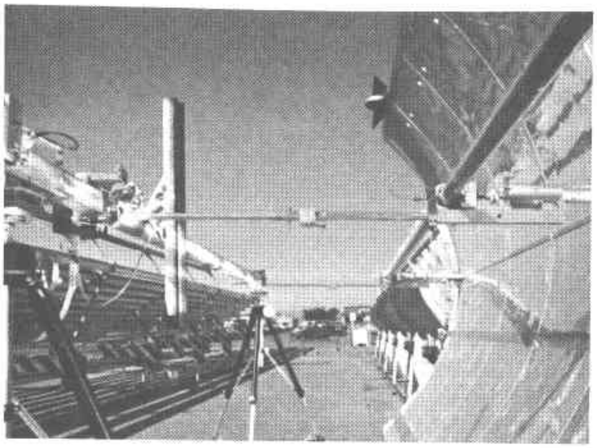


Figure 35. Sandia Field Laser Ray Trace Tester (Aligned Sandia Collector)

Solar Total Energy Systems

Applications Analysis

The Solar Total Energy Systems (STES) Program Mission Analysis objective is to support the DOE-STES with program planning, formulation, and coordination of the various projects. The work includes review and evaluation of current studies, the comparisons of STES with other total energy systems, assessment of the applicability of advanced technologies to STES, determination of STES market potential, and identification of institutional, financial, and other incentives and barriers to STES commercialization.

The STES mission analysis began in March 1977 with a market penetration analysis of STES in the industrial, residential, and commercial sectors. Final reports presented the results of a STES cost-effectiveness study and documented the STES Systems Applications Model, Market Penetration Model, and energy use and price projections. Some applications were found cost effective for 1985 with significant penetration through the 1990s and almost 2 quads/year of fuel savings by the year 2000.

In FY 1978, results of the previous Market Penetration Analysis and Industrial Applications Analysis were studied and compared. These results differ with respect to the initial market penetration date, primarily because of differences in projected fuel prices. Market penetration is expected between 1985 and 1995 depending upon projected fuel costs, collector costs, and government tax policy. A survey of industrial concerns with a high potential for STES applications revealed that land availability for a solar energy collector field is a major physical constraint for STES applications. Recommendations made as a result of this study included (1) a wider dissemination of information and other solar options to industry, (2) analysis of STES benefits in locations where EPA regulations limit plant expansion, and (3) financing short, aggressive development/demonstration programs to answer industry's concerns about technical risks.

A study of institutional factors involved in solar applications led to the following consideration: An appropriate method for resolving utility/consumer relations where solar generating equipment is involved would be to contract directly with utilities to test solar facilities on customer installations. This procedure allows the state public service commissions and the equipment manufacturers to become involved, while performing their normal functions, on a case-by-case basis. This recommendation was made and such a plan will be developed during FY 1979.

During FY 1979, application analysis will be expanded to include mission analysis for all Solar Small Power System Applications and Remote (Irrigation) Solar Power Systems from 0.1 to 10.0 MW_e including an implementation plan for development of Remote Solar Power Systems. Monitoring of the Mississippi State University Resource Study will be continued.

A review and cataloging of heat engines that are either available or under active development will be completed during the third quarter of FY 1979. Heat engines capable of reducing collector field sizes through increased efficiency are of particular interest.

The application of STES to a residential/commercial community will be studied in comparison with use of other total energy and conventional systems, and the effect of community energy conservation will be determined.

Methods of delineating and resolving institutional problems that arise from including solar powered systems on an electric grid will be examined by discussion with equipment manufacturers and electric utilities. Efforts will be coordinated with the Division of Electrical Energy Systems to ensure safe, controllable, and beneficial coupling of STES with the electric grid system.

As an extention of the completed STES market assessment, the potential application and markets for STES in industries with process heat requirements above 320°C will be examined.

Fort Hood Project

The Fort Hood Solar Total Energy Project objectives include demonstrating the technical, economic, and institutional feasibility of the solar total energy concept and promoting within an appropriate industrial sector a technology that offers the prospect of being economically competitive with other energy sources. This large-scale experiment (LSE-1) is located at Fort Hood's 87000 Troop Housing Complex near Killeen, Texas, as indicated on Figures 36 and 37. Figure 38 is a photograph of a

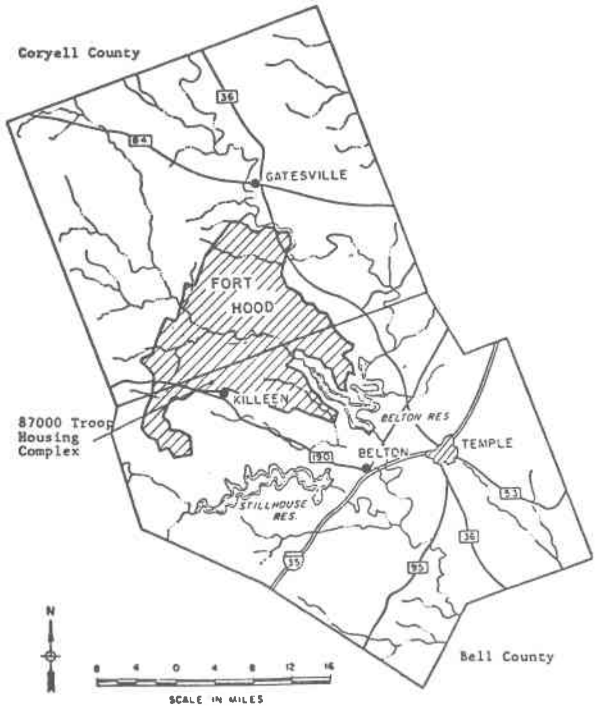


Figure 36. Location of the 87,000 Troop Housing Complex at Fort Hood

scale model of the system as it will appear when installed at the complex. The collector field is at the right, and the balance of the system (storage tanks, equipment building, etc.) is immediately to the left of the collector field. The entire barracks complex lies across the street to the left of the solar total energy system.

A simplified schematic diagram of the Fort Hood System is shown in Figure 39 and key system data are summarized in Table 2. The preliminary design includes approximately 125,000 ft^2 (aperture) of parabolic trough concentrating collectors in a unique collector field layout with feed-forward temperature control. During normal operation, 550°F heat-transfer oil from the collector field is used to generate superheated steam to drive a conventional 250-kW turbine-generator set. Consis-

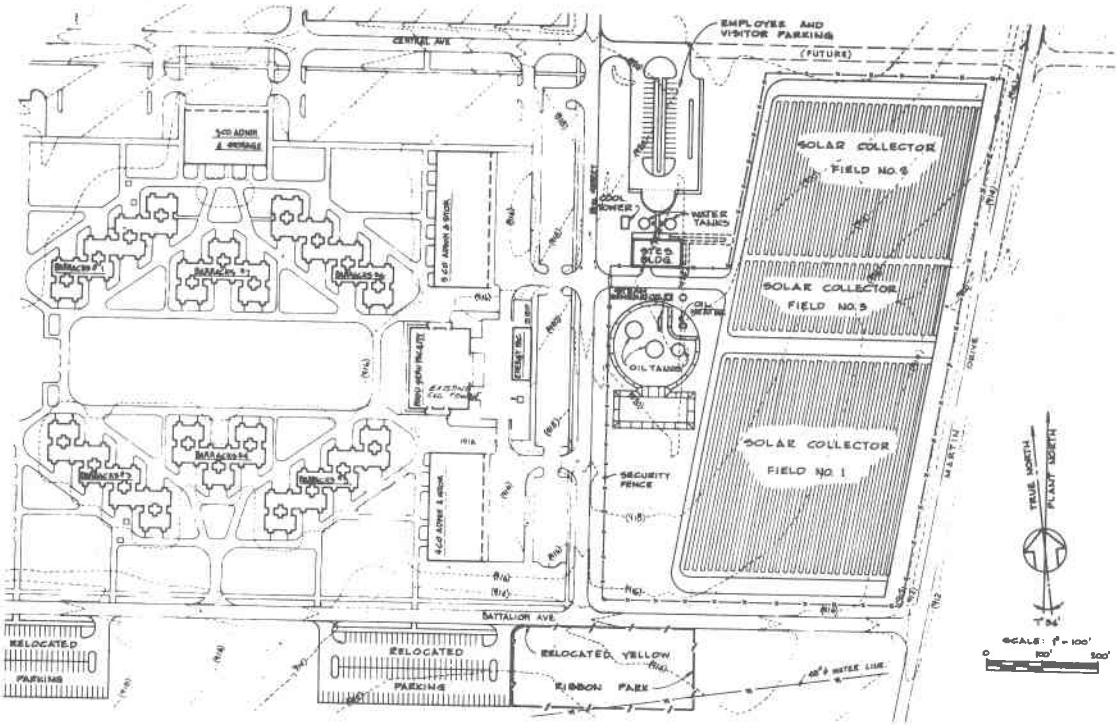


Figure 37. Fort Hood Overall Site Plan

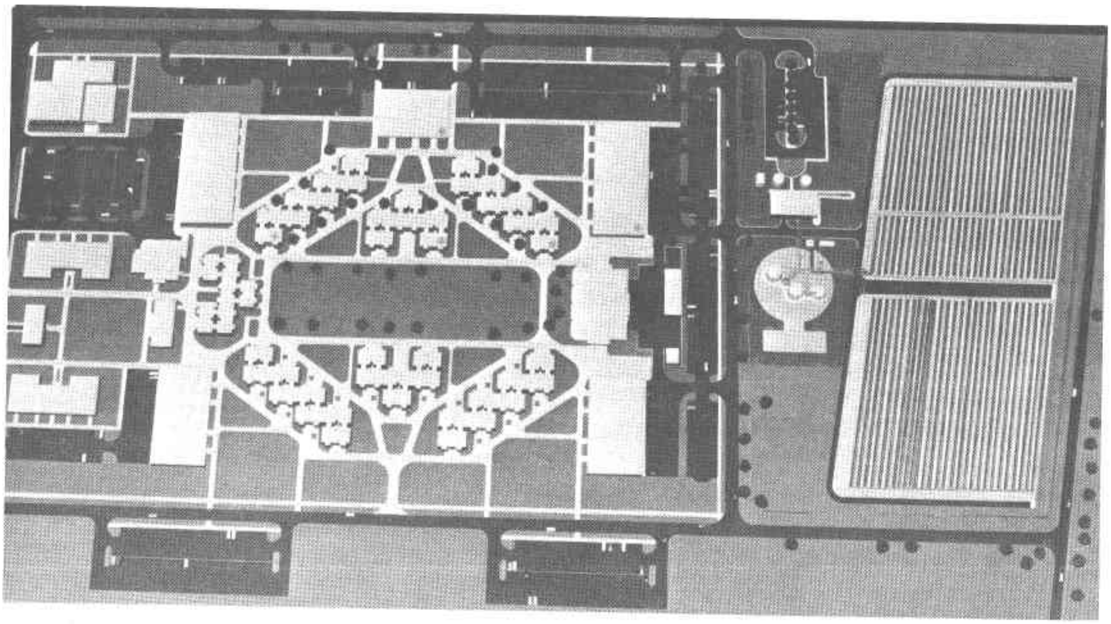


Figure 38. Scale Model of Fort Hood Solar Total Energy System and 87000 Complex

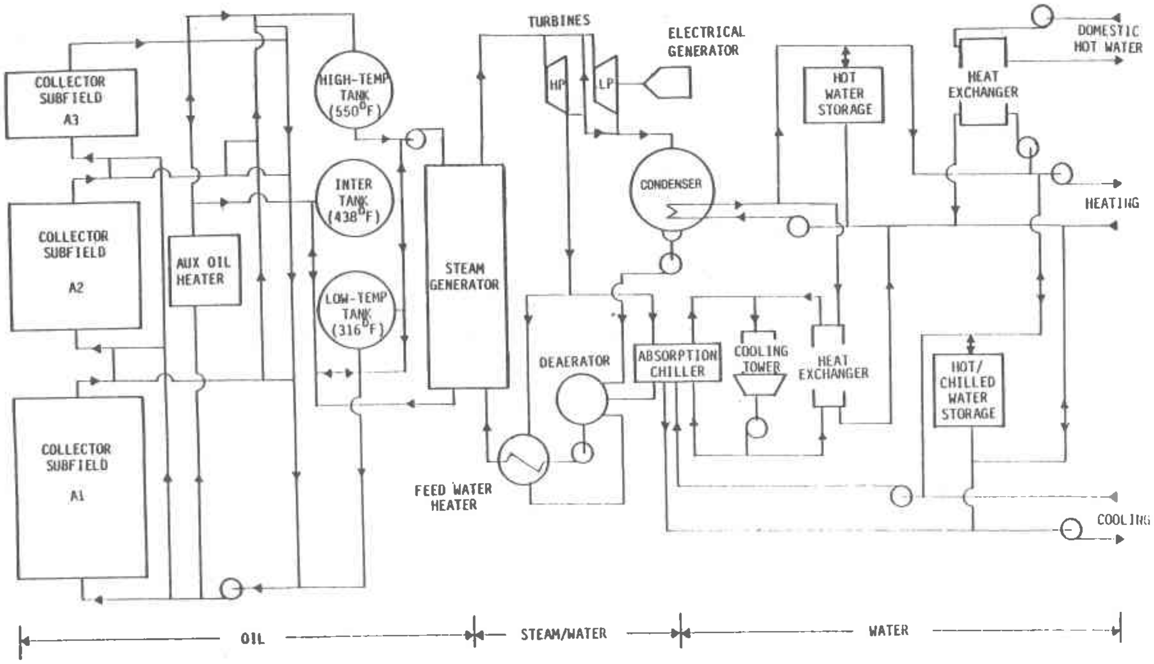


Figure 39. Schematic Diagram of Fort Hood Solar Total Energy System

Table 2. Fort Hood Solar Total Energy System Characteristics and Parameters

COLLECTOR

TYPE: Parabolic Trough (~N-S aligned)
FIELD SIZE: 125,000 ft² (aperture)
HEAT-TRANSFER FLUID: Sun 21 (paraffinic oil)
INLET TEMPERATURE: 316°F
OUTLET TEMPERATURE: 550°F
PEAK OUTPUT: 16.7 x 10^6 Btu/hr

AUXILIARY HEATER

TYPE: Oil Fired
RATING: 5 x 10^6 Btu/hr

HIGH-TEMPERATURE THERMAL STORAGE

APPROACH: Sensible Heat in Sun 21
HIGH-TEMP. TANK: 33,662 gal @ 550°F
INTERMEDIATE-TEMP: 116,771 gal @ 438°F
LOW-TEMP. TANK: 109,141 gal @ 316°F

STEAM GENERATOR

TYPE: Unfired Three-Stage Counterflow Heat Exchanger
RATING: High-Temperature--6000 lb/hr superheated steam @ 500°F and 315 psia
Intermediate-Temp.--4012 lb/hr saturated steam @ 298°F and 65 psia

STEAM TURBINE

TYPE: Two Single-Stage Units to Simulate Multistage Turbine
HIGH-PRESSURE UNIT: 315 psia @ 500°F
LOW-PRESSURE UNIT: 65 psia @ 304°F

ELECTRICAL GENERATOR

TYPE: Synchronous
RATING: 250 kW (nominal) @ 480 volts

COOLING SYSTEM

TYPE: Two-stage Absorption
CAPACITY: 175 tons
LOAD: 49x10^6 Btu/day (summer day full load)
STORAGE: 41,000 gal @ 140°F (minimum)

HEATING SYSTEM

TYPE: Hot Water
LOAD: 66x10^6 Btu/day (winter day full load)
STORAGE: 41,000 gal @ 140°F (minimum)

DOMESTIC HOT WATER

LOAD: 20x10^6 Btu/day
STORAGE: 25,000 gal @ 140°F (maximum)

tent with the definition of a total energy system, the turbine exhaust is the heat source for absorption air conditioning, space heating, and domestic water heating.

A high-temperature thermal storage subsystem provides hot heat-transfer oil for producing steam for night operation, and dual-purpose tanks store hot and chilled water for the thermal applications. A fossil-fueled auxiliary heater provides backup to the collector field during extended periods of poor insolation. The highly flexible system has numerous operating modes, and the mode of operation at a particular time depends upon both real-time and projected energy demands and energy supply. Operations are monitored and controlled by a digital system which includes a central minicomputer and distributed microprocessors.

As a large scale experiment, the Fort Hood Project is directed toward developing experience with large hardware systems and establishing the engineering capability required for subsequent demonstrations. This large scale experiment is a military application of solar total energy, but is essentially residential in nature because it is limited to a barracks complex.

The system design goals are to provide over 50 percent of the thermal energy (space heating, cooling, and domestic hot water) required annually by five buildings with a total floor area of approximately 156,000 ft^2, and to provide an average gross electrical output of approximately 1600 kWh per day. The thermal output will be interfaced with the existing mechanical systems at the barracks complex, and the electrical output will be synchronized for parallel operation with the existing electrical system. Thus, consistent with the experimental nature of the solar total energy system, it may be shut down temporarily for adjustments or modifications without interfering with normal activities at the site.

The Fort Hood Project was initiated in 1974 under National Science Foundation sponsorship. The project was transferred to ERDA in 1975 (and subsequently to DOE), and initial conceptual design studies were completed in 1976. A design competition was conducted in 1977 to finalize the conceptual design approach. The preliminary design for the Fort Hood system was initiated March 1, 1978, and scheduled for completion October 31, 1978.

Major managerial accomplishments during FY 1978 included the following:

- Assembled an effective project team consisting of American Technological University with subcontract support from Westinghouse Electric Corporation, Georgia Institute of Technology, and Heery and Heery, Inc., and with technical monitoring by The Aerospace Corporation;
- Negotiated the Phase III contract within project funding;
- Obtained Fort Hood concurrence with project objectives and installation site interfaces;
- Obtained approval from Texas Power and Light Company for parallel electrical operation;
- Prepared RFP for collector field procurement;

- Completed project cost analysis; and
- Established construction phase project organization.

Major technical accomplishments during the same period were:

- Established optimum system size;
- Completed functional system design;
- Completed preliminary design of subsystems;
- Devised innovative feed-forward control scheme for solar collector field;
- Developed preliminary specifications for all major components;
- Completed system model;
- Prepared project briefing materials and brochures;
- Verified Fort Hood insolation model; and
- Implemented comprehensive measurements to verify system loads.

Following completion of the preliminary design phase on October 31, 1978,* a 10-month definitive design phase is planned. Highlights of the FY 1979 plans are the following:

- Negotiate Phase IV contracts without interruption of progress;
- Update and finalize system design;
- Validate feed-forward collector field control scheme;
- Issue RFP for collector field;
- Initiate procurement of long-lead time items, including power conversion and thermal storage subsystems;
- Complete site preparation and facility installation specifications;
- Initiate preparation of collector-field site;
- Initiate software development for control system;
- Develop program plan for construction phase; and
- Prepare test plan for 2-year operational testing phase.

Definitive design will be followed by a 16-month construction period with system completion scheduled for January 1981. After initial start-up, the system will be operated in an experimental mode for 2 years, during which time numerous tests will be conducted and data will be collected and analyzed. The project phasing is shown in Figure 40.

*Subsequent actions by DOE place this plan under review and it may be significantly modified.

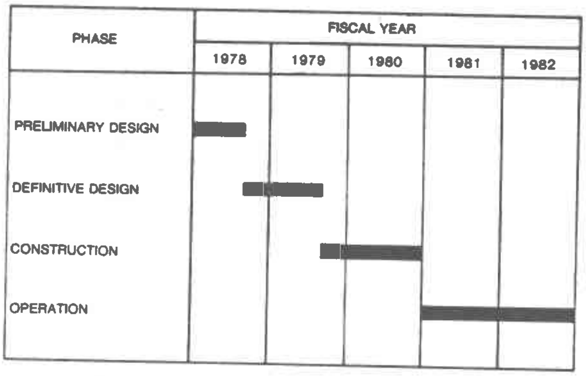


Figure 40. Fort Hood Project Phasing

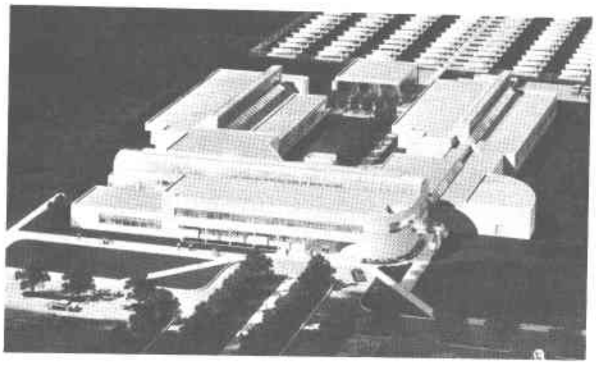


Figure 41. MCCC Building Complex

Mississippi County Community College Project

The Mississippi County Community College (MCCC) Project is a Total Energy System* that utilizes photovoltaic and thermal energy conversion that has been incorporated into the design and construction of a new college building complex at Blytheville, Arkansas. The intent is to provide a demonstration of solar total energy utilization, energy-conserving design, and adaptive facility operating practices which take advantage of the characteristics of solar energy supply systems in a higher-education institution. The design incorporates a U-shaped building complex plus a small utilities building in which the space cooling, lighting, and ventilation are provided by photovoltaic (PV) cells mounted in 20:1 solar concentrators (as indicated by Figures 41 and 42), and the space heating is accomplished by circulating hot water which discharges from the PV cell cooling system, as indicated by Figure 43.

The project was initiated in mid-August 1977 and is operated under a

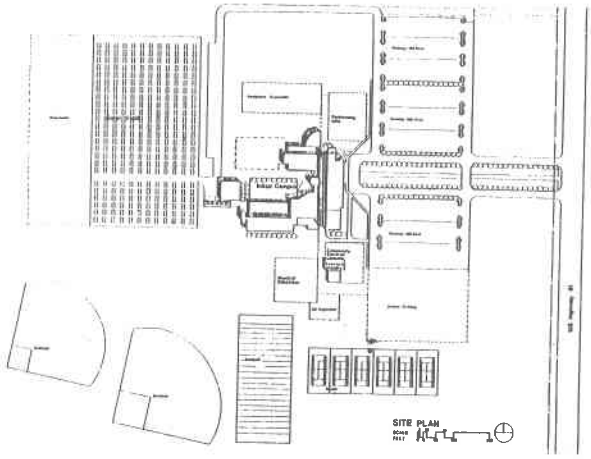


Figure 42. MCCC Site Plan

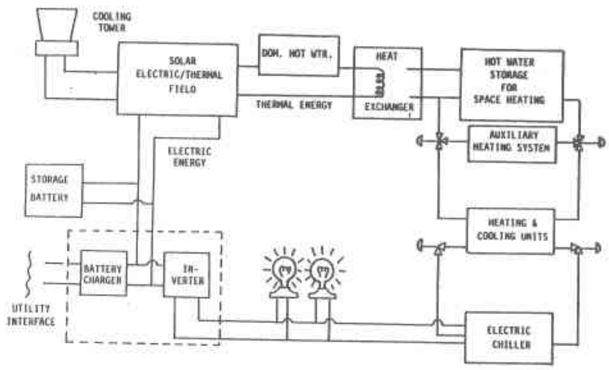


Figure 43. MCCC Total Energy System

*Project management during FY 1978 was under the Total Energy Projects of the Solar Thermal Power Systems Program; subsequently, the management was assigned to the Photovoltaic Systems Program.

fixed grant from DOE to MCCC. The project management organization is shown in Figure 44. A development contract for the solar concentrating mount was awarded to Honeywell, Inc., and a second development contract for a storage battery was awarded to GEL, Inc., of Durham, North Carolina. In both cases, the contractors were to construct and test a working prototype that would typify a full-scale module; if successful, the contractor would be awarded an order for a sufficient number of modules and their associated accessory equipment to constitute a full system component for the MCCC project. Preliminary purchase specifications for the PV cells were also prepared. Detailed design on the building complex was begun by Cromwell, Neyland, Truemper, Levy and Gatchet, Inc. (CNTLG) of Little Rock, Arkansas, the project architects.

Site grading commenced in late October 1977; the building design concept was approved by the MCCC Board of Trustees on October 12; and detailed design was begun. An Energy Conservation Plan draft was prepared in

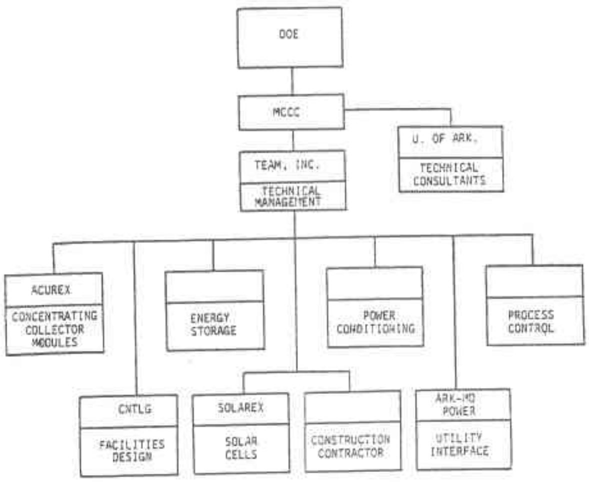


Figure 44. MCCC Project Organization

November and revised during the next 3 months. At a review meeting with DOE-Conservation personnel in mid-February, a decision was made to seek a computer analysis of the building's energy consumption during a typical year at the college site. Therefore, analysis using the DOD code BLAST was started. At approximately the same time, Oak Ridge National Laboratory (ORNL) conducted an independent analysis using the DOE-1 code. A simplified model of the solar power supply was prepared by ORNL to investigate the match between supply capability and building requirements.

Although different assumptions were made, the results from DOE-1 and BLAST calculations are encouragingly supportive of one another. Also, the first estimate of the capability of the solar power supply to meet the campus energy requirements (over 80 percent) suggests generally good matching between supply and load.

A more rigorous model of the solar power supply is being developed on the ORNL hybrid computer for use in future analyses. Because work on the design was suspended during the approximately 2-month period while the analyses were being performed, the bid package was not completed until July 1978. Most major construction contractors were committed by that time. Bids were few, and were at least 33 percent over the architects' estimates of \$2.7 million. All bids were rejected by the MCCC Board of Trustees. Design modifications are now progressing, including a reduction of building sizes for a combined total of $\sim$51,500 ft^2; a new bid package is anticipated in mid-October 1978.

The winning bid for single-crystal Si photovoltaic cells with 12- to 14-percent efficiency at 55°C was submitted by Solarex, Inc., of Frederick, Maryland (Figure 45). The effective price of the cells, assuming 14-percent efficiency and net illumination of 15 suns, would be just over $3.00 per peak watt. A portion of the cells has been manufactured, and production schedules are being met. Sample batches have been tested, using the Honeywell prototype concentrator. Efficiencies of about 14 percent have been observed.

Under its development contract, Honeywell, Inc., undertook to design, build, and test a concentrator prototype by the end of July 1978. The design employed a flat Fresnel reflector with a 20:1 geometric concentration ratio and E-W tracking about a manually tiltable N-S axis. The cells were cooled by a closed, forced-convection cooling loop that would also furnish hot water for building heating. An intermediate model, Engineering Test Model (ETM), was constructed (Figure 46). The ETM was subsequently converted to the final prototype design and retested. The design was judged to be qualified; however, the manufacturing cost of the prototype was higher than orginally anticipated. A competitive procurement followed the prototype contract, and a parabolic trough design by Acurex, Inc., was the winning concept (Figures 47 and 48). Using the design day peak system concentrator, cost was estimated at $4.50

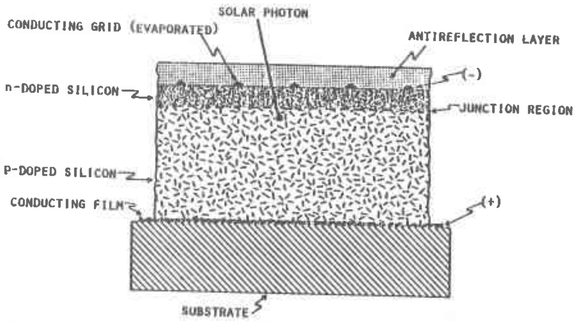


Figure 45. Schematic Cross-Section of Solarex np Photovoltaic Cell

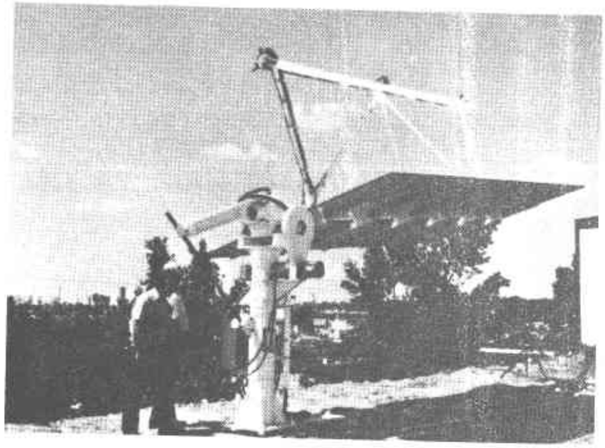


Figure 46. Honeywell Solar Concentrator

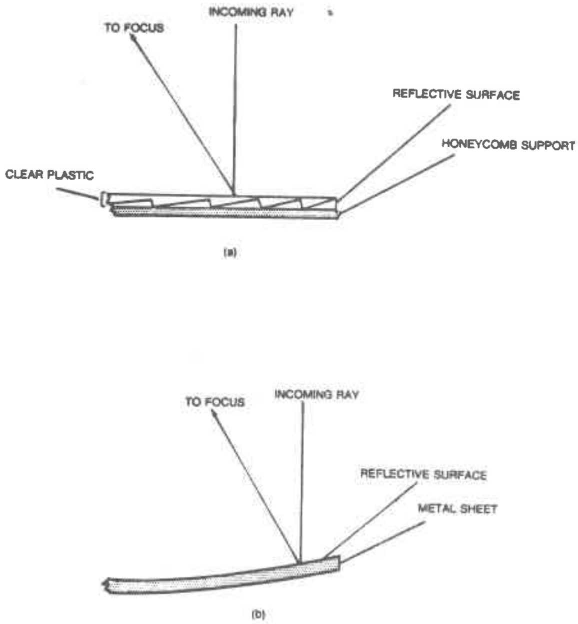


Figure 47. (a) Honeywell Concentrator Concept and (b) Acurex Concentrator Concept

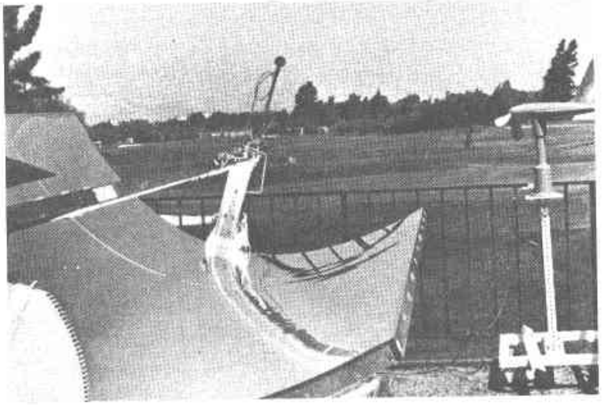


Figure 48. Acurex Concentrator

per peak W_e, exclusive of PV cells. Field layout drawings adequate for the cost estimates of solar field site preparation were furnished by Acurex.

At the inception of the project, a development contract for a 10-kW working prototype battery module was awarded to GEL, Inc., of Durham, North Carolina. Working single-cell models of the Iron-Redox design were fabricated with electrodes of up to a 1-ft^2 active electrode area (Figures 49 and 50). A 26-cell battery was assembled and operated briefly in early February, with the expressed intention of developing 8.5-ft^2 cells for the 10-kW

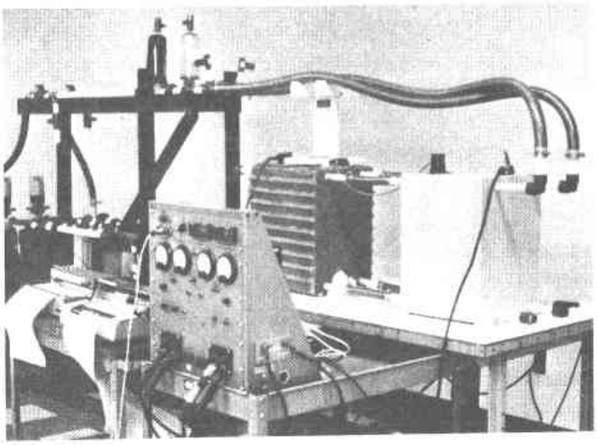


Figure 49. MCCC Redox Battery Prototypes

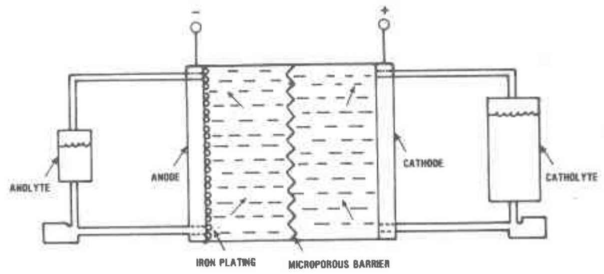


Figure 50. A Single Iron-Redox Cell Showing Electrolyte Flow Circuits

prototype. Subsequently, GEL proposed that its prototype consist of ganged batteries using 1-ft^2 components; this was approved. By the end of the development contract period, GEL succeeded in building and testing an 8-unit array of 41-cell batteries capable of producing ~4 kW for 10 hours at a nominal 220 volts. The best individual batteries produced internal energy efficiencies between 45 and 50 percent, over the the 8-hr-charge, 10-hr-discharge cycle. If pumping power, pH adjustment requirements and other parasitic loads are accounted for, actual efficiencies should be lower by several percent.

Independent estimates for producing a complete MCCC storage bank using the GEL design indicated a potential cost of \$1.1 million or more (roughly four times the cost of a competing lead-acid battery bank). The Iron-Redox concept is no longer being considered due to its cost and need for additional development. A request for vendor qualifications from lead-acid battery manufacturers was to be issued on September 27, 1978.

Bids for the new energy storage bank will be requested in October 1978. A different power conversion system employing a single 300-kW line-commutated inverter will probably be used.

Bids on the redesigned buildings complex will be requested during October 1979, with contract award in late November. Beneficial occupancy of the services building is anticipated by mid-May 1980, at which time connections to the solar field and installation of the battery bank can commence. Occupancy of the school building is anticipated by the end of August 1980.

Shenandoah, Georgia, Knitwear Plant Experiment

The Shenandoah experiment is part of the STES Program which undertakes the design, construction, and operation of solar total energy systems for the purpose of demonstrating technical feasibility of appropriate technologies and for stimulating private industry to participate, both as manufacturers and as users. The objectives of the program are to (1) develop within industry, the engineering and development experience on large scale solar total energy systems; (2) acquire data to reduce the uncertainties of cost and performance predictions; (3) assess the interactions of solar total energy technology in an industrial application and with an electric utility system interface; and (4) ensure dissemination of technical data to provide a basis for expanded growth of solar total energy.

This project is the first industrial application of the solar total energy concept. The Bleyle knitwear factory (Figures 51, 52, and 53), the site application (1 of 16 as indicated in Figure 54), was proposed by the Georgia Power Company and its team in answer to the RFQ issued in spring 1977. The factory was fitted with the necessary equipments to interface with energy forms from the solar system during

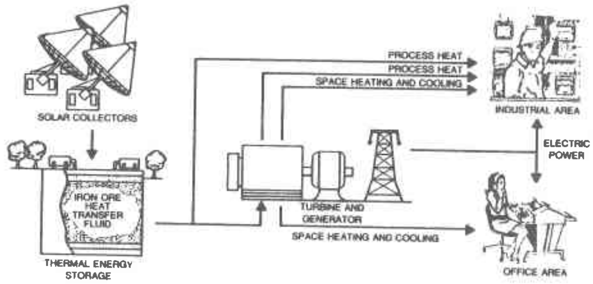


Figure 51. Simplified Schematic of the Solar Total Energy Large-Scale Experiment at Shenandoah

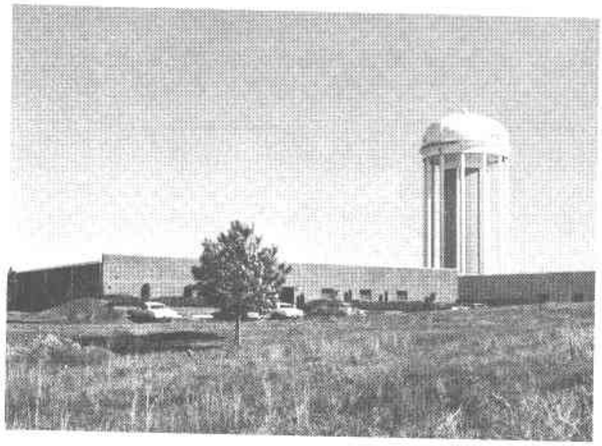


Figure 52. Bleyle Knitwear Plant

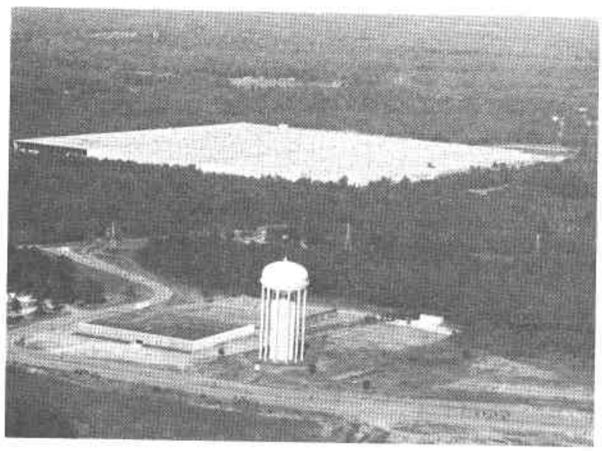


Figure 53. Aerial Photograph (Looking North) of Bleyle Plant

factory construction which was completed in December 1977.

From among 17 applicants submitting proposals for the conceptual design of a solar total energy system, 5 were selected. Of the five finalists, three contenders were asked to submit proposals directed to fulfilling Shenandoah requirements. General Electric Company, Space Division, was declared the Conceptual Design winner for the Shenandoah experiment and was awarded a 10-month contract to pursue a preliminary design for the knitwear factory application. The total program schedule is shown in Figure 55.

An on-site weather station (Figure 56) was established in late FY 1977 to provide solar and weather data for correlation with a solar model year synthesized from a 25-year collection of weather data for Atlanta (the nearest weather station with usable information). This model year is being used as the weather input for the initial design of the solar system for the knitwear application.

The Bleyle building was redesigned to include energy conservation features as a result of the DOE Cooperative Agreement with Georgia Power Company. This redesign resulted in a predicted 46-percent annual energy saving and a net reduction in factory cost. Initial production activity was started in the knitwear factory in November 1977 with a skeleton crew. By the end of FY 1978, the plant was operating in two shifts with a total of 52 employees. The Bleyle knitwear factory received the 1978 Energy Efficiency Competition Award for new industrial construction from the South-

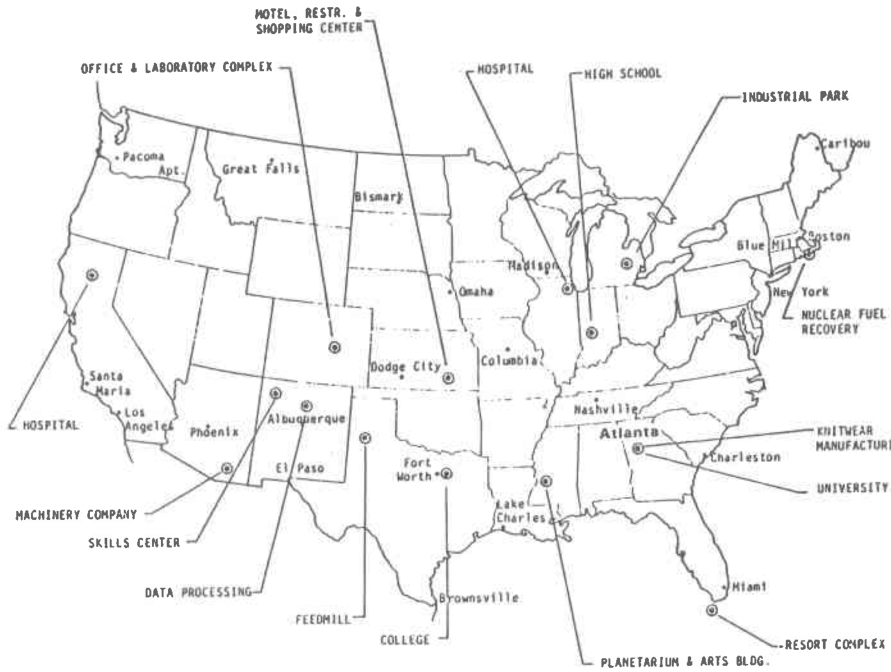


Figure 54. Responses to DOE Request for STE-LSE Site/Application Proposals

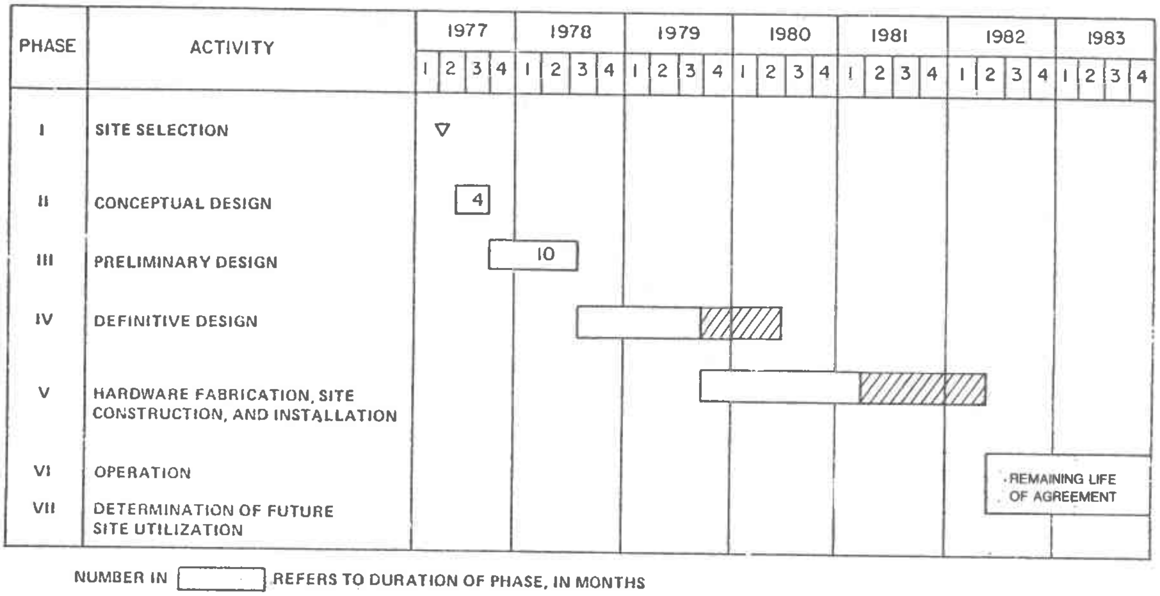


Figure 55. Solar Total Energy — Large-Scale Experiment Program Reference Schedule

eastern Electric Exchange (a group of southeastern electric utility companies).

Georgia Power Company installed instrumentation to monitor the energy demands (electrical and thermal) of the plant, and data collection was inaugurated in early summer 1978 (Figure 56). These data are extrapolated to requirements which would be imposed by a factory expansion from the present 25,000 ft^2 to 42,000 ft^2 for establishing the required solar system capabilities.

The solar system site installation was dedicated in July 1978. The preliminary design of the solar energy system evolved from a concept of subsystems in early FY 1978 to a substantive system of realistic "hardwarable" parts at the end of FY 1978. As the application demands, weather and solar data, operating philosophy, and budgetary constraints became better defined.

A system of 192, 7-m parabolic dish collectors (Figures 57 and 58) is planned* to satisfy at least 60 percent of the total annual energy usable, estimated for the expanded 42,000-ft^2

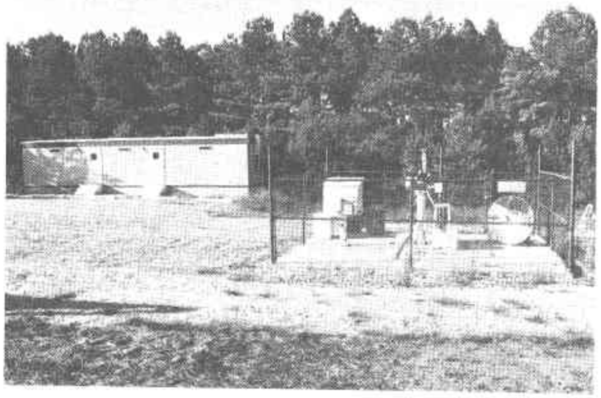


Figure 56. Government-Supplied Weather Station and Mobile Instrumentation and Data Acquisition Center (Shenandoah Site)

*This plan is under review at DOE and may be modified.

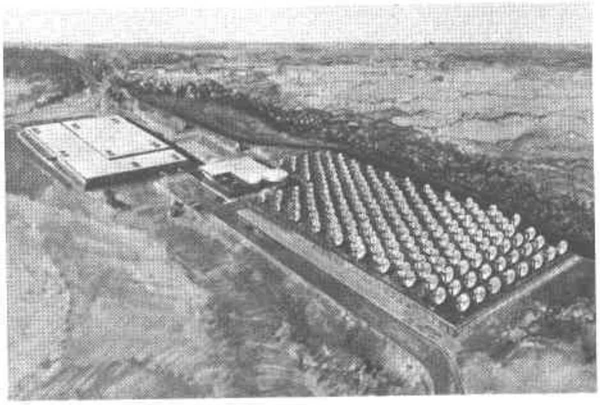


Figure 57. Solar Total Energy — Large-Scale Experiment at Shenandoah, Georgia

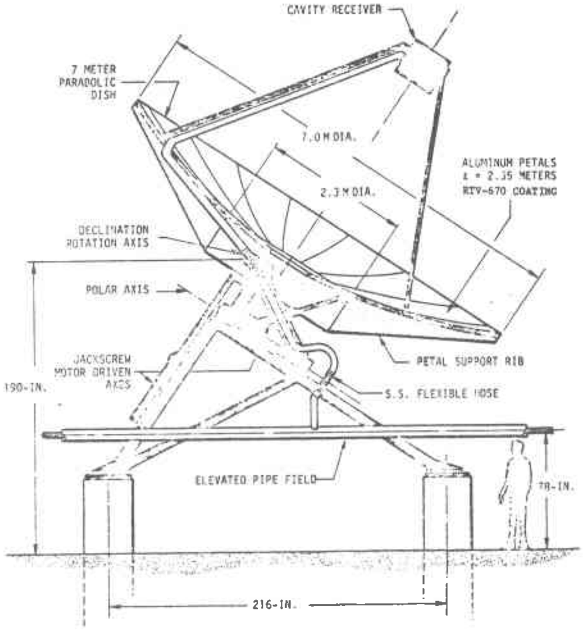


Figure 58. Shenandoah Parabolic Dish Solar Collector to be used at Shenandoah STE-LSE

plant. The energy demands are a 260-kW electrical load, a 1380-lb/hr, 337°F process steam load, a 525,000-Btu/hr office area winter heating load, and a 143-ton factory-year-round air conditioning load with the insolation predicted for the area.

A four-tank storage system is proposed for accumulating the excess collected energy for subsequent use during periods of low or no insolation. The storage medium will be iron ore (~3/8 in. ϕ) to which energy is transferred by "trickling" hot silicone oil over it. The "trickle" concept is proposed to reduce the fluid inventory of the silicone oil which costs approximately $16/gal (Figure 59).

A four stage steam-Rankine turbine with intermediate extraction and full condensing output will power the 500-kV-A generator. The extracted steam provides the thermal process needs, and the condensed output provides the HVAC requirements of the plant and the solar system operations facility.

The thermal utilization system is configured to provide the simultaneous heating and air conditioning needs required by the knitwear plant (e.g., office area heat, factory area air conditioning in winter). The total system is shown schematically in Figure 60. Table 3 describes the four major components of the system.

A prototype parabolic dish collector was fabricated from a Scientific-Atlanta 5-m dish antenna by adhering an FEK-244 (3M Company)

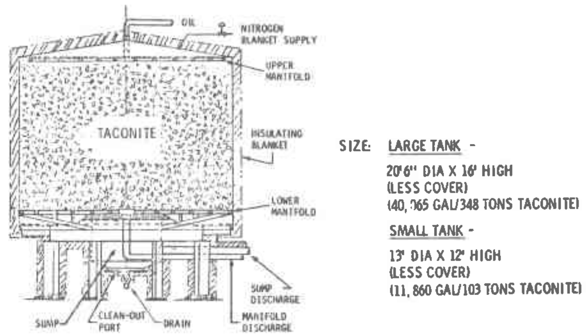


Figure 59. Dual-Media Test Tank

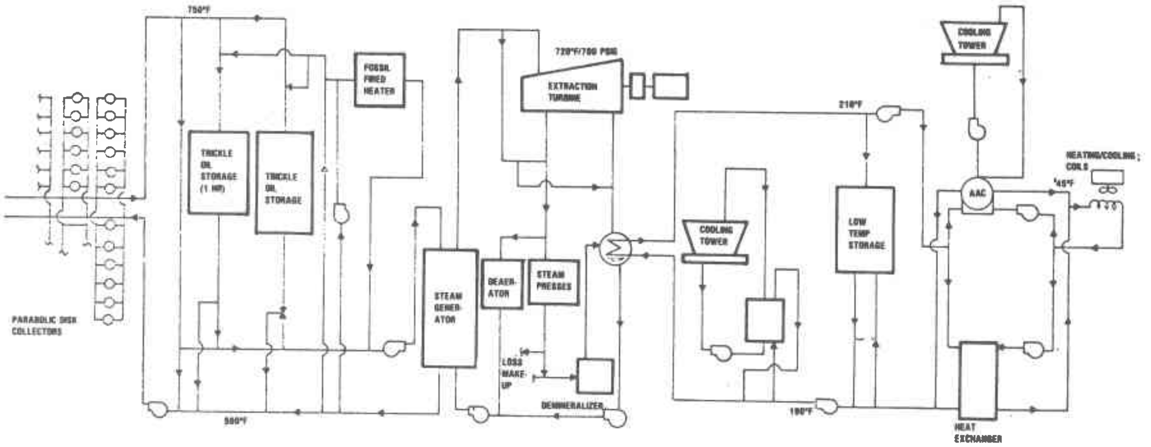


Figure 60. Baseline Design Concept for STE-LSE at Shenandoah, Georgia

Table 3. Preliminary Specifications for Major Items of Equipment (May 1978)

COLLECTOR FIELD

Type: Parabolic Dish
Size: 7-m dia
Area: 79,500 ft²
Fluid: Dow Corning Syltherm TM 800
Outlet Temperature Collector: 750°F
Minimum Inlet Temperature Collector: 500°F
Maximum Fluid Flow Rate: 387 gpm
Minimum Collectible Insolation: 50 Btu/hr-ft²

TURBINE-GENERATOR SET

Cycle: Rankine Turbine
Working Fluid: Steam
Admission: Multivalve
Stages: Multiple
Pressure Ratio: 140
Inlet Condition: 720°F/700 psig
Extraction Steam Condition: 105 psig
Condensing Condition: 5 psig
Generator: Brushless Air Cooled
Maximum Rating: 400 kW

HIGH-TEMPERATURE THERMAL STORAGE

Type: Trickle Oil
Volume: 17,600 ft³
Size: 13 ft dia, 12 ft high (1 tank) 20.6 ft dia, 16 ft high (3 tanks)
Storage Medium: Iron Ore
Void Fraction: 40%
Temperature Change: 250°F
Capacity: 100 million Btu
Maximum Charge/Discharge Rate: 16/8.2 million Btu/hr
Insulation Thickness: 12 in.
Oil Inventory: 11,225 gal

LOW-TEMPERATURE THERMAL STORAGE

Type: Stratified Water
Volume: 120,000 gal
Size: 18 ft dia, 63 ft long
Storage Medium: Water
Temperature Range: 210°F - 190°F
Capacity: 20 million Btu
Insulation Thickness: 4 in.

reflective film to the surface (Figure 61). A cavity receiver (Figure 62) using stainless steel tubing, was mounted on the dish, and the unit was tested for several months at the Sandia Collector Module Test Facility. Subsequently, indicated receiver modifications were implemented, tests were rerun, and significant improvements were noted. These tests have had an invaluable influence on the design of the collector.

A small scale model of the trickle oil storage system was treated at GE's Evendale, Ohio, facility (Figure 63).

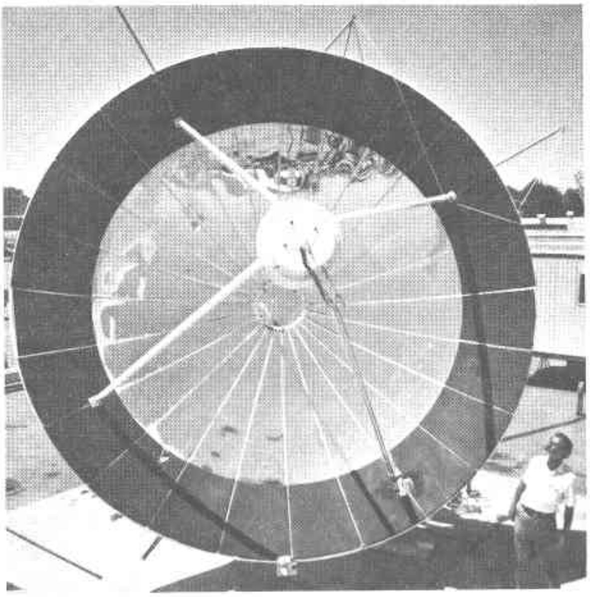


Figure 61. Prototype Parabolic Solar Collector

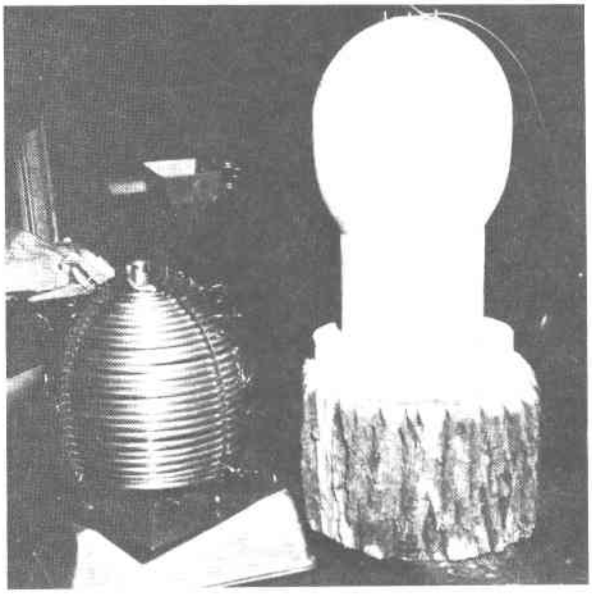


Figure 62. EPC Receiver — Coil Assembly

A glycerine/water mixture was used as the heat transfer fluid, and granite was used as the solid medium to demonstrate the proof of principle of the trickle storage concept. The storage tank design was modified to incorporate a bottom manifold permitting a dual-

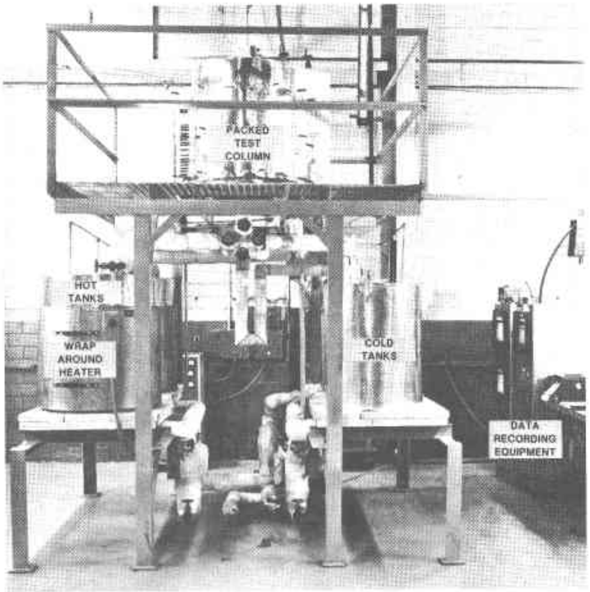


Figure 63. Trickle Oil Test Column

media storage mode of operation. Static tests on iron ore have indicated a higher than desired fluid degradation rate.

A contract was competitively awarded to Mechanical Technology, Inc., to design and build a steam turbine/generator. Input/output compatibility between the turbine/generator and the system is governed by the implementation of a formal interface control documentation system. A similar interface control system has been implemented between the solar system, the utility, and the user.

Four Shenandoah prototype, 7-m dish collectors, with piping simulating the Shenandoah installation, are planned for testing at the Midtemperature Solar Subsystem Test Facility. The control system will also simulate the Shenandoah system. This small-scale counterpart will permit the verification of the collector subsystem design and the evaluation of components and procedures. It will also provide facilities installation experience and a long-term test and evaluation of a dish collector subsystem.

The testing of the 5-m prototype collector will be continued through the early months of FY 1979. Flux density measurements of a dish reflector with the room temperature vulcanizing silicone protective coating (RTV 670) surface is planned for November 1978.

Extended column tests of the trickle storage system are planned at Evendale, Ohio, to obtain empirical confirmation of the thermocline profile in a long tank. The static bomb-type fluid/solid compatibility studies will continue investigations of purer states of iron materials. An additional consideration, that of dynamic effects, will be investigated in simulated piping loops where the fluid will be cycled through its temperature variation and subjected to mechanical shear effects through the pumps.

Small Community Systems

Applications Analysis

The overall goal of the Small Power Systems Applications (SPSA) project is to establish the technical, operational, and economical readiness of small solar thermal electric power systems less than 10 MW_e in size. The project will develop systems to the point at which subsequent commercialization activities can lead to successful market penetration. Initial commercial adoption for higher-cost energy markets is targeted for the mid-1980s, with widespread adoption occurring in the post-1990 time frame.

To monitor progress and ensure the objective is met, a number of interim objectives and system cost targets (in 1978 dollars) have been developed.

- Install experimental power plants demonstrating small power system feasibility, with the first being in operation by 1982.
- Achieve initial commercialization of small power systems in various early markets by 1985.
- Demonstrate, by 1985, capital costs less than \$2000/kW_e and an energy cost below 100 mills/kWh.
- Demonstrate, by the late 1980s, the practicality of building power plants, with a potential mass produced cost less than \$1000/kW_e and a resulting life-cycle energy cost below 60 mills/kWh.

These interim objectives and targets are under continual review and, as new information becomes available, will be revised as appropriate.

The SPSA project was initiated in August 1977 with Jet Propulsion Laboratory (JPL) providing direct support. FY 1977 activities were limited to organization and staffing of key project personnel. Administrative and control procedures were established to provide project management with a system for implementing and monitoring project activities.

In FY 1978, a comparative study of generic power plants for small power systems (< 10 MW_e) was initiated (Figure 64) consisting of three independent studies by Solar Energy Research Institute (SERI), Battelle Pacific Northwest Laboratories (BPNL), and JPL. These studies will be completed in mid-FY 1979 allowing the small power program to reduce the number of options being considered for development and identifying optimum generic concepts for particular applications. The ranking

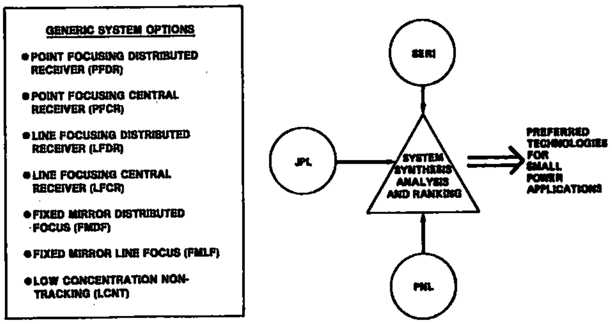


Figure 64. Generic Power Plant Ranking Studies

methodology being developed and used in this study should result in a rigorous treatment of the power system attributes that can be well documented.

Two study contracts for the investigation of (1) the potential of small power systems in small utilities and (2) the barriers and incentives relative to the introduction of the small power system concept were completed. These studies identified factors and issues important to the acceptance of small power systems by the utility sector and provided recommendations concerning the commercialization of small power systems.

Planning was initiated for a series of engineering experiments aimed at testing power plants in specific applications. The flow of these experiments is shown in Figure 65. The first series

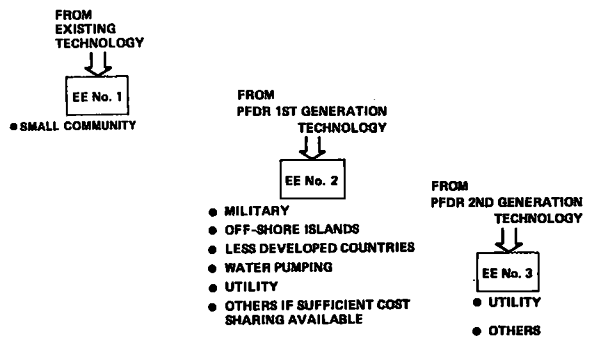


Figure 65. Experimental Power Plants

of experiments, Engineering Experiment No. 1 (EE-1), is based on the use of existing technology. In FY 1978, three Phase I concept contracts were awarded for EE-1 (Figures 66, 67, and 68), one or more of which will be selected for development, construction, and installation in a small community site by 1982. In addition, a Commerce Business Daily announcement and an RFP for the selection of a suitable site for EE-1 were prepared and presently await DOE release. The overall SPSA EE-1 schedule is shown in Figure 69.

The second series of engineering experiments, Engineering Experiment No. 2 (EE-2), will consist of several smaller experiments utilizing first-generation Point Focusing Distributed Receiver (PFDR) hardware with a system cost goal, in mass production, of 100 mills/kWh. The military market has been identified as one of several early markets which could lead to development of a suitable industrial infrastructure to allow costs to approach those necessary to penetrate the longer-term and lower-cost utility market. To this end, a joint effort, between the U.S. Navy and DOE, has been initiated to install a small solar electric plant at a military site. This

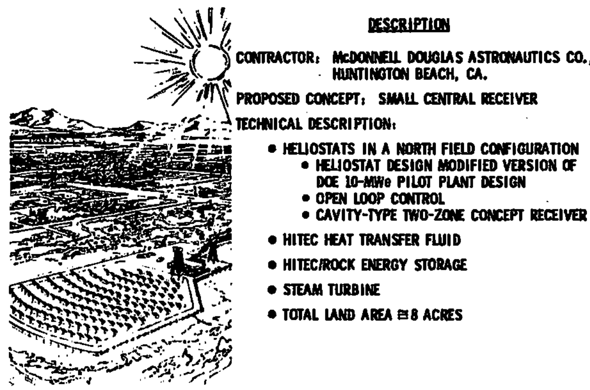


Figure 66. Proposed Engineering Experiment No. 1 — Phase I 1-MW_e System Concept (Category A - General)

DESCRIPTION

CONTRACTOR: GENERAL ELECTRIC CO., SCHENECTADY, N.Y.

PROPOSED CONCEPT: DISTRIBUTED RECEIVERS WITH CENTRAL STEAM CONVERSION

TECHNICAL DESCRIPTION:
- 150 7.9-m DIA ENCLOSED POINT FOCUSING COLLECTORS
- BALL-TYPE RECEIVERS WITH INTEGRAL HEAT PIPE/BOILER
- CENTRAL RANKINE CONVERSION - TRANSPORT VIA VACUUM INSULATED PIPE
- TOTAL LAND AREA ≅ 11 ACRES

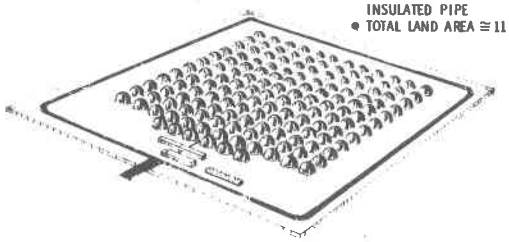


Figure 67. Proposed Engineering Experiment No. 1 — Phase I 1-MW_e System Concept (Category B - Point-Focusing, Distributed Collector, Central Energy Conversion)

DESCRIPTION

CONTRACTOR: FORD AEROSPACE AND COMMUNICATIONS CORP., NEWPORT BEACH, CA

PROPOSED CONCEPT: DISTRIBUTED RECEIVER WITH ENERGY CONVERSION AT THE COLLECTOR

TECHNICAL DESCRIPTION:
- 23 16-m DIA CONCENTRATORS
- CAVITY RECEIVER WITH SODIUM HEAT TRANSFER MEDIUM
- UNITED STIRLING OF SWEDEN P-75 ENGINE (DIRECTLY COUPLED TO RECEIVER)
- BATTERY STORAGE
- TOTAL LAND AREA ≅ 8 ACRES

Figure 68. Proposed Engineering Experiment No. 1 — Phase I 1-MW_e System Concept (Category C - Point-Focusing, Distributed Collector, Energy Conversion at the Collector)

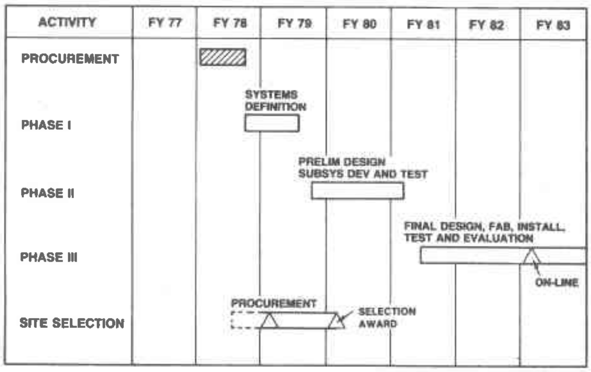


Figure 69. SPSA Engineering Experiment No. 1 Schedule

effort, one of the experiments in the EE-2 series, will be jointly funded by the Navy and DOE. The application areas of the other experiments are yet to be selected.

At the very outset of the project, an interactive workshop with electric utility and small community representatives was held. Inputs from the workshop, as well as subsequent dialogue between the project and the potential users of the hardware, have influenced the structure of the project and the engineering experiments.

Concurrent with the development of the engineering experiments, study contracts were awarded to:

- Determine the potential of small power systems in small utilities;
- Study the barriers and incentives relative to the introduction of small power systems and provide recommendations concerning their commercialization;
- Define/develop potential markets;
- Define system design constraints/requirements;
- Define the industrial process for mass production and its effects on cost; and
- Define techniques to accelerate the innovation process.

The basic technical approach is centered around system experiments and demonstrations of appropriate technologies and applications. Figure 70 indicates a plan that will lead to a high probability of successful experimental system design, implementation, operation, and eventual commercialization of selected technologies.

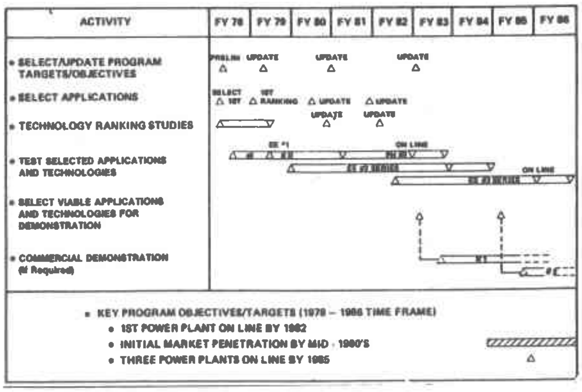


Figure 70. SPSA Project Plan

Crosbyton — Fixed Mirror, Distributed Development

The Crosbyton Solar Thermal Electric Power System (Figure 71) is a fixed-mirror, distributed-focus (FMDF) system, which conceptually consists of 10, 200-ft diameter concentrators, producing 5-MW_e nominal output. The objective of the project is to develop the FMDF concept and demonstrate its technical feasibility. This project was started in 1976 to establish a near-term design for a system in which high temperatures can be achieved without moving large areas of reflectors to follow the sun. In the FMDF system, a spherical reflector is stationary and the receiver is moved within the focal region. The reflector unit can be made much larger than units used in movable reflector systems; however, it suffers from "cosine losses" during the day. Cost projections show that the collector

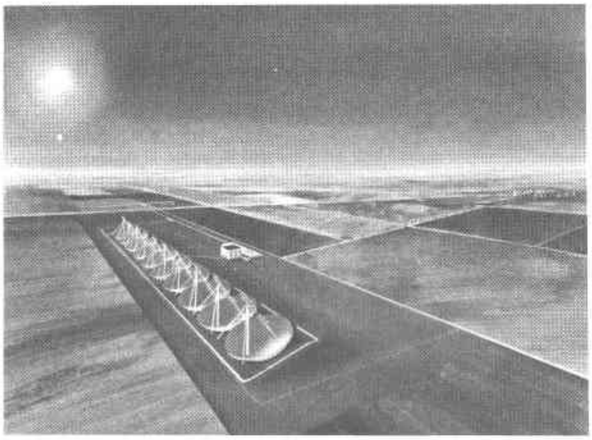


Figure 71. Artist Concept of a 5-MW_e Fixed Mirror Distributed Focus Collector System

subsystem for the FMDF is much less costly than central tower collector subsystems and results in comparable levelized bus-bar costs for a 30-year life cycle. Conceptual engineering analysis of performance and cost were completed in FY 1977. During FY 1978, the conceptual design of a 5-MW_e FMDF system was completed and the design specification and cost estimates for an Analog Design Verification System (ADVS) for a 20-m (65-ft) diameter unit were prepared. In conjunction with these efforts, analytical and experimental results were obtained for the optical properties of the collector and receiver, structural and dynamic analyses were conducted, and a 3.35-m (11-ft) diameter system (Figure 72) was constructed and tested. The control system designs were refined and operational software requirements were completed. Full-scale mirror panels were constructed and tested, including weathering and cleaning effects. A conceptual design for thermal storage for the ADVS was completed. Operational options were investigated, including system performance for various geographic locations (Figure 73). Instrumentation and data requirements

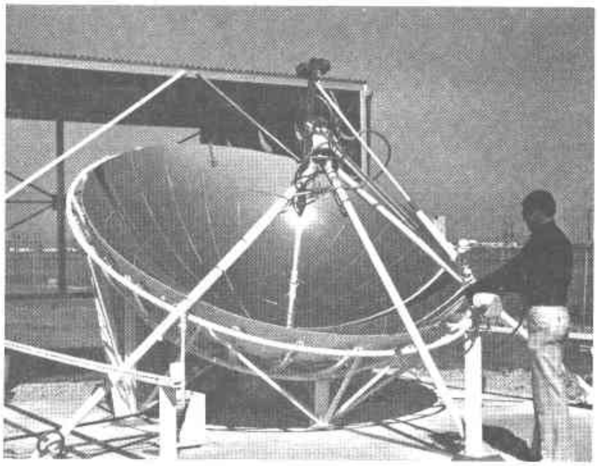


Figure 72. Crosbyton 3.35-m-Diameter FMDF

for ADVS were defined, insolation measurements at Crosbyton were taken, and wind tunnel tests were conducted on a 1/75 scale model of the concentrator.

Design, fabrication, and checkout of the ADVS are planned for FY 1979 with operation to begin immediately thereafter. Milestones include (1) reviews of the preliminary design, (2) final design, (3) checkout plan, (4) experimental test plan, and (5) completion of construction. In addition, analyses and tests will be continued in all phases of FMDF power systems.

Point Focusing Distributed Receiver Development

The Point Focusing Distributed Receiver (PFDR) Development project is concerned with developing small solar thermal power systems to provide thermal and/or electrical power. The PFDR objective is to develop within industry the technology for cost-effective modules for electric and thermal power applications.

To meet the stated objectives, efforts are underway to make technology and mass production techniques available for SPSA experiments that meet the cost and performance targets shown in

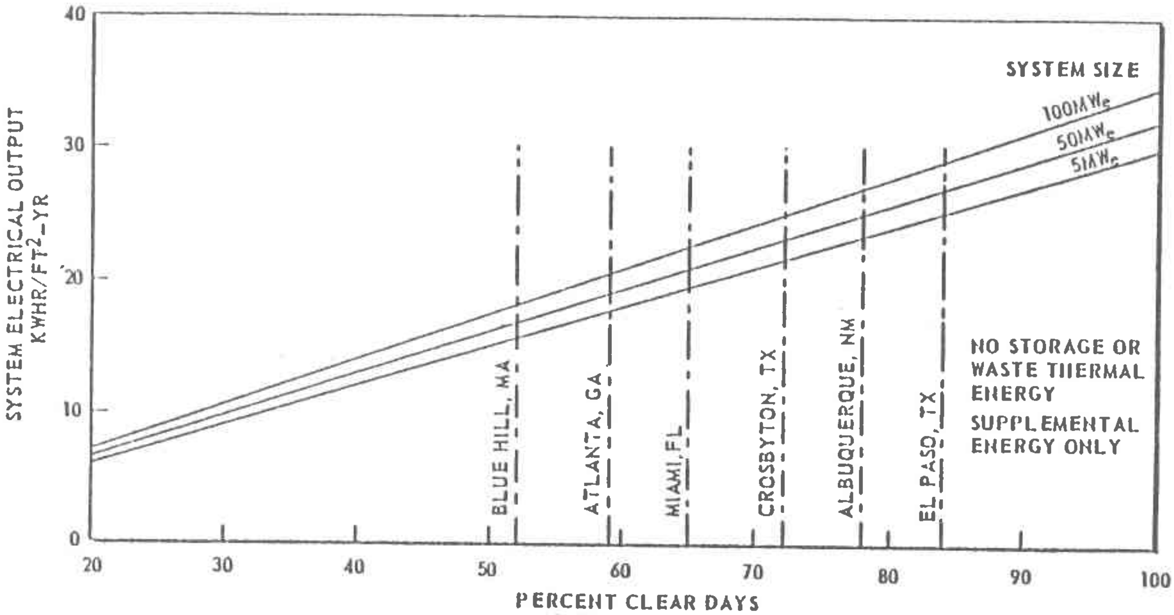


Figure 73. FMDF Annual System Output for Various Locations

Table 4. Two generations of hardware are planned. The first, to be available by 1982, is based on cost targets that reflect the upper boundary of projected utility costs for conventional systems. The second, for 1985, reflects the corresponding lower boundary and should result in systems that are extremely competitive (Figure 74).

Table 4. Preliminary Cost and Performance Targets

Test and Evaluate	Targets for FY	1982	1985
Concentrators	Cost in mass production	\$150/m²	\$100/m²
	Reflector efficiency	90%	92%
Receivers and Energy Transport	Cost in mass production	\$30/kW_e	\$20/kW_e
	Efficiency	80%	85%
Power Conversion	Cost in mass production	\$75/kW_e	\$60/kW_e
	Efficiency	25%	35%

The PFDR technology project was initiated in August 1977 with JPL providing direct support for the project. Progress for FY 1977 was limited to the staffing of key personnel and planning for FY 1978.

During FY 1978, progress was made in several areas. All subcontracts for the development of first-generation subsystems were initiated and include (1) test bed concentrators (Figure 75), (2) low-cost dish concentrators (Figure 76), (3) steam and gas energy receivers (Figures 77 and 78), and (4) heat engines. These first subsystem study contracts will enable selection of suitable concepts that will lead to fully qualified hardware by 1982 which meet the first-generation cost and performance targets.

NASA's Lewis Research Center provides direct support in the area of

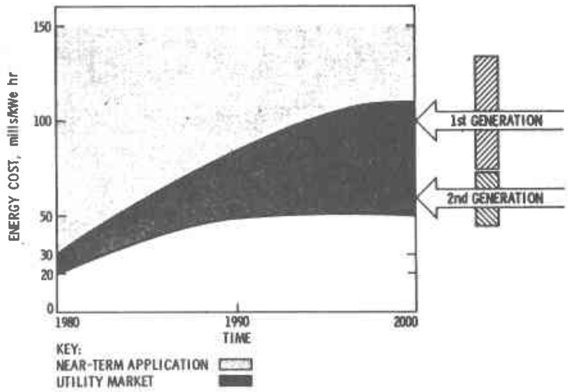


Figure 74. Projected Utility Costs from Conventional Systems

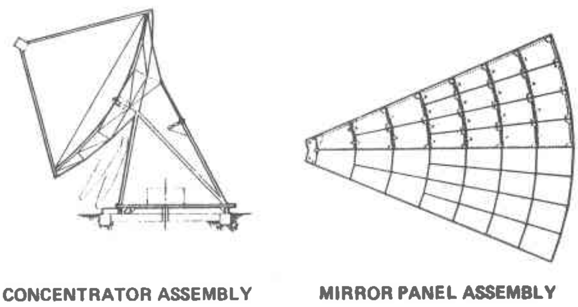


Figure 75. Test Bed Concentrators (E-Systems Concept)

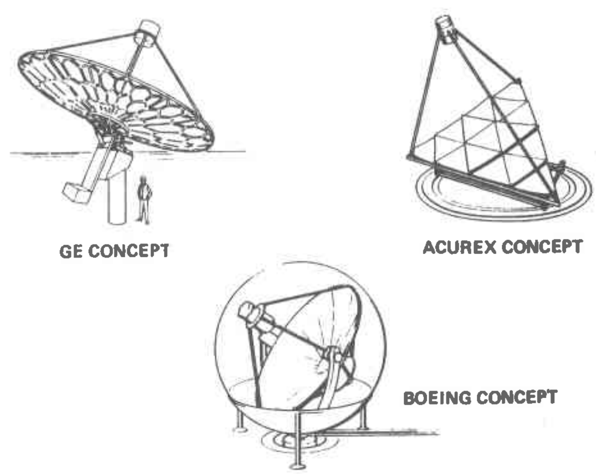


Figure 76. Low-Cost Concentrator Concept

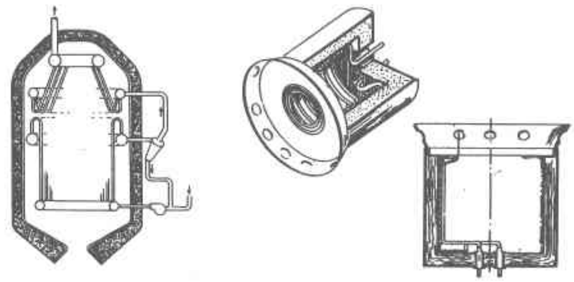


Figure 77. Steam Receiver Concepts

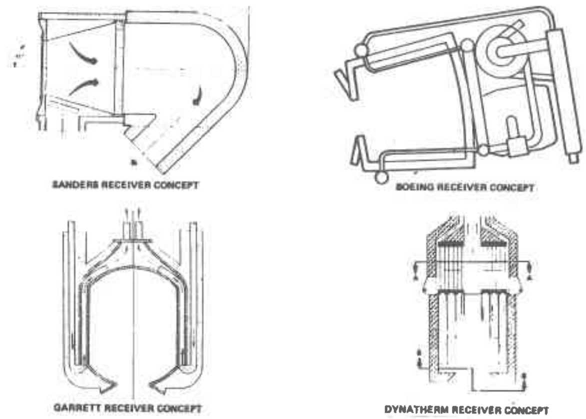


Figure 78. Gas Receiver Concepts

power conversion and has awarded contracts for both steam-Rankine and gas-Brayton engine development. Three concept definition contracts were awarded for a 15-kW_e steam-Rankine engine (Figure 79) and two contracts were awarded for development of a 15-kW_e gas-Brayton engine (Figure 80).

Efforts at JPL, in the area of concentrator development, have centered around the development of a precursor concentrator (Figure 81) for testing foam glass mirror facets (Figure 82) which are being developed for use on the test bed concentrators. The test bed concentrators will enable evaluation of the receiver and heat engine subsystems prior to delivery of the low-cost concentrators.

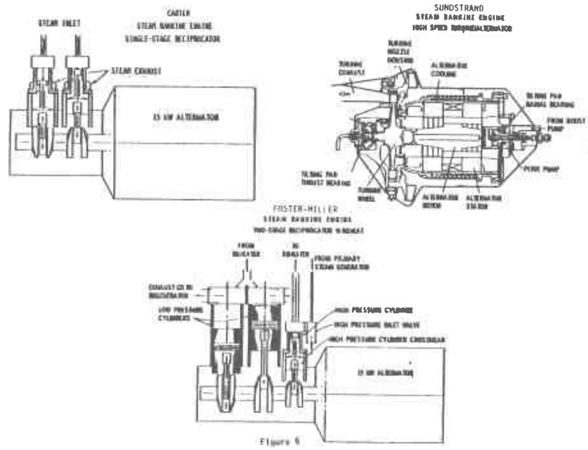


Figure 79. Steam-Rankine Engine Concepts

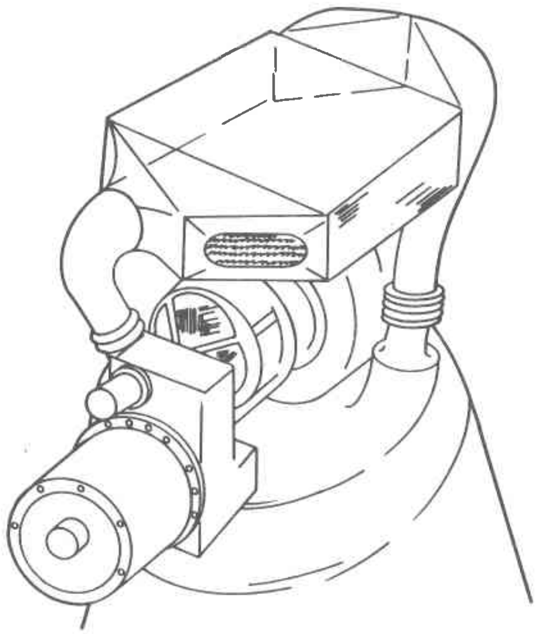


Figure 80. 15-kW_e Solar Brayton

An Omnium-G module (Figure 83) was purchased for testing and evaluation at the JPL Point Focus Solar Test Site (PFSTS) located at Edwards Air Force Base, California. Testing will provide required data regarding the actual performance potential of this commercially available unit as well as provide JPL test engineers early hands-on exper-

Figure 81. Precursor Concentrator

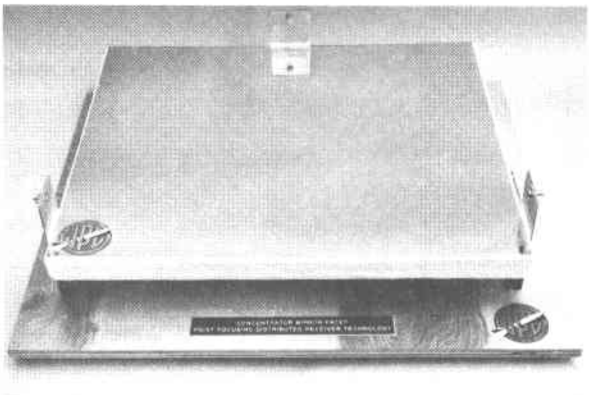


Figure 82. Early Foam Glass Mirror Facet

ience with the testing and evaluation of a point-focusing concentrator and enable the full debugging of the test facility.

Detailed cost studies of the Omnium-G concentrator subsystem have been initiated. The Omnium-G module enables accurate costing of a fully developed unit that can act as a baseline and model for costing studies of more advanced concentrator designs as well as provide information on mass production cost potential of the unit.

Detailed designs were completed of the JPL PFSTS (Figure 84), and site modifications such as concrete pads for concentrator support were started. The precursor concentrator was assembled at the test site and preliminary check-out was initiated. Completion of the PFSTS will enable the test phase of the program to proceed on schedule, pending the availability of hardware. The proposed schedule of early testing to be conducted at PFSTS is shown in Figure 85.

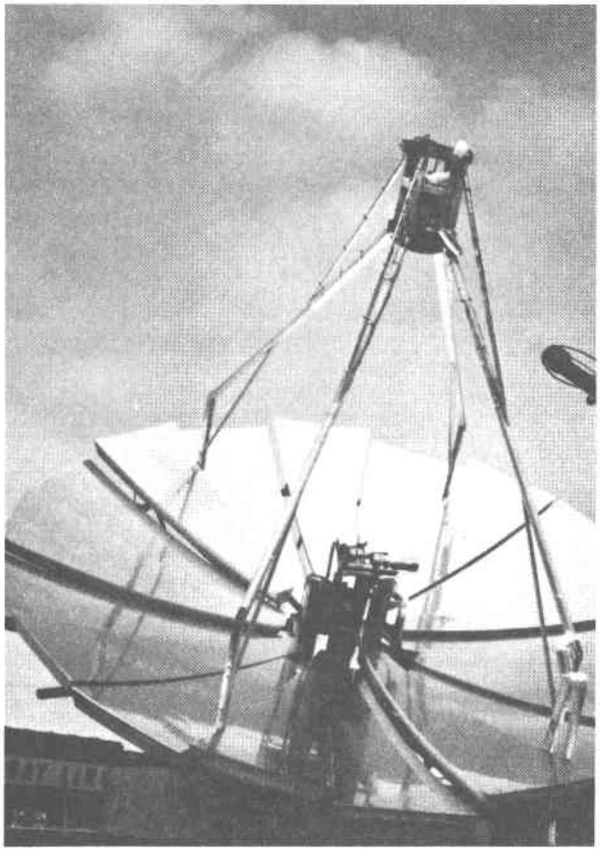


Figure 83. Omnium-G Module

The technology effort centers on the development of key subsystems for point-focusing distributed receiver systems. Testing of the test bed concentrator will begin in the latter portion of FY 1979 (Figure 86). After test and evaluation, the initial steam receiver will be installed and tested. The steam power conversion unit will then be added to the assembly and tested. This process will also be used with the gas system. Complete module testing for the steam system should be completed in early FY 1981 and the gas system late in FY 1981. These module evaluations will be compared with the 1982 cost targets. Periodic assessments of the technology to determine which configurations should be pursued in the following time period will be made, and second-generation subsystems will be developed to meet the 1985 cost targets.

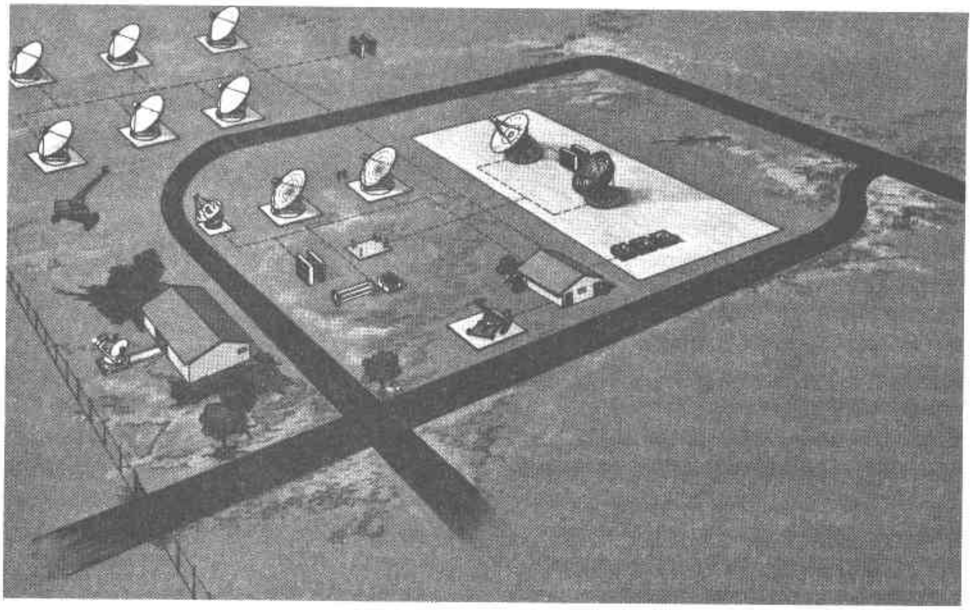


Figure 84. Point Focus Solar Test Site

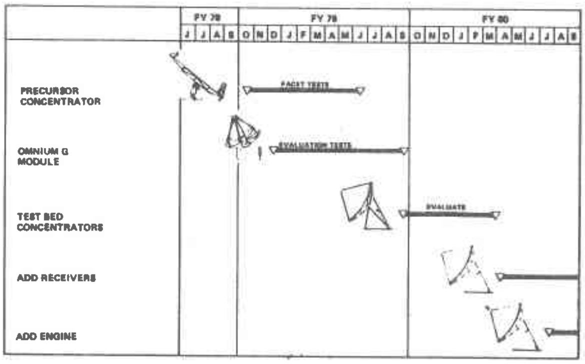


Figure 85. Test Schedule

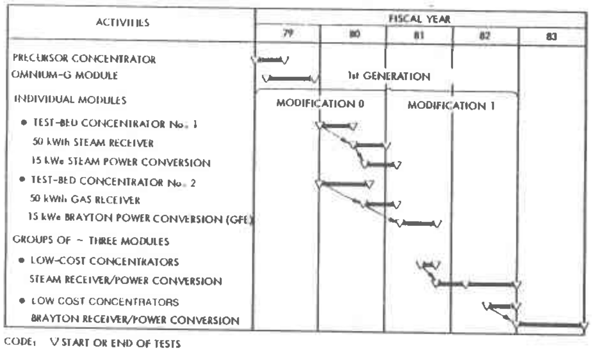


Figure 86. Five-Year Subsystem Test Period Schedule

Remote (Irrigation) Systems

The Remote (Irrigation) System projects undertake the design, construction, and operation of on-site power conversion systems in order to demonstrate the technical feasibility of appropriate technologies and to stimulate private industry to participate, both as manufacturers and as users, in this solar energy program. The objectives of the projects are (1) develop within industry the engineering and development experience on large scale solar power systems for remote application, (2) acquire data to reduce the uncertainties of cost and performance predictions, and (3) ensure dissemination of technical data to provide a basis for expanded growth of on-site power systems for remote applications.

Applications Analysis

A computer program capable of optimizing solar or solar hybrid power plant designs for lowest cost energy production was developed. This program is used in preliminary design studies and sensitivity analyses of solar power system designs. An analysis to determine the value of heat engine performance improvements using this code showed that savings obtained were proportional to system power level and/or utilization factor and not to initial heat engine cost. Further analyses have shown that collector performance and heat engine performance are the most sensitive parameters with respect to energy costs for a solar thermal power plant. A study has been initiated to determine the effect of operating temperature on energy costs from solar thermal power plants.

A Solar Irrigation Program Data Base has been assembled at Sandia Laboratories. The data base contains information on farm characteristics, agricultural practices, water supply characteristics and agricultural energy consumption characteristics. The data were assembled and archived from three principal sources:

- Census of Agriculture, 1969 and 1974;
- Energy and US Agriculture, 1974 Data Base; and
- USGS Groundwater Survey.

A data retrieval and management system has been developed for use with this data base.* A study to identify and compile irrigation water application and energy demand schedules for major irrigated crops grown in the Western United States was performed for Sandia Laboratories by the University of Arizona.** This study also computed irri-

*P. C. Kaestner, "Solar Irrigation Program Data Base Management System (SIPDBMS)," SAND78-0641.

**University of Arizona, "Agricultural Practices Which Could Enhance Solar Powered Irrigation Plant Utility," SAND78-7071.

gation costs and compiled thermal and electrical energy demand schedules for other agricultural applications. A second part of this study* examined the effect of cropping patterns and alternate energy demands on solar power plant on farm utilization.

Willard, New Mexico, Shallow Well Irrigation Pumping Project

The objective of the experiment was to design, build, and operate a solar powered irrigation system to determine system feasibility. Data from the experiment would be gathered and analyzed to determine the economic potential for powering irrigation pumps with solar energy.

In late 1975, a group of New Mexican farmers approached Sandia Laboratories personnel for assistance in finding an alternate energy source to natural gas, the availability of which had been curtailed. In February 1976, a joint solar irrigation experiment with the State of New Mexico was initiated in the Estancia Valley with federal, state, and local assistance. Sandia undertook the solar power portion, New Mexico State University the associated agricultural experiments, and the State of New Mexico purchased the solar collectors for the experiment on a private farm. Funding was provided by DOE ($600,000), State of New Mexico ($200,000), and Four Corners Regional Commission ($50,000). Construction was completed, and the system was dedicated on July 8, 1977.

During FY 1978, the system was upgraded to incorporate low energy center pivot irrigation (Figure 87), an additional 650 m^2 (7000 ft^2) of solar collectors, and an additional 25,000 liters (6500 gallons) of heat transfer fluid thermal storage (Figure 88). Plans for increasing the engine size have been delayed indefinitely due to proposed engine cost. An electric generator was added to the system to allow year-round operation. The upgraded system is shown in Figure 89. The farm owner built a 50,000-CWT potato warehouse adjacent to the site, and the electric power produced will be consumed by the potato warehouse air conditioning system (Figure 90.)

Currently, DOE plans to support New Mexico State University in operating the system for the next 2 years, and Sandia will support serious maintenance requirements. This com-

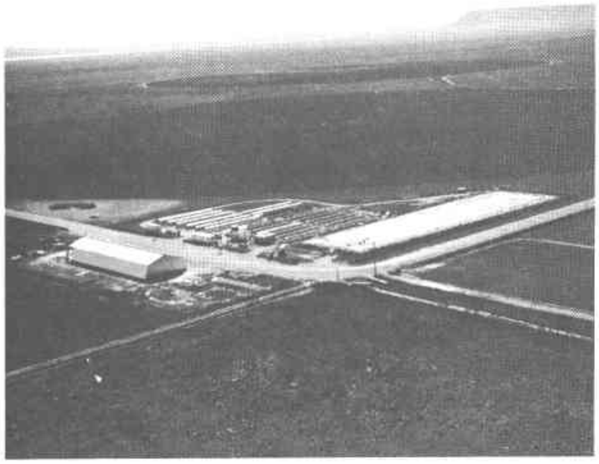


Figure 87. View of Willard Solar Irrigation Facility Showing Comparison Between Center-Pivot Irrigated Cropland (center) and Uncultivated Rangeland (foreground)

*University of Arizona, "Agricultural Practices Which Could Enhance Solar Powered Irrigation Plant Utility: Energy Demand and Plant Utilization."

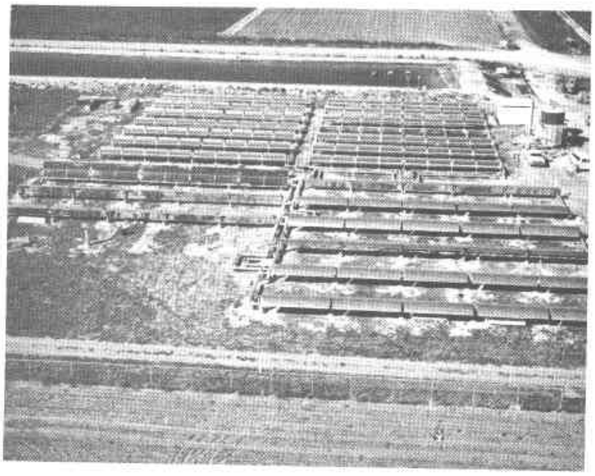


Figure 88. Willard Solar Irrigation Facility with the Installation of Additional Collectors and Thermal Storage Nearing Completion

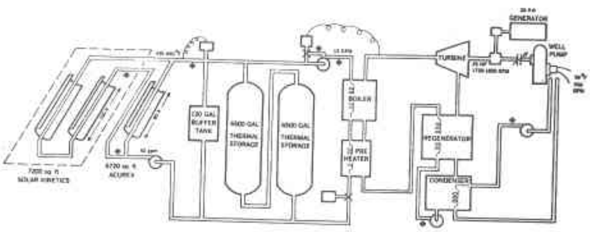


Figure 89. Electric Generator Added to System at Willard

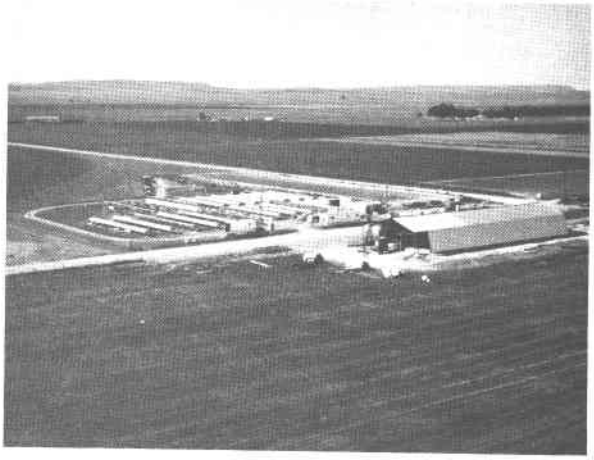


Figure 90. Construction of Potato Storage Warehouse (right foreground) Nearing Completion (Willard)

bined support will supply the desired operation and maintenance data. Sandia and DOE participation will be terminated at the end of this period.

Coolidge, Arizona, Deep Well Irrigation Pumping Project

This project has three objectives: (1) prepare a detailed design of a solar-powered experimental facility to provide 150 kW of electric power for the operation of deep well irrigation pumps; (2) construct the facility in accordance with the prepared design and install it on a farm near Coolidge, Arizona; and (3) operate the facility in an actual farm environment as well as gather and evaluate data on facility performance.

The Coolidge project is the first large-size application of using solar energy to pump irrigation water from a deep well and is conducted jointly by DOE and the State of Arizona. A preliminary design study was undertaken early in 1977 by three contenders and completed in August 1977. The project site (Dalton Cole farm, southwest of Coolidge, Arizona) was selected by Arizona State officials in February 1977. Acurex Corporation was selected as the prime contractor and as the supplier of the solar collectors. Acurex's major subcontractors are Sundstrand Corporation and Sullivan and Masson Consulting Engineers. Sundstrand is the supplier of the Organic Rankine Cycle (ORC 200) power generation unit. The team of Sullivan and Masson and Acurex is responsible for the detailed design task.

Early in FY 1978, Acurex began preparation of the detailed design for the deep well experiment. Detailed design proceeded (Figures 91 and 92) and a design review was held in January 1978. The system design was frozen at this time.

The Sundstrand-Acurex contract was signed in September, including the DOE patent clauses that were delaying negotiations. Sundstrand had received most purchase order items, and assembly of the ORC 200 unit has started (Figure 93). The construction contract was approved and site work began on September 5, 1978 (Figures 94, 95 and 96).

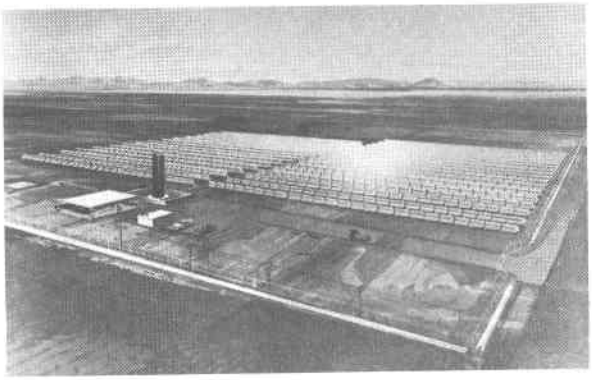


Figure 91. Coolidge Deep Well Solar Irrigation System (DOE, Sandia, Acurex)

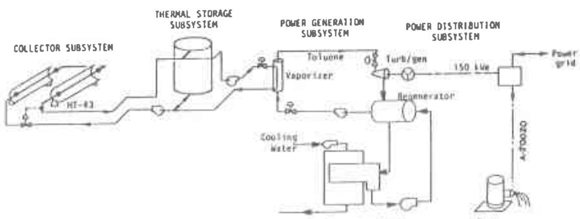


Figure 92. Schematic Diagram of Deep Well Solar Irrigation System

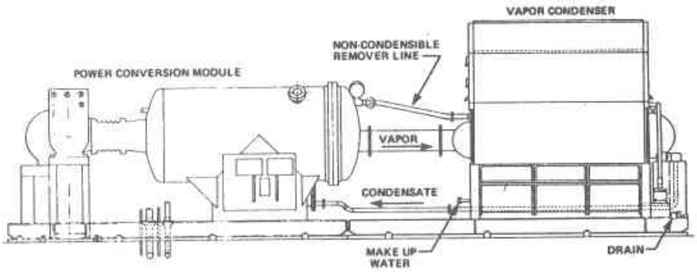


Figure 93. Sundstrand ORC 200

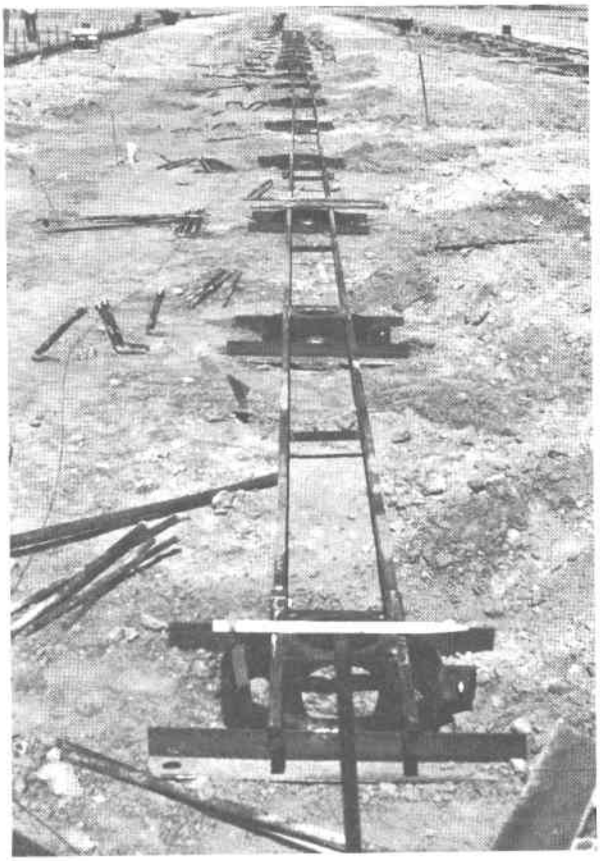


Figure 94. Collector Foundation Template, Coolidge Facility

An agreement with the electric utility was reached in November 1977, allowing the experiment to be connected to the grid, the power generated, and

Figure 95. Pouring Collector Foundations at Coolidge

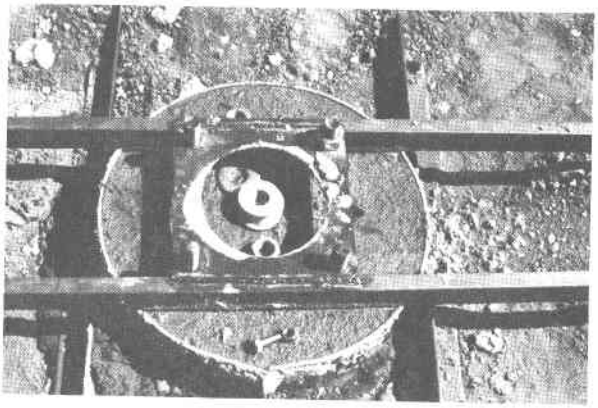


Figure 96. Collector Foundation Before Forms and Template are Removed

power consumption recorded. The arrangement is cost-effective because separate power lines will not have to be run to the three wells.

The mechanical construction package was expected to be bid by November 15, 1978, with mechnical work and assembly of the collectors to start in January 1979. Sundstrand is expected to deliver the ORC 200 to Coolidge by February. A new black chrome process, that is thermally stable after heating in air at 350°C, is planned for the receiver tubes for Coolidge.

Construction should be finished in June or July, with checkout and operation to start thereafter (see Figures 97 and 98). The dedication of the completed facility is planned for late August 1979.

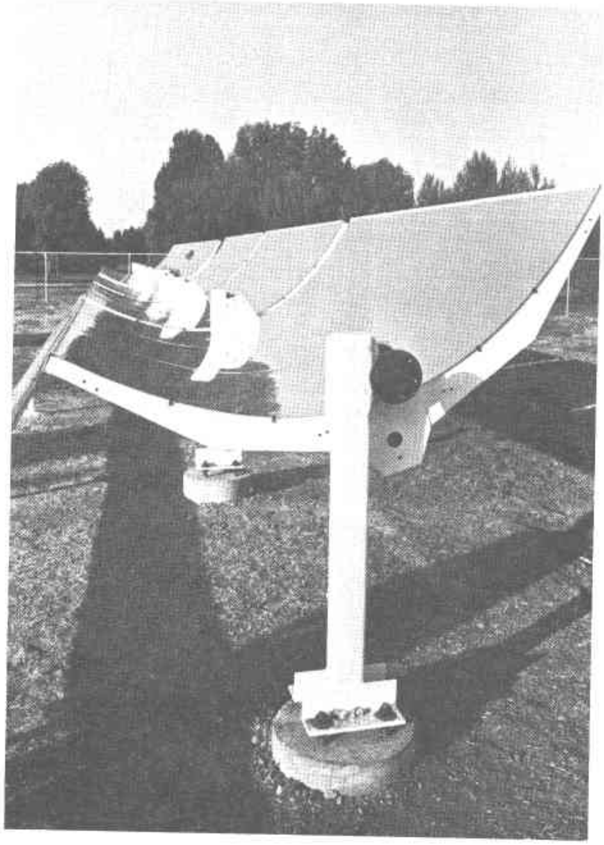


Figure 97. Initial Collectors Installed

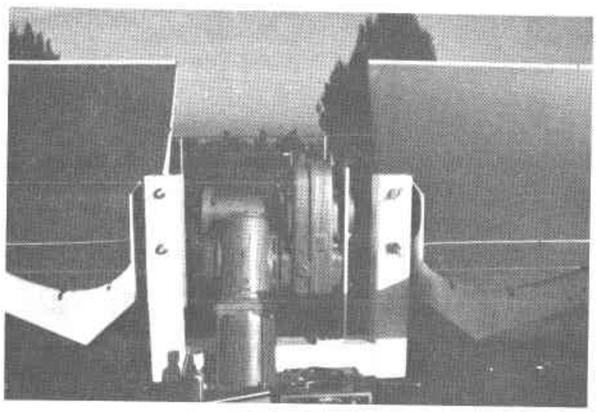


Figure 98. New Enclosed Drive Unit, Coolidge Facility

Gila Bend, Arizona, Tail Water Irrigation Project

This project was an industry effort to investigate the feasibility of using solar energy to power irrigation pumps. The project was funded by Northwestern Mutual Life Insurance Company, and the site was their Paloma Ranch near Gila Bend, Arizona. The system was designed, constructed, and operated by Battelle-Columbus Laboratories. It was placed into operation during spring 1977. The system is shown in Figures 99 and 100.

Operation in 1977 showed the feasibility of using solar energy for powering irrigation pumps, but the system operation did not coincide with the irrigation practices. The practice demanded a constant flow of water in which the system was incapable of supplying.

DOE supported Battelle-Columbus in modification and operation of the system in 1978. The modification consisted of changing the system to a solar power plant assisting an electrical motor in powering the irrigation pump (see Figure 101). This design allows the solar energy to be utilized and guarantees the farm operator a constant flow of irrigation water. The operation was considered satisfactory and operation and maintenance data were collected.

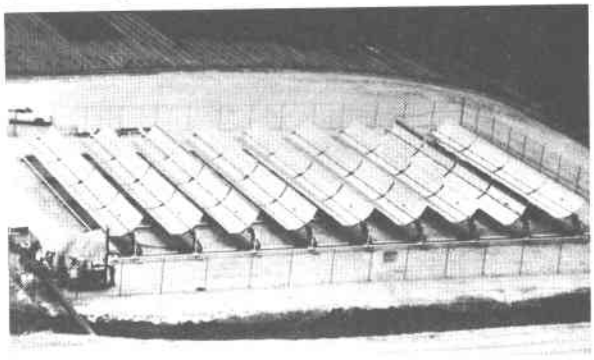


Figure 99. NML/BMI 50-Horsepower Solar-Powered Irrigation System (1977)

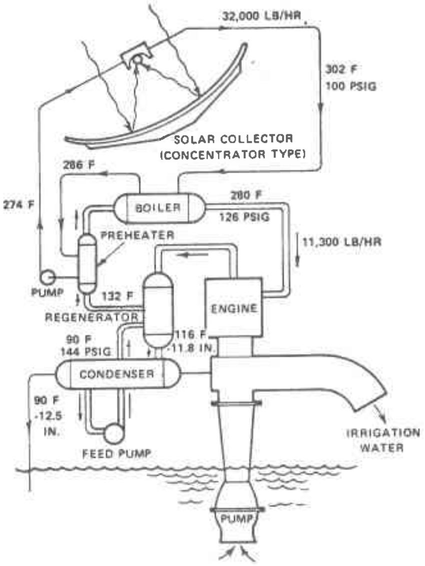


Figure 100. Schematic of Solar-Powered Irrigation System (1977)

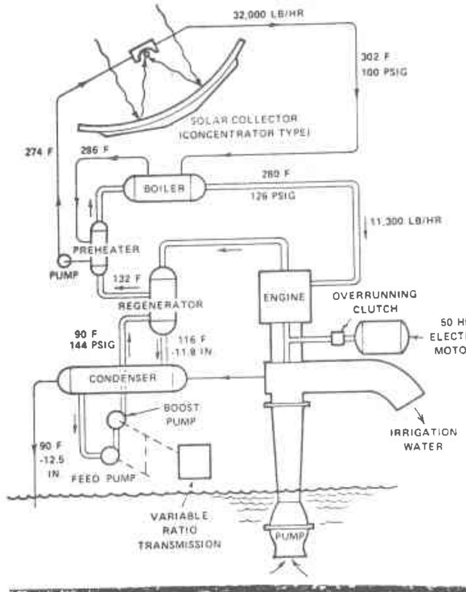


Figure [illegible]ered
Irrigation System — Hybrid Configuration

ADVANCED SOLAR THERMAL TECHNOLOGY

The Small Power and Large Power Applications programs are utilizing existing, proven technology wherever possible in order to meet the needs of their applications. The Advanced Solar Thermal Technology program, by contrast, develops and applies advanced technology with improved component efficiencies to achieve significant energy cost reductions. Specifically, the goal is to conduct research and development for materials, components, and systems that, by the mid-to-late 1980s, will lead to solar thermal energy costs approximately 50 percent lower than systems based on current or near-term technology. Innovative ideas and new concepts of high potential payoff, although of greater developmental risk, are being sought.

Energy costs of solar thermal power systems may be reduced through the use of lower-cost, longer-life surfaces and components, by increasing system operating efficiencies, and by reducing the requirements for maintenance. At this time, emphasis is being placed on improving system operating efficiencies. The results of analysis of the economics of future solar thermal power systems (Figure 102) indicate that increased system operating efficiency significantly lowers energy costs through reductions in the number of concentrators that must be installed for a given output and in their reduced maintenance and land requirements. Increased system operating efficiencies, in turn, are achieved with higher-temperature receivers, improved power conversion machinery, improved-reflectivity surfaces, etc., all of which require the development of new technology beyond what is now considered current or near-term. Hence, a major role of the Advanced Solar Thermal Technology program is to identify and develop innovative concepts within industry, universities, and government laboratories that will result in systems of increased operating efficiencies and to demonstrate their tech-

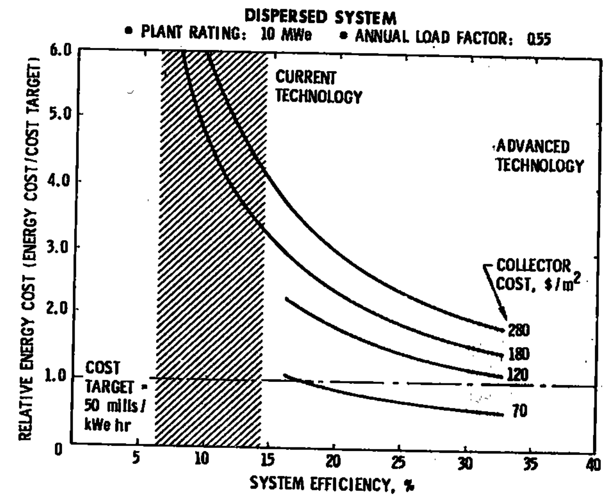


Figure 102. Effect of Improvements in System Efficiency on Achievement of Energy Cost Reductions

nical viability by the mid-1980s. These systems will then be available for small power and large power applications and ultimate commercialization at a faster pace than would normally occur. The efforts under the Advanced Solar Thermal Technology program can therefore be expected to increase the market penetration of solar thermal systems in the late 1980s.

The program is divided into four subprograms:

- Technology Assessment
- New Components
- Materials Support
- Advanced Systems

Of these, Technology Assessment is primarily a management support activity aimed at providing the technical and economic analysis and interagency coordination needed to guide and direct the program. The Materials Support subprogram conducts the research on materials, coatings, etc., generic to both advanced small and large power systems. The New Components subprogram provides the initial demonstration of the technical feasibility of new, innovative ideas for components/processes, such as advanced heat receivers. Finally, the Advanced Systems subprogram provides the focus for identification, component development, and demonstration of technical feasibility of advanced systems. These key program activities are shown in Figure 103, and the program summary schedule is shown in Figure 104.

These subprograms have important interrelationships (Figure 105). The Technology Assessment subprogram identifies new program directions and emphasis based on assessments of the status of current technology and projections of advanced technology. These data provide the criteria for selecting which new, innovative component concepts should be demonstrated under the New Components subprogram. The assessments and projections of technology together with the successful experimental demonstration of new component concepts provide the bases for the definition of advanced solar thermal systems. Such systems are analyzed under the Advanced Systems subprogram, and the more attractive of these are developed and demonstrated. Feedback is provided to the Technology Assessment subprogram to allow assessment of progress and reevaluation of program direction. The Materials Support subprogram provides technical support in absorber coatings, reflective surfaces, and other materials to the Advanced System Development subprogram.

TECHNOLOGY ASSESSMENT
- ASSESSMENT
  - —Current Technology
  - —Economic Targets
  - —Advanced Planning
- NEW APPLICATIONS
  - —Fuels & Chemical Manufacture
  - —Other
- TEST FACILITIES
- TEST FACILITY COORDINATION

NEW COMPONENTS
- —Receivers
- —Concentrators
- —Engines
- —Storage/Transport
- —Chemical Processes
- —New Systems

MATERIALS SUPPORT
- —Absorber Coatings
- —Reflective Surfaces
- —Other Materials
- —Manufacturing Processes
- —Analytic Techniques
- —Standards and Quality Assurance

ADVANCED SYSTEMS
- IDENTIFICATION
  - —Concept Definition
  - —Cost/Performance
  - —Subsystem Trade-Off
  - —Specifications
- SUBSYSTEM & COMPONENT DEVELOPMENT
  - —Concept Design
  - —Development & Tests
  - —Test of Advanced Systems

Figure 103. Key Activities

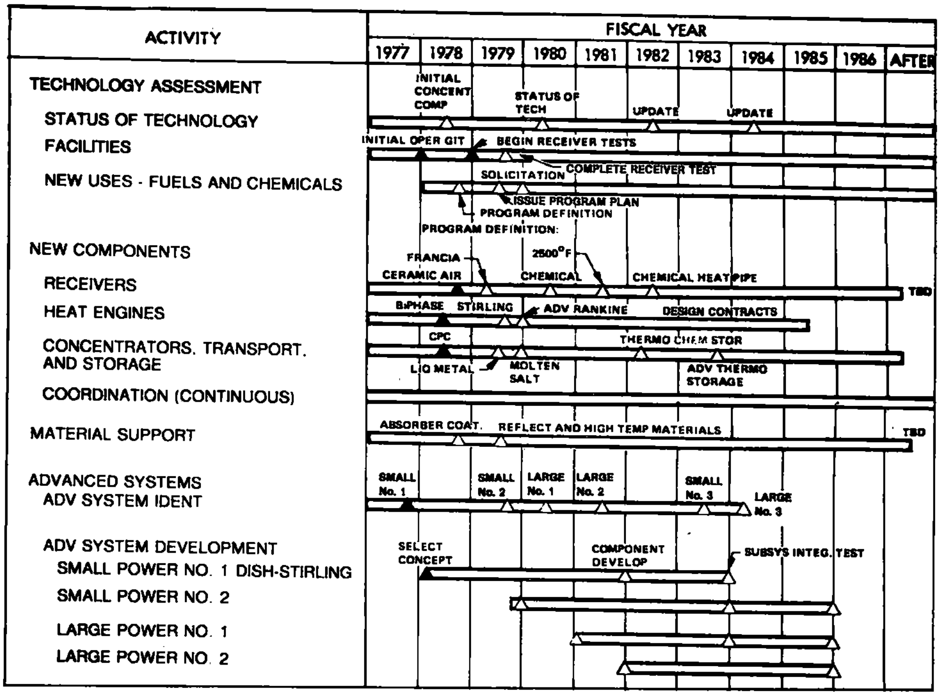


Figure 104. Summary Schedule

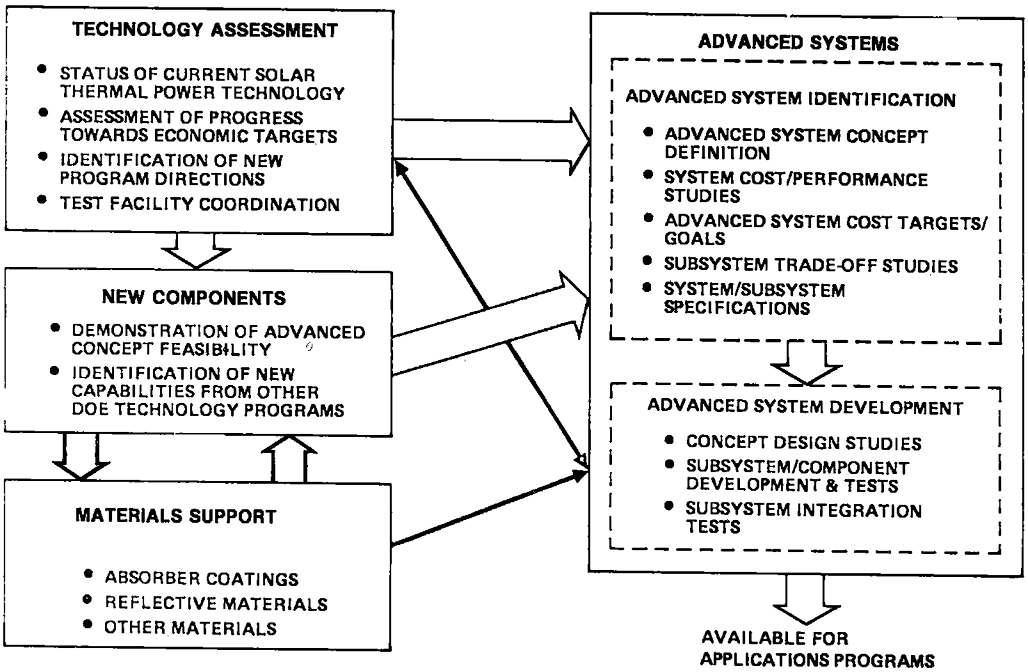


Figure 105. Advanced Solar Thermal Technology Interrelationships

Technology Assessment

The Technology Assessment subprogram provides overall direction to the Advanced Technology program. Efforts under this element include the status of technology, new applications, and facility coordination as shown in Figure 106.

The progress of solar thermal power systems toward cost targets and developmental milestones will be monitored and assessed, and new targets will be established as required. The purpose of this activity is to assist in setting development funding priorities and provide the analytical basis for selection of New Components as well as provide the guidance for the work to be conducted under Materials Support. A major output was the preparation of the program plan for the Advanced Solar Thermal Technology program. This plan will be updated periodically to reflect progress in solar thermal technology and reassessment of the most effective use of resources to reach cost goals and development milestones. Program plans in the following areas have been prepared and will provide guidance and direction for future advanced development thrust and help maximize the effective use of technology funds.

- Advanced Technology
- Fuels and Chemicals
- Hybrid Systems

Analyses have shown that high-temperature heat receivers for central and dispersed systems and high-efficiency small heat engines for dispersed power applications offer significant economic gains. The Stirling engine, not yet commercially available, was found to offer the greatest potential for energy cost reductions, and the high-temperature Brayton engine is also under consideration. Use of high-efficiency conversion subsystems could provide approximately 50 percent of the cost reduction required to meet energy cost targets. Studies have shown that the concentrator array is the most costly subsystem of a solar thermal power facility and, therefore, is the most significant area for cost reduction; thus, increased conversion efficiencies will reduce the required quantity of concentrators. Because of extensive efforts directed at concentrators and heliostats in other Solar Thermal Power programs (i.e., Small Power Applications), this area was determined to be of lesser priority for the Advanced Solar Thermal Technology program;

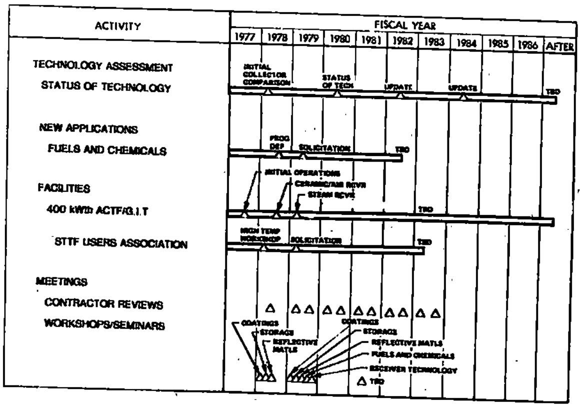


Figure 106. Technology Assessment Schedule

however, improvement of reflective materials for concentrators is of prime importance.

Subsystem Technology Development plans are being prepared for both Small and Large Power Advanced systems. Technical data on subsystems such as receivers, concentrators, engines, applicable materials/processes etc., are being compiled for analyses of their future potentials. Technical review summaries are maintained with appropriate references to provide both an overview of solar thermal technology status and specific examples of technology direction. Technical reviews and workshops are held to disseminate solar thermal technology information to concerned agencies and private industry.

The identification of new applications of solar thermal power will assist the Nation in reducing its dependence on the critical fossil fuels. Other applications would provide additional market incentive to reduce collector/heliostat costs through mass production. Research and technology will be conducted on an ongoing basis to identify additional attractive processes for implementation. Where new applications for solar thermal systems are identified as meeting a national need, new solar thermal program initiatives will be recommended.

During FY 1977, studies for small heat engines and absorber coatings materials were conducted. The results of those studies indicated that for small heat engines, the cycle efficiencies for steam Rankine with a steam turbine are typically of the order of 10 percent. Small reciprocating steam engines can obtain efficiencies greater than 20 percent. Small organic engines capable of efficiencies in the 30- to 35-percent region and Stirling engines with 40- to 45-percent efficiency are candidates for significantly improved performance.

Reviews of absorber coatings materials indicate that above about 600°F, absorber coatings for line-focusing collectors do not clearly demonstrate the necessary consistency, durability, and stability under the operating conditions required and with the spectral characteristics desired.

Also, intermediate- and high-temperature distributed collector efforts were reviewed. NASA's Jet Propulsion Laboratory and Lewis Research Center provided technical monitoring for 25 DOE contracts. In addition, approximately 100 proposals were reviewed, and support was provided for several major contract reviews and procurements.

One new application area for which there is strong industrial and university interest is fuels and chemicals manufacture. During late FY 1977 and early FY 1978, studies were initiated to explore potential commercial uses for solar thermal power in the fuels and chemicals industry and to develop preliminary program recommendations. Initial results from these studies suggest the outline of a new solar thermal power initiative. Analyses will be continued to identify likely candidate chemical processes for the earliest use of solar thermal energy. Expansion of this work with greater emphasis on methodology and selection criteria will be undertaken early in the program, followed by selection and development of technically feasible, economically attractive, solar thermal fuels and chemical processes. If the results of process development unit tests are attractive, chemical process pilot plants will be built and operated. Assessment of the results of the pilot plants would lead to the selection of processes for demonstration plants.

In order to provide technical coordination, a joint workshop on Thermal Storage applications was organized and conducted. This workshop was instrumental in greatly improving communication between the Storage (STOR) and Solar Thermal Power Systems areas of DOE. As a result of this workshop, a joint Solar Thermal/STOR program plan for accelerating the development of thermal storage subsystems has been prepared based on inputs from the various application centers. This plan will be made available to the public for comments by the interested community during FY 1979.

Under the Technology Assessment subprogram, a study of facility needs for the High-Temperature Process Heat Technology element is currently being performed by the Solar Energy Research Institute (SERI). This study will evaluate the capabilities of the existing facilities, the Advanced Component Test Facility (ACTF) at Georgia Institute of Technology (GIT), the CRTF and MSSTF at Sandia Laboratories, Albuquerque, and others.

The Technology Assessment subprogram task to provide necessary planning and coordination ensures that the testing needs of the Advanced Solar and Thermal Technology program are met and that existing facilities are utilized in the most cost-effective way. It is also the responsibility of this subprogram to ensure that industry, universities, and laboratories have access to and are encouraged to use solar thermal power facilities, particularly where these facilities are unique and do not exist in the private sector. Finally, a part of this subprogram is to support the ACTF, Georgia Institute of Technology, Atlanta, Georgia.

The Advanced Component Test Facility is a tracking-mirror solar collector, patterned after Professor Giovanni Francia's solar steam generating facility located near Genoa, Italy. The facility is operated by GIT's Engineering Experiment Station for the Department of Energy and is located on the GIT campus in downtown Atlanta, Georgia (Figure 107). The ACTF has as its primary purpose the encouragement of research and development in the area of high-temperature solar technology. It serves as a flexible and convenient test facility accessible to both public and private research and development organizations.

In 1965, Professor Francia built and operated the first of several solar powered steam generators in Italy. Since the operation of this first system, Francia refined and enlarged the design through three generations of systems. The largest and latest test system was first operated at St. Ilario, Italy, in 1972.

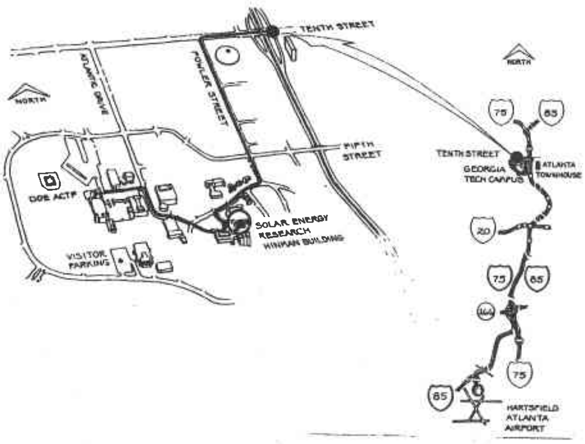


Figure 107. Map of ACTF Location

In 1975, the Energy Research and Development Administration purchased a Francia solar powered steam generator through the Italian firm Ansaldo, SpA, in order to install and operate the system in the United States. The operation of the facility has accomplished two objectives: (1) transfer of the technology that Francia has developed in Italy (accomplished by installing and operating the mirror field and central receiver and documenting their performance) and (2) provide a place to test innovative solar receivers and systems on a moderate scale (accomplished following the system characterization by converting the system to a general purpose test facility). GIT's Engineering Experiment Station characterized the original facility, converted it to a test facility, and since conversion, operates the facility.

The design of the facility makes it particularly well suited for the testing of:

- Central receivers and central receiver components such as boilers or air heaters and liquid heaters;
- High-temperature materials--both metallic and nonmetallic;
- Photovoltaic conversion systems;
- High-temperature chemical reaction systems and components; and
- Total energy systems powered by solar energy alone or by hybrid systems of solar and fossil fuels.

The ACTF is shown in Figure 108. Major components of the facility (Figure 109) include a collector mirror field, an experiment platform located above the center of the mirror field, an instrument and control building, a computerized data acquisition system, and a heat rejection system. The octagonally shaped mirror field contains 550 mirrors that focus sunlight into a focal zone 21.3 m (69.8 ft) above the center of the field. The mirrors are driven by their mechanical supports (Figure 110)

Figure 108. Advanced Components Test Facility

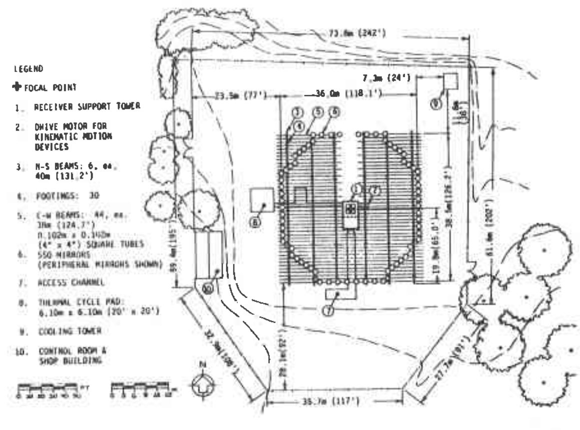


Figure 109. Ground Layout of the Advanced Components Test Facility

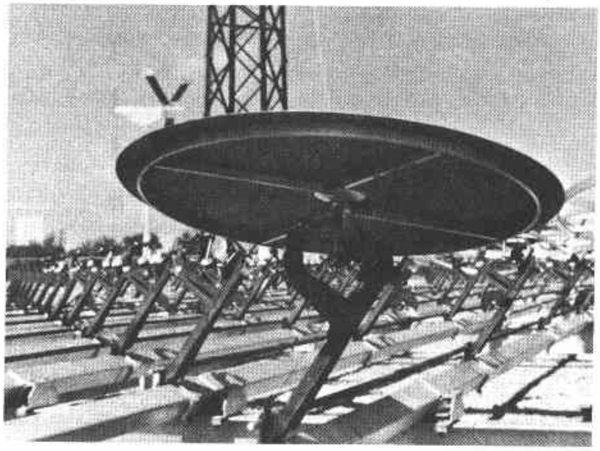


Figure 110. Kinematic Motion Device

so that the focal zone remains stationary throughout the day. The maximum calculated radiation flux density in the central focal zone is of the order of 220 W/cm^2 (698,000 Btu/hr-ft^2), and the design total power into the focal zone is approximately 400 kW (1.88 x 10^6 Btu/hr). The original test stand was an articulated truss located in the center of the field capable of supporting a 700-kg (1540-lb) test device. This stand was replaced by a rigid stand capable of supporting a 9100-kg (20,000-lb) test device.

Outfitting of the new experiment tower began in May 1978. Utilities installed on the tower include electric power, cooling water, drain, and compressed air. The air conditioned instrument building at the top of the tower was installed in early summer; installation of the data system components at the top of the tower and thermal qualification testing occurred in June 1978. The scissors lift structure was installed on the tower during August 1978. All software required for the Sanders Associates receiver program was completed by September 1978.

Installation of the Sanders Associates receiver package was initiated on September 20 and the receiver was operated for the first time in a solar environment on September 27, 1978. Soon thereafter, the receiver had accumulated approximately 29 solar test hours at the facility with no significant difficulties. (For details, see the following section "New Components.")

Major facility activities included:

- Outfitting the experiment tower with a 1.82- x 2.74-m (6- x 9-ft) instrument enclosure building and a scissors lift;
- Installation of the data acquisition computer and related components at the top of the tower;
- Completion of special data system software required to support the test program for the Sanders Associates receiver;
- Installation and use of the ACTF scanning calorimeter to map the volume surrounding the focal zone;
- Preparation for the Sanders Associates receiver test program, including installation of special utilities and collection of cavity heat flux data using a scanning bar and terminal concentrator supplied by Sanders;
- Installation, checkout, and operation of the Sanders Associates 150-kW Brayton cycle receiver with output air temperatures of 1950°F; and

- Construction of a visitor viewing stand which overlooks the ACTF.

All interested scientific and engineering organizations are encouraged to use the Advanced Components Test Facility. Experiments will normally be scheduled into the facility through DOE or the Solar Thermal Test Facility Users Association. If, in response to a Department of Energy RFP, DOE selects a proposal for funding, the experiment will automatically be placed on the ACTF schedule, and the experimenter will work directly with facility personnel from the beginning of the program. Experiments scheduled at the facility by submitting a proposal describing the experiment to the Solar Thermal Test Facility Users Association (STTFUA), will be funded by STTFUA or by SERI through STTFUA or directly by DOE. More information on the Users Association, including a description of the requirements for proposals, may be obtained through its Executive Director:

Executive Director
STTF Users Association
Suite 1507
First National Bank Building East
Albuquerque, NM 87108
(505) 268-3994 (Commercial)

If a program is scheduled into ACTF through the Users Association, the experimenter will begin work with facility personnel after the program has been approved for funding.

The Solar Thermal Test Facility Users Association (STTFUA) was funded to provide a single, convenient point of contact for industry and universities desiring to use the existing Solar Thermal Facilities. From discussions of ways to accelerate the advancement of solar thermal energy technology and encourage more university and industry use of DOE's solar thermal test facilities, it was determined that an independent Users Association could be effective in providing liaison among experimenters, facility operators, and DOE and in facilitating use of the government-owned facilities by outside experimenters. Furthermore, such an organization could provide an interface with other available solar test facilities, such as the Department of Defense White Sands facility and the French facility at Odeillo, France. The objectives of the STTFUA are:

- To act as the point of contact for users of solar thermal test facilities and as the primary access link between users and operators of STTFs;
- To solicit and review proposals for experiments to be performed on the STTFs and to make recommendations regarding utilization of STTFs;
- To provide funding for STTF users, subject to DOE program approval and funding availability; and
- To disseminate STTF and experiment information on a regular basis.

These objectives will be met by disseminating information on the facilities through workshops, conferences, and newsletters; by providing funds for experiments to be performed on STTFs; by establishing straightforward procedures for soliciting and reviewing experiment proposals; and by coordinating test plans/schedules with experimenters and facility operators.

STTFUA was organized early in 1977. The University of Houston was awarded a contract in June 1977 to support the first 6 months of operation of STTFUA and to organize an Association office. These tasks have been accomplished; STTFUA is now a functioning organization, incorporated in the State of Texas as a nonprofit organization. The Association's Executive Committee has been organized; an Experiments Committee has been organized to review proposals; and Membership and Publicity Committees have been named. Dr. Alvin F. Hildebrandt of the Unversity of Houston was elected President of the Association. The executive committee selected Mr. Frank B. Smith as the Executive Director for the Association. The Association office has been established and is located in Albuquerque, New Mexico. In September 1977, management responsibility for the STTFUA was transferred to the Solar Energy Research Institute in Golden, Colorado.

The achievements of the STTFUA during FY 1978 included the assumption of the management responsibility for STTFUA by SERI. In June 1978, SERI awarded the University of Houston a contract to continue operation of the STTFUA for 1 year. Fourteen proposals for experiments were received and reviewed by STTFUA: three were funded, six are in contracting process, four were rejected, and one was withdrawn.

Several workshops and meetings were held. The High Temperature Sciences Workshop was held in November 1977. Approximately 20 high-temperature scientists met to consider the current status and needs of high-temperature research and to define some of the experiments which might be undertaken on the STTFs. Proceedings of the workshop are available.

The First Annual Meeting was held in April 1978. Solar leaders from France, Japan, and the United States participated; 88 people attended the 2-day meeting. Papers on test facility status, proposed experiments for STTFs, and 20 technical papers on Optics, Materials, Energy Conversion and Storage, Industrial Chemical Process and Testing/Simulation were presented. Proceedings of this meeting are available.

The High Temperature Industrial Process Heat Workshop was held in September 1978. The thrust of the workshop was on the use of high temperatures ($>600^oF$) for industrial processes. Representatives from major oil, chemical, basic metal, and aerospace industries, as well as personnel from material laboratories, universities, and other research organizations discussed means of using solar thermal energy as a source of the high temperatures. A proceedings document will be issued.

During FY 1979, the STTFUA will continue to provide a full array of services to enhance the coordination and use of STTFs by all interested in the development of Solar Thermal energy use. Approximately 10 to 20 new experiments will be funded.

New Components

The New Components subprogram identifies new, innovative concepts for solar thermal components, subsystems, and processes and provides the first experimental demonstration of their technical feasibility in a solar thermal environment. It is expected that this subprogram will be at the forefront of technology, providing the Solar Thermal Power program with significantly improved components and with new capabilities for using solar thermal power. The New Components subprogram provides the focus for taking large risks where the payoff is commensurate. The experimental demonstration of the component and process concepts will provide a basis for identifying solar thermal systems of high performance and low-cost energy to be developed under the Advanced Systems subprogram.

Although consideration is given to the demonstration of concepts for all components of solar thermal systems as shown in Figure 111, emphasis is being placed on high-temperature receivers and small heat engines in accordance with the results of cost-sensitivity studies obtained under the Technology Assessment subprogram. The achievement of high operating temperatures provides the basis for use of high efficiency engines and the opportunity to develop useful chemical processes. Preliminary studies have shown the need for development of high-temperature metallic and nonmetallic receivers and chemical

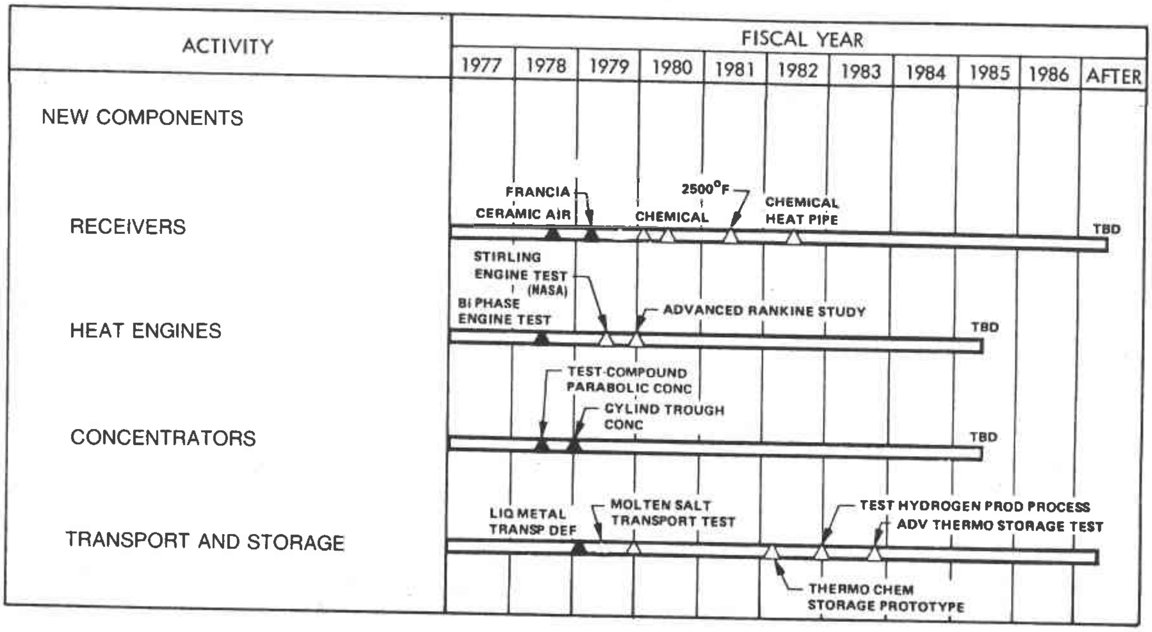


Figure 111. New Components Schedule

reactor receivers. New, innovative receiver concepts for both small and large power applications are being sought that promise significant improvement in operating efficiency, temperature, and reliability. Attainment of 2500°F operating temperatures for process heat and chemical production in FY 1982 has been established as a preliminary target. Efforts funded under the New Components subprogram include the conceptual study, development and test of high temperature ceramic receivers (2000°F), heat pipe receivers (1500°F), receivers that absorb heat by decomposition of SO_3 (1500°F), and receivers that utilize a falling molten salt film to directly absorb heat.

The demonstration of technical feasibility of reliable, high efficiency, economically attractive, energy conversion subsystems for small power and large power solar thermal applications is another key objective. Considerable potential for improvement in efficiency exists for small heat engines suitable for Small Power applications. Energy conversion targets for advanced engines range from 35 to 50 percent. Candidate energy conversion systems include: high-temperature steam-Rankine, Brayton cycles, Stirling cycles, and other novel thermodynamic concepts. The characterization of these energy conversion systems, and their potential for successful implementation in Solar Thermal Power Systems, will be analytically and experimentally determined. A 35-kW_e, two-phase turbine having design performance efficiencies greater than existing Rankine engines has been built and tested. Engine technology developed by DOE Divisions of Fossil Energy and Transportation Energy Conservation (TEC), and by both United States and foreign industry, are being assessed for possible solar thermal power applications and attractive candidates will be tested.

New concepts for concentrators will be pursued that utilize advanced concepts in materials usage, manufacturing technology, or structural design beyond the scope of the concentrator development program currently underway in the Small Power and Large Power branches. Attractive concepts for energy transport will be evaluated including liquid metal, molten salt, and chemical systems.

Sanders Associates tested their 250-kW_t Air Cycle Solar Receiver at the Georgia Institute of Technology (GIT) Advanced Components Test Facility (see previous section, "Technology Assessments"). The receiver (Figure 112) was designed to deliver air at 2000°F, operate at ambient pressure, and does not require a window to seal the aperture. By using a novel ceramic matrix for solar energy absorption and heat transfer, the receiver can provide high efficiency solar energy collection with very low pressure drops. An additional feature is

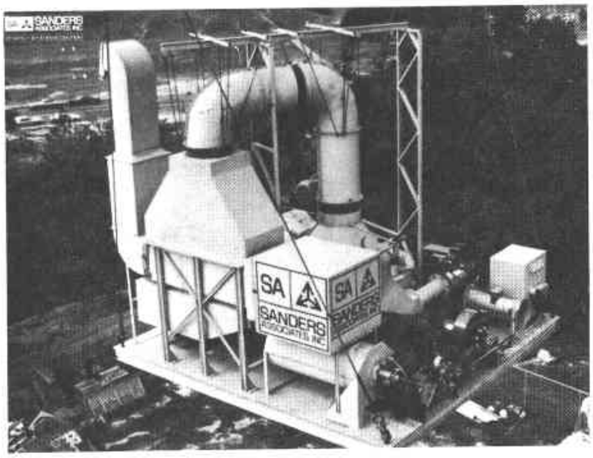


Figure 112. Sander's Receiver

a compliant ceramic support system which minimizes the thermal stresses.

Before beginning the receiver tests, the flux distribution near the focal zone was mapped by GIT personnel. As part of the test series, additional measurements were made using both the GIT flux scanner and a flux scanner built by Sanders to map the flux distribution on the receiver surfaces. The flux scans indicated a mirror aiming and tracking error, σ = 11.8 milliradians for the facility. The tracking error (σ) has a large impact on the amount of energy that can be directed into a receiver. The Sanders receiver is designed for a field pointing dispersion of σ = 6.6 milliradians. The receiver aperture diameter was reduced to 20 inches by using a terminal concentrator to redirect the outer rays into the aperture. The increase in σ from 6.6 to 11.8 milliradians resulted in a reduction in the solar energy, which can be directed into the receiver, from 316 kW to 190 kW.

Based on this evaluation of the facility, a limited test plan aimed at providing a shakedown of both the Sanders receiver and the GIT facility was followed. The objectives of this revised test plan were to:

- Operate at reduced flow to obtain design temperature,
- Operate at design mass flow and determine operating temperature and power delivered to the airstream, and
- Make a measurement of the convective losses.

The objectives of the revised test plan were accomplished, and the receiver will be stored while modifications are made to the solar facility to bring the sigma up to the design value: 6.6 milliradians. At that time, the receiver will be tested at full power to measure its efficiency and the response to the high flux values. The results of the successful first series were the following:

- Output air temperatures of 1950°F were maintained with honeycomb temperatures of ~2200°F for reduced flow with an average insolation of ~900 W/m^2. No visible changes in the receiver interior were noticeable after thermal cycling.

- Output air temperatures of ~1530°F were obtained for design mass flow with approximately 100 kW delivered to the air. Insolation for this test was ~805 W/m^2.

- Several hot convective loss runs were conducted using excess nitrogen as the trace gas and oxygen concentration as the measured variable. Maximum wind velocities of 8 fps produced heat loss determinations that confirmed the previous convective loss tests, i.e., ~0.5 percent of design thermal input.

Materials Support

The long-range goal of materials support research is to lower the life-cycle costs of solar thermal systems. This can be accomplished by improving performance, lowering cost, increasing useful life, or by combinations of the above. The program has been divided into research and development to support three major technologies. They are: high-temperature materials for receiver technology; optical concentrator technology, and standards and reliability technology. In each of these areas, limitations have been identified by the major hardware demonstration projects. The activities in each of these technologies are shown in Table 5. Major activities in this program have centered on developing the program plans and coordinating the solar-related materials R&D within the DOE program. In FY 1977, materials research was carried out by the National Laboratories and companies supporting the national program. The research was oriented toward near-term mate-

Table 5. Materials Support Research Summary

RECEIVER TECHNOLOGY

Ceramics
- Thermochemical receivers
- Porous ceramic thermal receivers (SiC, cellular glass)
- High-temperature receiver tube development

Metals
- Receiver materials characterization (9Cr-1Mo, Inconel 617, Incoloy 800)
- Heat transfer fluid compatibility and stability

Absorber Surfaces
- Low-temperature selective absorbers (black chrome, alumina-molybdenum-alumina)
- Intermediate temperature selective absorbers (black cobalt, organometallic solutions, cermets)
- High-temperature absorbers

OPTICAL CONCENTRATOR TECHNOLOGY

Transmitters
- Glazing characterization

Reflectors
- Silver alloy research for polymer reflectors
- Thin and ultrathin glass research
- Polymer coatings for silver mirrors
- Thin aluminum reflectors
- Reflectance measurement standard development
- Mirror corrosion (silver)

Structures
- Cellular glass research
- Advanced lightweight structures, and designs to utilize them

PERFORMANCE & RELIABILITY TECHNOLOGY

Characterization
- Optical characterization of reflectors and transmitters
- Absorber characterization
- Mechanical characterization

Degradation
- Optical polymers
- Glass
- Dust accumulation & cleaning

Corrosion
- Monitoring of solar systems
- Failure analysis

Thermal/Mechanical Fatigue and Shock
- Metals
- Ceramics

Life Testing
- Accelerated
- Real time

rials selection and evaluation. Long-range work was identified by Sandia Laboratories and Jet Propulsion Laboratory. Major activities in these areas are being planned and developed.

Receiver Technology

The major material problems associated with the thermal receiver technology are thermal stress and fatigue of materials, corrosion and compatibility of receiver/heat exchangers with heat transfer fluids, and properties and stability of absorber surfaces. The high-temperature (1100°C) and high-concentration (1000x) applications are stimulating work on metallic superalloys and high-temperature ceramics (e.g., silicon carbide). Heat transfer fluids (liquid sodium, molten salts, high-pressure steam) and high-temperature gases (He and air) add to the severity of the thermal environment.

Environmental and thermal stability of solar-to-thermal absorber surfaces are important because they affect both performance and life. High-temperature, high-absorptance surfaces are being studied for high-temperature, high-concentration systems. High-absorptance, low-emittance, "selective" coatings are being studied for the 600°C temperature range, and improved low-temperature selective coatings are also being studied for line focusing collector concepts.

The absorber materials research is centered on achieving high absorptivity and low emissivity and maintaining these optical properties under operating conditions. Chemical changes resulting from high-temperature diffusion and reaction with both the atmosphere and substrate presently limit operating temperatures. Research to understand and mitigate these effects is the thrust of the absorber program.

Research on selective absorbers began in 1955 and was pursued by NASA during the 1960s for controlling the thermal environment of spacecraft; however, the materials developed were not optimized for terrestrial solar energy conversion. Funding for absorber materials for solar applications was initiated by the National Science Foundation in 1974, and this work was expanded under ERDA and, more recently, under DOE.

During FY 1978, a working group on the Optical Properties for Solar Materials was established. Personnel from JPL, National Bureau of Standards (NBS), Sandia (Albuquerque and Livermore), Battelle Pacific Northwest Laboratories, and SERI participated in this Committee. This Committee has been chartered to work on the development of national plans for absorbing, transmitting, and reflecting material.

The absorber program has included studies on the importance of retroreflectance, polarization, and high-temperature solar absorptance measurements for the characterization of absorber surfaces and the effects of the choice of solar spectrum, air mass, glazing spectral transmittance, and collector spectral reflectance on the collector performance. The calculation of solar absorptance from the measured spectral, hemispherical reflectance also has been investigated. A National Absorber Surfaces Program Plan has been produced for DOE by the Solar Energy

Research Institute with the help of the absorber materials community.*

Several major technical accomplishments occurred during FY 1978 in the area of selective absorber surfaces for intermediate temperatures (600°C).

- A coevaporated Pt/Al_2O_3 cermet on Pt deposited on a quartz substrate has exhibited outstanding optical properties ($0.8 \leq \alpha_s \leq 0.94$, $0.1 \leq \epsilon_t$ (500°C) ≤ 0.3) and is stable in air at 600°C for 300 hours.

- The IR reflectance of thin film CVD molybdenum has been dramatically increased using simple processing techniques to within 0.7 percent of the value of the pure bulk metal. Stability is similar to the bulk material. This work has shown that a material can be produced with the IR reflectance of aluminum and the high-temperature capability of a refractory metal.

- The addition of stabilizers to an organometallic absorber system has extended the thermal stability without sacrificing optical properties ($\alpha_s = 0.92$, ϵ_t (100°C)=0.05). Thermal stability tests of films for 900 hours at 500°C in air show only a slight decrease in optical performance.

For absorber surfaces for high temperatures (>700°C), nonselective paints comprised of (Fe-Mn-Cu)O pigments in a silicone or silicate binder have demonstrated a solar absorptance greater than 0.98, stable to 700°C in air.

Major accomplishments for other materials include work performed in metallurgical research which is aimed at understanding how metals respond to the thermal fatigue, stresses, and environments produced by central receivers. The effects of alloying elements, heat transfer fluids, and thermal transients on metals must be known in order to design long-life receivers.

The ceramic research activities are focused on receiver design with brittle ceramics instead of metals. Their thermal shock and fracture toughness must be related to their microstructure and processing history. Research should yield tailored ceramics and metals for solar applications.

Optical Concentrator Technology

Optical concentrator technology hinges on the performance of optical transmitting and reflecting materials. Many materials have been used for solar concentrators, but have not been optimized. The durability and stability of composites of silver on glass, silver on plastic films, anodized aluminum, and other coatings are being investigated. The mechanisms of silver corrosion will be studied in detail to determine how

*"National Program Plan for Absorber Surfaces R&D" SERI-TR-31-103.

to protect the silver in outdoor environments. The optical properties of transmitting plastics and structures to support and shape mirror surfaces are also being optimized.

During FY 1978, major technical events were in the areas of materials evaluation, information dissemination and standards development, and instrumentation development. Assessments and studies of environmental degradation, correlation of accelerated testing of mirror materials, and noncontact cleaning agents for mirrors were accomplished. A Solar Reflector Materials Workshop was organized, a direct result of which was a National Reflector Materials Program Plan currently being implemented at SERI. The American Society for Testing Materials (ASTM) and the National Bureau of Standards (NBS) participation has contributed to several new proposed standards for solar materials. New techniques and instrumentation for measuring specularity were developed.

Performance and Reliability Technology

The performance and reliability technology has had the least emphasis in the past, but is now receiving more attention. The performance of a given solar system depends on the optical properties and geometry of the components. The appropriate optical properties must be measured to allow systems designers to calculate expected performance. Optical property standards and measurement procedures are being developed by NBS, ASTM, and the National Laboratories. Mechanical characterizations are already available for most structural materials except high-temperature receiver materials. Changes in optical and mechanical properties can cause scattering and absorption. Dust can have similar effects. How and why these changes take place are the subjects of many investigations. Polymers and glasses are being most widely studied. Corrosion often limits the component life, so quantitative corrosion monitoring techniques are being developed to study life prediction and inhibition of corroding systems.

The area of appropriate life testing is being studied intensively. Ways to certify both performance and life have been pioneered by the automobile industry. Automotive technology and methods will serve as a guide to the solar program. Accelerated life testing will be performed in the laboratories and at the solar thermal component test facilities at GIT, Sandia, SERI, and JPL. Specification of the operating environments will be a primary thrust of this program.

Circumsolar Radiation

The objectives of the circumsolar radiation effort were to obtain quantitative information on the effect of circumsolar radiation on the thermal efficiency of various generic types of concentrators and to develop procedures for sizing receivers to optimize their performance for various amounts of circumsolar radiation.

At SERI, the angular response characteristics of concentrating collectors is determined from analytical and ray trace techniques. Taken together with the size of the solar disk and statistical expressions for concentrator imperfections and circumsolar profiles, energy collection as a function of receiver size, i.e., concentration ratio, can be determined and compared to the receiver's thermal losses in order to optimize performance.

During FY 1978, analytical calculation had been shown to be equivalent to detailed ray trace, but a much simpler graphical procedure has been developed for optimizing concentration ratio and rim angle for all parabolic trough collector designs. Sensitivity of optimization to varying operation conditions and to changes in collector parameters were investigated. If the 16 standard circumsolar profiles provided by Lawrence Berkeley Laboratories (LBL) are typical, then output variations for current generation line focus collectors with varying circumsolar levels are estimated to be on the order of one percent under reasonable operating conditions. A formal report is underway to document this work.

FY 1979 activities will be performed in accordance with the strategy established in the Multi-Year Program Plan (unpublished). Because of the demonstrated optical performance and thermal stability of vacuum-deposited multilayer and cermet films, vacuum processing suitable for solar applications will be explored as part of the intermediate temperature selective absorber surface development effort. Support activities will be augmented to include durability test definition and durability testing, further degradation mechanism studies, component evaluation, systems benefit analysis, and a data base activity that includes relevant field experience.

A decision will be made in late FY 1979 to concentrate R&D efforts on the development of a single selective absorber surface concept for intermediate temperatures and to identify a backup absorber surface for such applications.

The systems analysis activity initiated by JPL in FY 1977 and FY 1978 will be refined and extended through a joint SERI/JPL effort. Major activities in FY 1979 will determine the minimum solar absorptance as a criterion in judging intermediate temperature selective absorptance development, refine estimates of absorber surface and program cost/benefits, and determine the optimum optical properties for cavity absorbers.

Several activities are planned in circumsolar radiation work. Ray trace and analytical techniques to determine collector response will be refined to include point-focus devices. This portion of work should be completed by January 1979. Line focus collectors will also be reviewed using actual frequency distributions of circumsolar radiation as supplied by LBL. Results are expected by February 1979. Results will be summarized in the annual report by September 1979.

The Advanced Systems project was established to identify and develop advanced systems that will accelerate the commercialization of thermal power systems by reducing energy cost and improving system performance over that provided by first-generation systems. The approach is to focus on one or more specific advanced systems for dispersed power applications and develop components and subsystems aimed at a single module demonstration on feasibility and performance of the system design. A combination of low collector cost and high system efficiency, which will reduce the cost of solar produced electricity to 50 mills/kWh, is the target of this project as shown in Figure 113.

The emphasis will be to:

- Identify candidate advanced systems through tradeoff studies, analysis, and feasibility tests;

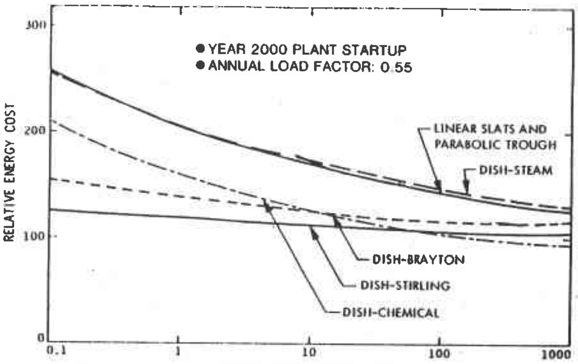


Figure 113. Advanced System — Energy Cost vs Plant Size

- Develop the key subsystems and components needed for a successful low-cost subsystem operation and demonstration of the (second-generation) advanced systems;

- Provide the support and test facilities needed to demonstrate feasibility of the systems; and

- Plan and support a limited number of high technology projects aimed at potential early breakthroughs.

In addition, the project will conduct early definition work to develop new programs such as the direct use of concentrated solar energy in manufacturing transportable fuels, essential chemicals, and other applications.

Early in FY 1978, the Advanced Solar Thermal Technology Project completed the systems study, "Projection of Distributed-Collector Solar-Thermal Electric Power Plant Economics to 1990-2000." This study presents a comparison of several versions of point- and line-focusing distributed receiver power plants and documents the assumptions and methodologies used. As shown in Figure 113, several promising advanced distributed systems were identified: dish-Stirling, dish-Brayton, and dish-chemical. This dish-Stirling system was predicted to produce the lowest energy cost for systems ranging in size from 0.1 to 50 MW_e. The study formed the basis for tentative selection by DOE of the dish-Stirling as Advanced Systems No. 1 (ADS-1) and has provided insight into how best to allocate cost targets to the various subsystems.

As part of the ADS-1 development, two subsystem concepts were defined for a Stirling receiver (Figure 114) and for two advanced concentrator designs. One concept (Figure 115) is a high-performance, light-weight, low-cost structure that uses cellular glass gores for the parabolic dish (Figure 116). The second concept (Figure 117) uses a point-focusing Fresnel lens that allows the receiver and engine to be mounted

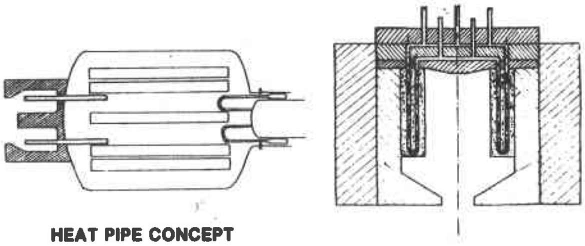


Figure 114. Receiver Concepts

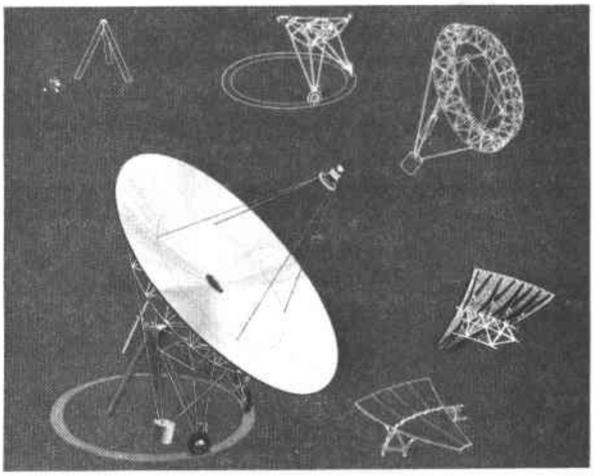


Figure 115. Light-Weight Parabolic Dish Concept

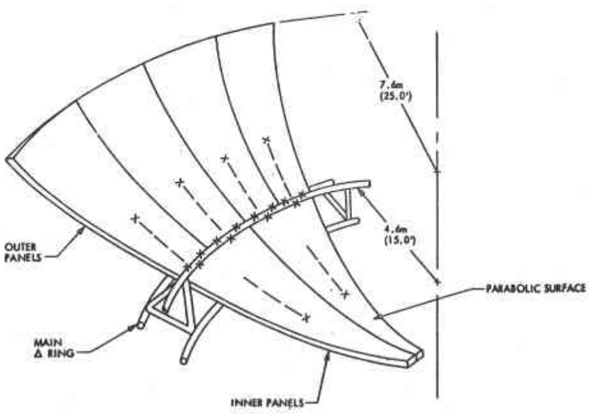


Figure 116. Cellular Glass Gores

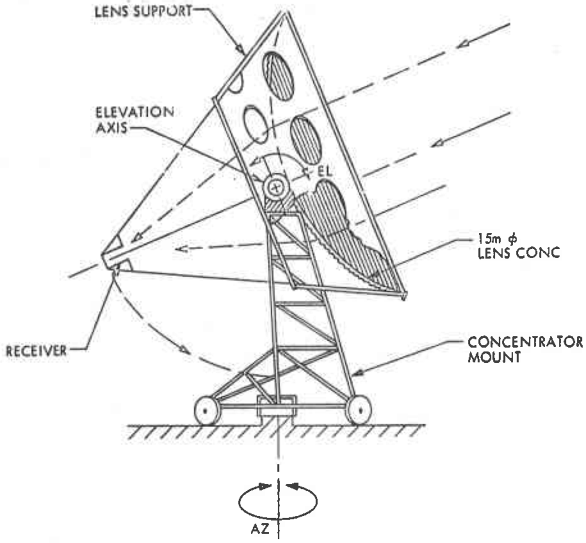


Figure 117. Fresnel Lens Concept

behind the concentrator. These advanced concepts for concentrators and receivers have a high probability of achieving the 1985 second-generation cost and performance goals. Relative to ADS-1, two subsystem contracts were awarded to study liquid metal heat pipe receivers and liquid metal transport. Also, contracts were awarded for the study of second-generation Stirling heat engines. To achieve the 1985 system goals of 50 to 60 mills/-kWh, it will be necessary to develop small heat engines that have net efficiencies of 35 to 45 percent. The first Semiannual Technical Progress Report summarizing the dish-Stirling subsystem development was published and distributed. The schedule is shown in Figure 118.

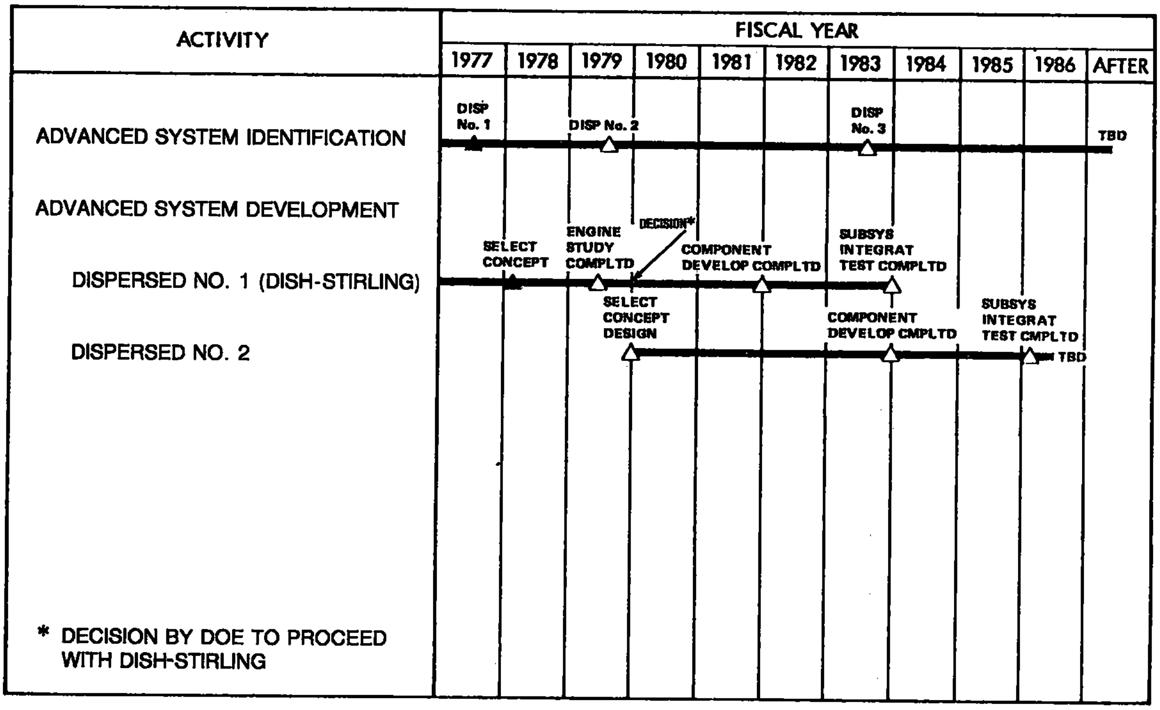


Figure 118. Advanced System Schedule

LARGE POWER SYSTEMS APPLICATIONS

LARGE POWER SYSTEMS APPLICATIONS

The primary objective of the Solar Thermal Power Systems program is to establish the technical readiness of cost-competitive solar thermal power systems for both small and large energy production applications. Within this overall objective, the large power systems, primarily based n the central receiver concept, are directed toward penetrating the utility and industrial markets. The competitive economic generation of electric power and intermediate- to high-temperature industrial process heat is the main thrust of the large power systems program. The commercialization of large central receiver power systems is based on user "hands-on" experience through joint government and industry pilot and demonstration plants; government sponsored research and development of advanced subsystem components to improve performance and reduce costs through industry participation; and advanced technology concepts to improve the cost effectiveness of the mid- and long-term applications. These efforts, combined with the projected increases in costs associated with other forms of energy production will lead to the attainment of the commercialization goals established in the National Energy Plan for solar energy production.

The major phases of the Large Power Program element are indicated in Figure 119. The four activity areas under large power are:

- The large-scale central receiver system experiment, a planned pilot plant to be located near Barstow, California;

- The development of systems for large-scale utility applications (which increasingly emphasizes near-term applications, e.g., repowering of oil- and gas-fired power and industrial process heat plants in the southwestern United States);

- The verification of subsystems and components through the use of the Central Receiver Test Facility (CRTF); and

- The development of lower cost and higher performance central receiver subsystems and components (with particular emphasis on heliostats and advanced heat-receiver technology).

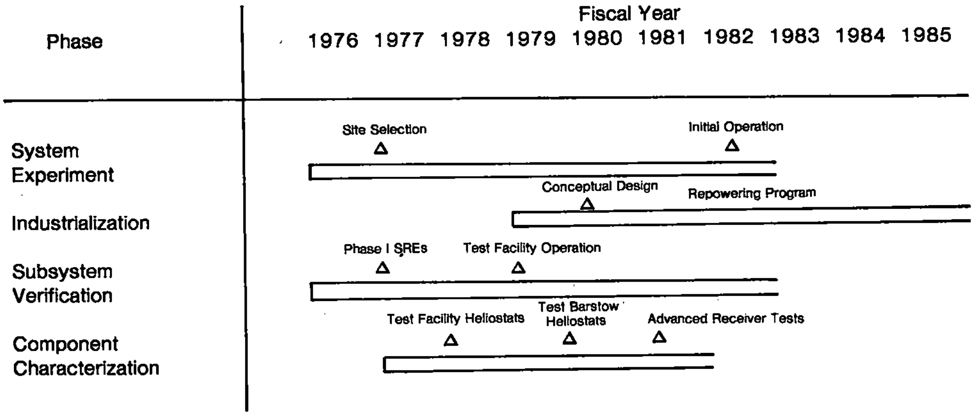


Figure 119. Large Power Program Milestones

The systems and applications segment of the Large Power Systems Program element has four activity areas, the progress of which will be reported in this section. These areas encompass the large-scale central receiver systems experiment, the 10-MW_e pilot plant at a site of Southern California Edison Company near Barstow, California, the development of advanced storage-coupled solar thermal generating systems, the application of solar power in repowering existing oil- and gas-fired plants, and the development of hybrid systems (e.g., first-stage solar heated, second-stage fossil-fuel fired in the instance of serial hybrids).

These activity areas are to some extent interrelated through common component development and common test bed utilization. The reports on progress in these areas will, however, be presented in separate sections.

10-MW_e Central Receiver Pilot Plant

The 10-MW_e pilot plant project has a unique and timely relationship to the Solar Thermal Power Systems Program and the furtherance of its objectives. The program goal of the Solar Thermal Power Systems Program is to foster the research and development necessary for:

> ...The large-scale commercial implementation of solar thermal power systems for electric utility applications, irrigation pumping, applications requiring a combination of electric power and heat energy (total energy systems), and applications requiring high-temperature process heat alone to replace the use of critical fossil fuels.

This effort has been divided into programs that distinguish between dispersed (or point-of-use) applications and centralized (e.g., utility) applications. Large power systems are included in the latter. The technical goals of the Solar Thermal Energy Conversion Program include the establishment of engineering understanding and economic and environmental feasibility which will lead to subsequent construction of solar thermal electric plants by industry. The 10-MW_e Central Receiver Pilot Plant will meet these goals.

The pilot plant is a cooperative effort between DOE and the Associates (Southern California Edison, Los Angeles Department of Water and Power, and the California Energy Commission). As shown in Figure 120, the day-to-day management responsibility has been assigned to the Solar Ten-Megawatt Project Office (STMPO) located in the greater Los Angeles area. The overall plant costs, estimated at $123 million, are divided between DOE and the Asso-

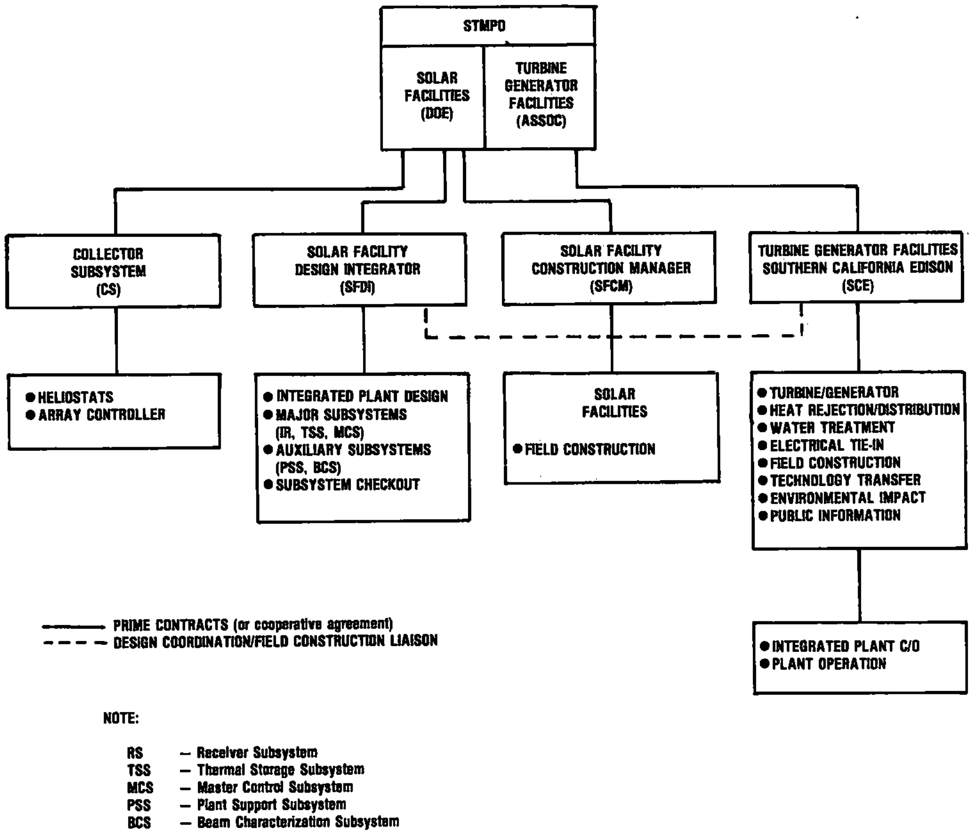


Figure 120. STMPO Management Responsibilities

ciates. DOE will fund the solar facilities (~ $108 million), and the Associates will fund the turbine-generator facilities (~ $15 million) and contribute an additional $5 million for noncapital expenditures for personnel and plant operations. DOE capital funding of $43.5 million has been provided through FY 1978, and $28 million in additional obligational authority will be available in FY 1979.

In addition, present DOE planning to meet program objectives provides for evaluation of technology at the 10-MW_e plant size and repowering plants of 25 to 100 MW_e as intermediate steps between pilot plants and 100- to 300-MW_e commercial plants. Repowering plants may include construction of solar thermal boilers next to an existing fossil-fueled power plant and connection of the solar boiler to the existing turbine generator. The repowering plants will provide construction and operating data that utilities can use to evaluate the technical and economic feasibility of commercial solar plants with greater confidence. Projects between the first pilot plant and the commercial-scale plant may be dropped or accelerated depending on the rapidity with which improved technologies can be developed. It is intended that all plants built will be under cost-sharing arrangements between Government and industry, with increasing industry involvement.

In furtherance of these technical goals, the specific objectives of the 10-MW_e Central Receiver Pilot Plant Project were established as follows.

- To establish the technical feasibility of a solar thermal power plant of the central receiver type, including collection of data for retrofit applications of solar boilers to existing plants fueled by oil or natural gas.

- To obtain sufficient development, production, operation, and maintenance cost data to indicate the potential for economic operation of commercial power plants of similar designs, including retrofit applications on a comparable scale.

- To determine the environmental impact of solar thermal central receiver plants.

- To gather operational data that can be used to determine system stability and safety characteristics.

- To further utility and commercial acceptance of solar thermal central receiver systems.

- To stimulate industry to develop and manufacture solar energy systems.

- To enhance public acceptance of, and familiarity with, solar central receiver types of systems.

Shortly after the formation of DOE's predecessor, ERDA, three contractors--Honeywell, Martin-Marietta, and McDonnell Douglas--were selected to conduct preliminary design and subscale experimentation on a central receiver plant using water and steam as the transport and working fluids and a steam-Rankine turbine as the heat engine. Designs were to be provided for both a utility-scale (100-MW_e) plant and a 10-MW_e pilot plant. A fourth contractor, Boeing, studied only the heliostat subsystem.

Two years of study, experimentation, and analysis by these contractors and evaluation by an ERDA team led to the selection, in the last quarter of FY 1977, of the McDonnell Douglas Astronautics Company (MDAC) configuration for the baseline design of a 10-MW_e pilot plant (Figure 121) designated "Solar One" to be constructed at a site near Barstow in Southern California (Figure 122). This design concept encompasses glass-mirrored, roughly square, pedestal-mounted heliostats in an approximately circular field. The receiver design selected is a cylindrical, externally illuminated, vertical tube, once-through-to-superheat boiler atop a steel tower somewhat south of the center of the field. Thermal storage will be in tanks which contain hydrocarbon-based heat transfer oil and are packed with rock. The principle of operation is natural thermocline separation of hot and cold fluids. A dual admission turbine-generator will be the energy conversion subsystem. The storage subsystem concept is currently undergoing final design as a separate project element of the Thermal Power Systems Program and is scheduled for initial operation in late 1981.

During FY 1978, certain activities by the above contractors have been continued. MDAC, Martin-Marietta,

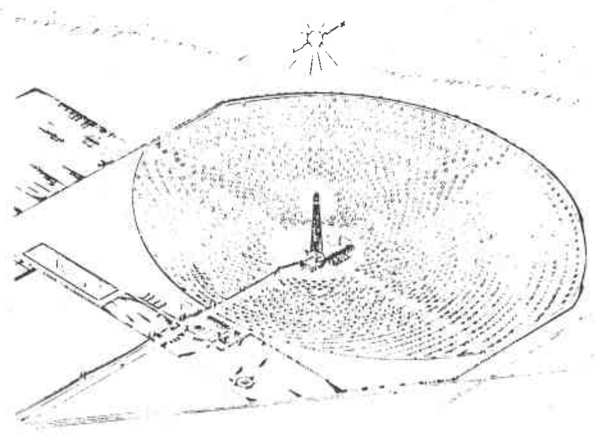


Figure 121. Solar 10-MW_e Central Receiver Pilot Plant

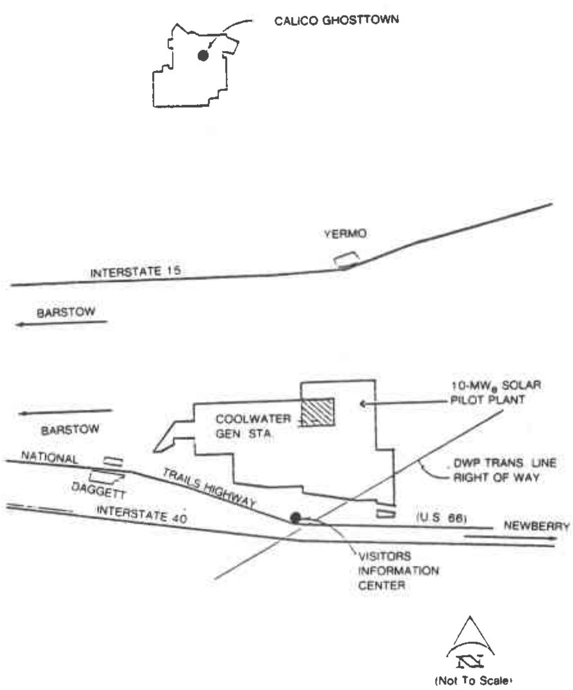


Figure 122. 10-MW_e Central Receiver Pilot Plant

and Boeing heliostats are being monitored for long-term effects of exposure to the natural environment; the MDAC heliostat shows some degradation in reflectivity due to dirt and dust build-up, with restoration of near-original performance following artificial or natural (rain, snow) cleaning. These effects are overlaid, in the case of the plastic-enclosed Boeing heliostat, upon a gradual degradation of the optical and material properties of the plastic at a rate yet to be established. Wind-tunnel tests of subscale arrays of heliostats by these contractors as well as by Honeywell and by Martin-Marietta showed the anticipated reduction in wind forces on interior-field heliostats (Figure 123). Exterior fences also reduced loads in general but, as shown in the Honeywell experiments, certain fence configurations can lead to localized enhancement of wind loading.

Townsend and Bottum (T & B) of Ann Arbor, Michigan, was selected as Construction Manager in July 1977 and is assisting STMPO with the construction and value engineering reviews, cost estimating, cost accumulation, and overall project schedule integration. T & B also will perform the field construction management services.

Figure 123. 1/30 Scale Model of Partial Heliostat Field Segments

In the fall of 1978, Robert D. Thorne, DOE's Assistant Secretary for Energy Technology, announced the selection of the solar facility contractors. Both Martin-Marietta and

McDonnell Douglas were selected for negotiation of a 1-year collector subsystem preproduction contract with options permitting the Government to determine whether one or both of the contractors will fabricate heliostats for the plant (approximately 1900). McDonnell Douglas was selected for negotiation of a contract to integrate the solar facilities design with the turbine generator facilities and to design and fabricate the remaining solar subsystems as the Solar Facilities Design Integrator (SFDI).

The selection of the pilot plant configuration was based upon the potential for low cost at the commercial size and the ability to simulate the commercial configuration at the pilot plant size. The choice between the externally illuminated MDAC receiver and the cavity-type receiver by Martin-Marietta was relatively close; the externally illuminated unit was considered to have somewhat better potential for low cost. For other applications of central receiver technology, the cavity receiver might still be preferred. Both contractors had built and tested, by radiant thermal heat, receiver models of approximately 5-MW_t capacity (equal to about 1-1/2 MW_e). It was decided to verify these tests by exposure of these models to actual sunlight conditions using the DOE Central Receiver Test Facility (CRTF) at Sandia Laboratories, Albuquerque. The MDAC receiver model, a 70-tube panel approximately 56 feet tall and 3 feet wide, representing one of the 24 facets of the complete receiver, has been modified for installation and remote control and monitoring atop the 200-ft tower of CRTF. This receiver model was delivered to Albuquerque in September 1978 and is scheduled for 4 months of testing, under a variety of static and dynamic operating conditions, during the early part of CY 1979. Preparations are also nearly completed for testing of the Martin-Marietta reduced-scale cavity receiver, following the MDAC receiver tests. These tests will be performed under the Central Receiver Technology Development (CRTD) program area. The MDAC heliostat design will be tested in a full-scale configuration for wind-load resistance in early FY 1979 in a wind tunnel. In addition, facility designs will be initiated for both the solar and the turbine generator installation segments.

In response to the recognized need for an all-digital, high fidelity, dynamic computer simulation, a solar 10-MW_e pilot plant simulation was developed so that all major plant subsystems are modeled in separate modules that can be run independently or collectively to study mode transitions, transients, and steady-state plant functioning. The environmental module contains data taken near Barstow, California, at 15-minute intervals for every day in 1976. Run time is approximately 10 times faster than real time on a CDC 7600 and permits tabular listing of any selected variable time history with 28 different variables as a function of time.*

Another critical need identified was for measuring cloud conditions to determine both the temporal and spatial variability of insolation over the collector field of the pilot plant site. Potential design impacts on the thermal

*The Aerospace Corporation, ATR-78(7747)-1, Vol. 1 (August 1, 1978).

stress in the receiver as well as control system design problems have been suggested due to this insolation variation. Because no relevant information of sufficient resolution is available, this measurements program was initiated by STMPO and is being supported and serviced by Southern California Edison Company. Preliminary data indicate a higher frequency of insolation variations than expected for August 1978.

The preproduction heliostat phase will include testing of full-size heliostats with associated controls at CRTF in Albuquerque, New Mexico, and environmental testing of components. Heliostats which successfully pass these tests will provide the project with a high degree of confidence that the production units will successfully perform at the pilot plant.

As a natural part of the 10-MW_e pilot plant project, a technology transfer effort was developed to promote public and institutional knowledge and acceptance of solar thermal power systems. The dissemination of solar thermal technology will be accomplished by Southern California Edison Company through various public relations and publicity programs as well as through design and operating reviews with potential users in utilities, manufacturers, and architect-engineer firms.

A Visitor's Information Center will be located on 5 acres of land to be leased from the State of California (Figure 122) adjacent to National Trails Highway in the County of San Bernardino. The building design selected provides a major display area, an office, projection room, auditorium, multipurpose room, and vending machine area. It is anticipated that this facility will be open to the public in the fall of 1979.

To enhance public awareness of solar thermal technology, the Associates have published a brochure describing the project and a fact sheet. They serve to answer general inquiries about the project description. Also, a speech script and slide presentation were developed for use at civic and private group meetings. Scale models of the pilot plant were constructed and will later be displayed at the Visitor's Information Center.

The establishment of Project Advisory (ad hoc) and Review Committees provide for the dissemination of solar thermal technology advances to potential users. The Project Advisory Committee will initially meet semiannually, then quarterly, during construction. Members will input continuing program appraisals. Annually, a full-project examination, including plant tour, will be held and a comprehensive report published. The Project Review Committee will attend the Annual Review Meeting and the plant tour.

The following list is a short chronology of important recent project events through September 1978.

<u>1977</u>

<u>January:</u> Site location and utility partner selected.

<u>May to June:</u> Four conceptual design contracts completed.

<u>March to September:</u> Project office (STMPO) formed and staff selected. System specifications and prime contractor RFP initiated.

<u>July:</u> Construction manager selected (Townsend & Bottum, Ann Arbor, Michigan).

<u>August:</u> Pilot plant conceptual design selected.

<u>October:</u> Project office installed in El Monte, California.

November: Project management plan approved by DOE and Environmental Impact Report (EIR) completed.

December: Site topographic survey and site plot plan completed.

1978 January: DOE and Associates cooperative agreement approved.

February: Collector RFP released.

March: Bidders conference for collector subsystem held. Received collector proposals and began evaluation. Filed site approval plan with San Bernardino County.

April: Solar Facility Design Integrator (SFDI) RFP issued. DOE and Associates cooperative agreement signed.

June: EIR approval and site zoning approval received.

July: Federal Environmental Assessment approved.

August: Collector subsystem contractors selected for 12-month preproduction phase (production phase TBD):

Martin-Marietta, Denver, Colorado

McDonnell Douglas Astronautics Company, Huntington Beach, California

Solar Facility Design Integrator selected (McDonnell Douglas Astronautics Company, Huntington Beach, California).

September: Two collector subsystem design contractors began work under advanced agreements.

The field construction is planned to be accomplished through Government prime, fixed-price, competitive bid contracts. Solicitations will be announced through the STMPO office and all contracts \$2 million or less will be small business set-asides.

The critical milestone schedule for August 1978 through October 1979 is given in Figure 124 and the project baseline is shown in Figure 125. Project schedules are given below.

1978 December: SFDI starts solar facility design under advanced agreement.

1979 January: Start turbine-generator facility design.

April to May: Initiate prototype heliostat CRTF testing.

April to June: Start site construction

August to September: Complete CRTF collector testing.

October: Select heliostat manufacturer.

1981 September: Complete plant/start operations.

Storage-Coupled Systems

As discussed in connection with the 10-MW_e Central Receiver Pilot Plant project, the program goal is to foster the development of large-scale solar thermal power systems for utility applications. Achievement of this goal would be enhanced if stand-alone capability could be attained through the use of facilities capable of storing thermal energy and releasing it on demand. This would eliminate the requirement of coupling solar plants in the utility grid with sufficient conventional fossil

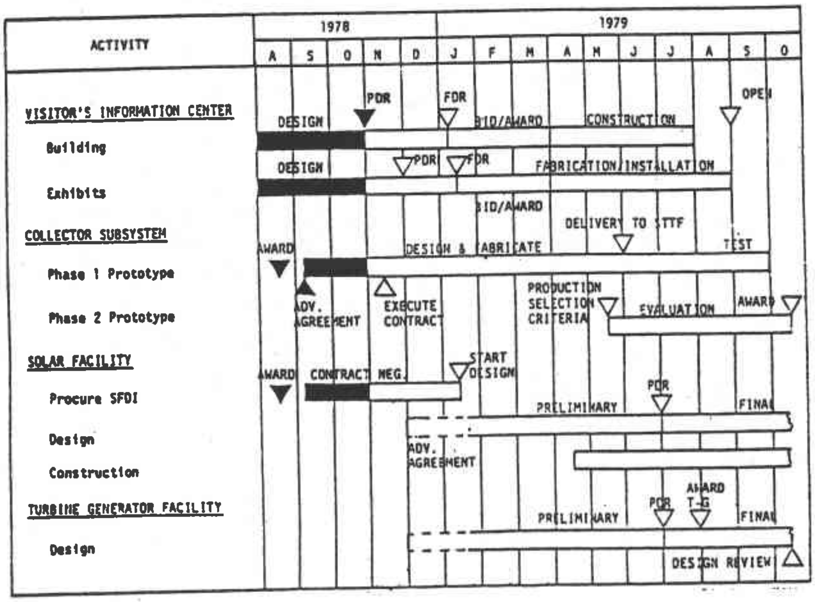


Figure 124. Critical Milestone Schedule

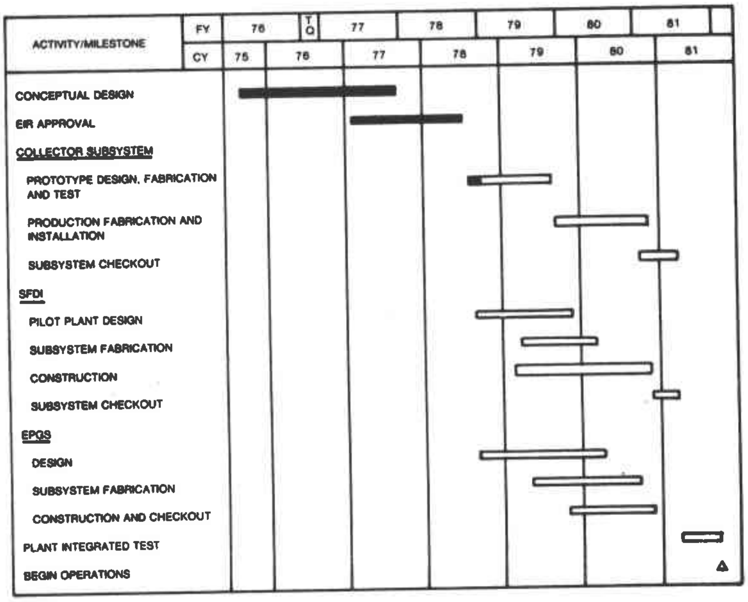


Figure 125. Project Baseline

energy plant standby capacity to meet demand during periods of poor insolation or at night. Technical goals of this program segment thus include the development of thermal energy transport and storage systems using fluids with sufficient stability to meet steam-Rankine turbine inlet temperature requirements at a minimum.

The objectives of the storage-coupled systems program element include improvements in working, transport, and storage fluids, as well as in means for removing impurities resulting from thermal degradation of transport and storage fluids. Specifically, these objectives are:

- Reduce the rate of thermal degradation of transport and storage fluids at temperatures of 600°F or higher;

- Develop means of continuously removing products of degradation from hydrocarbon transport and storage fluids, if such degradation is unavoidable;

- Develop power generation cycles employing high-temperature transport and storage fluids such as thermally stable hydrocarbons, molten salts, and liquid metals; and

- Develop cycles employing high-temperature fluids capable of serving as transport, storage, and working fluid, such as steam, air, or helium.

The early history of this project is associated with that of the 10-MW_e pilot plant and is therefore described by the history cited for that project. The work effort by the major contractors under the Barstow project--MDAC and Martin-Marietta--included static testing of various oils suitable for heat transport and storage, such as Caloria HT 43. In 1976, a joint study by the University of Houston and Rockwell International was initiated to evaluate more cost-effective transport and storage fluids in view of the temperature limits and the thermal degradation suffered by the hydrocarbon oils tested up to that date. This study indicated that liquid sodium metal would have advantages over the hydrocarbon oils for this application. A schematic of such a cycle is shown on Figure 126. In early FY 1977, four contractors began to perform conceptual design studies of advanced central receivers and of critical components and interfaces of systems utilizing alternate transport and storage fluids, and, in some cases, fluids that could addition-

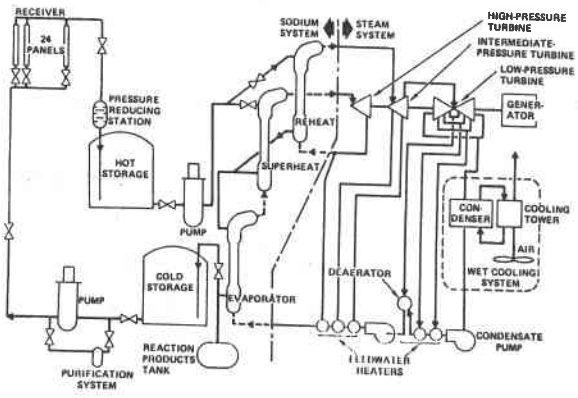


Figure 126. Advanced Central Receiver System — 100 MW_e Commercial Plant

ally serve as the working fluid. The fluids studied by these contractors (Atomics International, General Electric, Martin-Marietta, and Boeing) included liquid sodium metal, molten sodium/potassium nitrate salts, and helium and air. The latter two gases are intended for application to Brayton power cycles in which they would also serve as working fluids.

The significant accomplishments for FY 1978 included completion of the above mentioned study by the University of Houston and Rockwell International. It was recognized that a sodium environmental problem may exist. Tests were conducted to collect aerosol data to establish initial environmental impact data and additional work may be required. Static testing of hydrocarbon oils for high temperature degradation were conducted, and it was concluded that the relatively low-cost Caloria HT 43 oil exhibits reasonable stability up to temperatures of 600°F. These tests are continuing as is a test of a side-stream fluid purifier intended to remove products of degradation in a continuous process.

Another accomplishment resulted from studies by Atomics International and General Electric on advanced central receiver systems. From these studies it was concluded that substantially improved performance over a steam-Rankine cycle could be obtained from a system that uses an external receiver, liquid sodium heat storage, and a liquid sodium-fired boiler. This conclusion was based on the analysis of a conceptual 100-MW_e single-module plant. The GE study interim results showed that an external receiver and use of steam as the transport and working fluid would be preferable.

Similar advantages were cited for molten sodium/potassium-nitrate salts as the conclusion of the Martin-Marietta study. However, the baseline plant configuration studied by Martin-Marietta utilized cavity-type receivers in a triple-module arrangement for a 100-MW_e plant using a single turbine-generator. The Boeing study resulted in the selection of a 2-module plant developing 150 MW_e, with separate turbines, and using air as the heat transfer, storage, and working fluid.

In 1976, funding was provided for study of a "Line Central Receiver" concept proposed by the FMC Corporation as shown in Figure 127. Subsequent advances in both central and distributed receiver systems prompted issue of an RFP in mid FY 1978 for a two-phased study of line focusing systems. Respondents were asked to compare linear-focus concepts scaled to the 100-MW_e system size for capital and energy production costs and for costs of the collector subsystem on a unit-area basis with corresponding costs for the baseline Central Receiver System. Several concepts were offered which showed promise (see Table 6) and three contractors were selected for 1-year Phase I design studies extending into FY 1979. BDM Corporation of Albuquerque, New Mexico, offered two systems, one of which is shown in Figure 128. General Atomic offered a fixed-mirror, moving collector concept previously considered under ERDA, DOE, and Electric Power Research Institute (EPRI) funding and is shown in Figure 129; SRI International proposed further

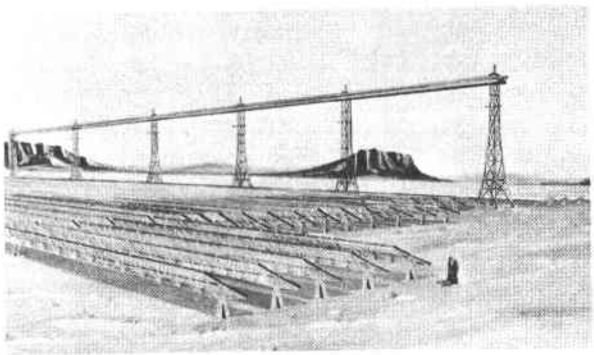


Figure 127. Linear Focus Central Receiver Systems

Table 6. Cost Proposals for Baseline Central Receiver System

	Strawman	BDM-A	BDM-B	GA	SRI
Capital Cost Plant # 1 $(1978)/kWe	2092	1810	1688	1817	1969
Capital Cost Plant # 80 $(1978)/kWe	1402	1184	1121	1227	1307
Busbar Energy Cost, 1990 IOC mills/kWe-hr	84	68	65	81	80
Concentrator Subsystem Cost Plant # 1 $(1978)/m²	80	—	—	66	46
Concentrator Subsystem Cost Plant # 80 $(1978)/m²	58	75	75	48	34

development of the Line Central Receiver in which they had participated with FMC earlier (Figures 127 and 130). At the conclusion of the Phase I studies, early in FY 1980, the resulting designs and performance analyses will be evaluated to determine if continuation to Phase II preliminary design is warrented. Support for this decision will be provided by tests in FY 1979 on the module of the Line Central Receiver linear heliostat previously fabricated by FMC.

The goals for FY 1979 include the completion of the Boeing study during the first quarter with an analysis of helium as the transport, storage, and working fluid. The GE study is scheduled for completion during the second quarter of the year. During the third quarter, one or more contractor(s) will be selected to continue with 1 or 2 years of experimentation and with preliminary design of the preferred alternate central receiver storage-coupled options.

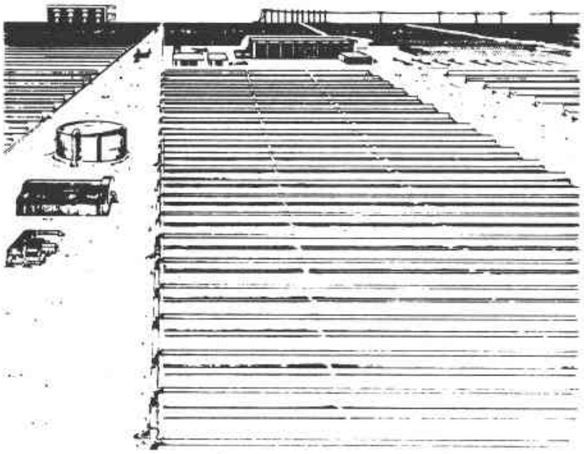


Figure 128. 100-MW_e Distributed Line Focus Solar Central Power System

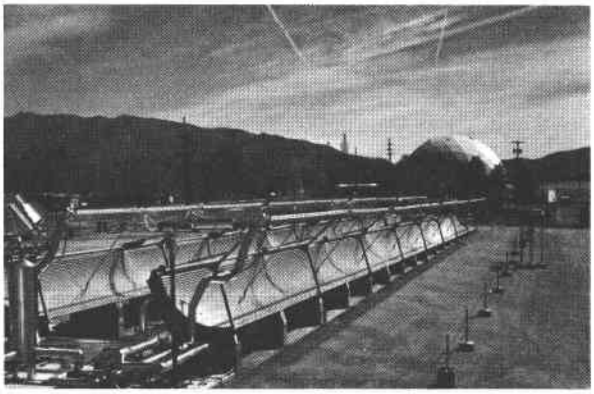


Figure 129. FMSC Heat Supply System at Sandia Laboratories

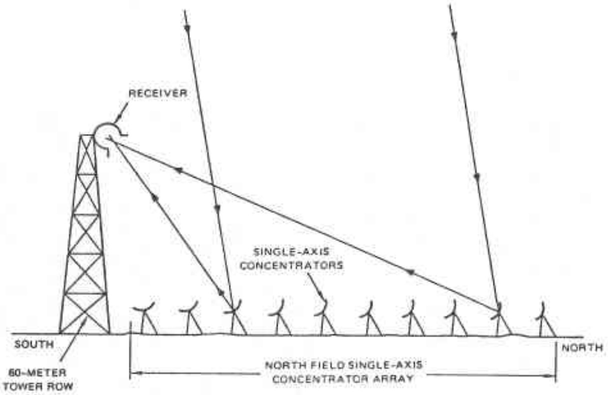


Figure 130. High-Temperature, Line-Focus, Central Receiver System

At the beginning of FY 1980, following completion of the 10-MW_e pilot plant design phase and testing of the baseline receiver model, at mid-course in Phase II of the Alternate Central Receiver study, and at completion of the conceptual phase of the Hybrid and Line-Focus studies, the overall technical status of the Large Power Systems Applications program will be reviewed in light of then-prevailing fiscal and programmatic considerations. Recommendations will be developed at that time as to which technology (or technologies) should be selected for the next stage of development beyond the 10-MW_e pilot plant. This will include not only comparisons among storage-coupled technologies (water/steam versus alternate heat collection/transport fluids; Rankine versus Brayton cycle systems; central receiver versus line-focus collector/receiver configurations), but also assessment of Large Power Systems goals for ultimate commercialization (stand-alone versus repowered/hybrid systems and electrical versus other energy forms, e.g., process heat, fuels, chemicals, etc.).

Repowered Systems

The program goal of furthering the commercial implementation of solar thermal power systems for utility applications would be served both by supplying new generating demand with solar plants instead of with fossil plants and/or by meeting existing demand through replacing existing but obsolete fossil-fired generating capacity with new solar capacity. In both instances, the national goal of displacing nonrenewable energy consumption with renewable resources would be served, and the technology of solar thermal power systems would be advanced even if only a portion of an existing fossil plant were to be repowered by solar facilities.

The technical goals of this project initially include the survey and assessment of potential markets for retrofitting existing fossil-fueled plants with central receiver-type solar heat sources, to be followed by the design of such a repowering installation to allow further analysis of technical requirements and of interfaces. The specific objectives of this project include:

- Identification of fossil-fueled power plants in the southwestern United States which possess a potential for solar repowering;
- Determination of the general costs and benefits of repowering for the type of installations identified above; and

- Provision of a conceptual design for a specific repowering installation for an actual power plant application in order to develop better cost estimates and to carry out analyses of interface and other technical problems.

The repowering project was initiated in September 1977 with a study by the Public Service Company of New Mexico (PNM) which provided a technical and economic assessment of solar hybrid repowering. This study indicated that, under a given set of constraints, at least 5200 MW_e of potential solar repowering capacity exists in the southwestern States. When less restrictive constraints were used by the Mitre Corporation in an independent assessment during FY 1978, a repowering potential of at least 11,000 MW_e was found to exist in the same area. An analysis of cost-benefit ratios by Westinghouse Electric Corporation in FY 1978 (under subcontract to PNM) indicated that ratios of less than one would be attainable for repowering of natural gas power plants while coal-fired plants showed positive ratios up to 1.5, indicating less favorable economics. However, when environmental considerations and potential pro-solar legislation are included, even coal-fired plants may benefit from solar repowering.

Several accomplishments during FY 1978 that are considered significant include completion of the PNM and Mitre studies which resulted in estimates of between 5200 and 11,000 MW_e or more of existing capacity which could be repowered by solar thermal power facilities, depending upon the nature of the constraints assumed for this study. These assumptions dealt with maximum existing plant capacity, the level of the repowering fraction, the availability of nearby land, etc. A conceptual design for a 25-MW_e solar repowering installation at a specific oil burning power plant in the PNM system was also completed. This design was based on existing solar thermal technology as represented by the pilot plant project near Barstow and would allow completion of construction within 42 months of start.

A workshop was held at SERI in August 1978 to discuss current study results. The conclusions of this workshop provided a basis for a venture analysis initiated by SERI in the last quarter of FY 1978.

The goals for FY 1979 include completion of the venture analysis by SERI on the subject of repowering, scheduled for the first quarter of the fiscal year. In addition, an RFP for the study of site-specific repowering applications is scheduled for release during the second quarter of FY 1979.

Following completion of the repowering concept studies initiated late in FY 1979, and assuming that the SERI study supports the implementation of repowering (or, alternatively, other retrofit applications), activities will begin in the third quarter of FY 1980 to identify one or more utility/industrial partners and their respective candidate sites for one or more plants having a solar component capacity in the vicinity of 25 to 50 MW_e.

Hybrid Systems

As in the instance of the Repowered Systems Project, the goal of the Hybrid Systems Project is to assist the large scale commercial implementation of solar thermal power for electric utility applications and, by extension, to assist process heat industrial application as well. It is anticipated that, as the repowering market saturates, the remaining existing fossil-fueled plants will also become obsolete. Opportunities may then become available for new plants designed initially as hybrids to further reduce consumption of fossil fuels. The technical goals of this project include the development of designs for power generation cycles which combine both solar and fossil (or other) energy sources in a manner that enhances plant performance and economics. Goals supporting this objective are the development of high-temperature receivers and high-temperature heat transport and storage fluids for improved performance from hybrid cycles.

The specific objectives of the Hybrid Systems Project include the following:

- Development of designs of power generating systems that utilize both solar and fossil cycles, either series or parallel connected, with operating temperatures up to 2400°F, and suitable for either Brayton or Rankine cycles, and
- Utilization of advanced technology both for solar central receivers and for thermal storage subsystems.

An RFP was released by the SAN Field Office in May 1978 soliciting proposals for a 1-year conceptual design and assessment effort (Phase I of a two-phase program, in which a promising concept may be subjected to experimentation and further development during Phase II) for hybrid systems. Three contracts were awarded at the end of FY 1978 as a result of this competition. Bechtel National, Inc., proposed a study of baseline and advanced combined-cycle, series-connected systems in which pressurized air heated to 1500°F to 2000°F in a multiple-aperture cavity receiver is further heated by the combustion of oil to 2000°F to 2400°F to drive a gas turbine; the turbine exhaust is used to fire a steam-Rankine bottoming cycle.

Steam-Rankine systems using central receiver systems cooled by liquid sodium and molten salt (Figure 131) in parallel with fossil-fired heaters and with varying amounts of storage capability, will be studied by Rockwell's Energy Systems Group and Martin-Marietta, respectively. These concepts draw heavily upon technology presently under development for DOE and are expected to have potential for market and fuel displacement impact in the 1980s.

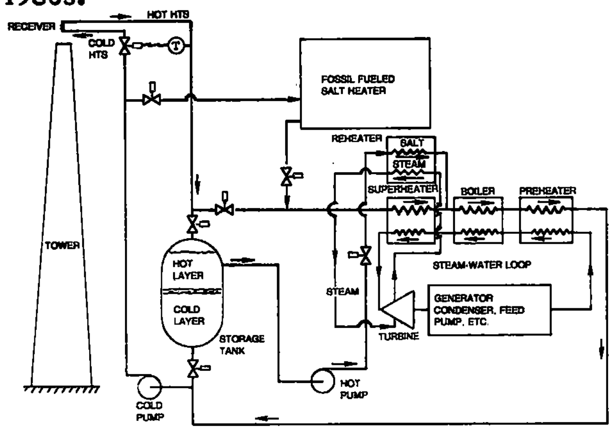


Figure 131. Molten Salt Hybrid Power Cycle

The significant accomplishments that occurred in FY 1978 included the award of contracts to Bechtel, Rockwell International, and Martin-Marietta during the last quarter. Goals for FY 1979 include completion of Phase I studies by Bechtel, Rockwell International, and Martin-Marietta and award of Phase II studies.

Following completion of the Hybrid Systems conceptual designs at the end of FY 1980, the designs will be compared with one another to determine their relative promise for meeting then-current program needs. The promising technology (or technologies) will then be compared across-the-board with the currently available storage-coupled technologies, and with available market penetration projections, to determine the relative suitability of the two approaches for the Nation's central power generation needs of the 1990s. The relative merits of completely new hybrid systems as compared with retrofitting of existing plants will also be considered in the nearer-term context of the repowering program element. The Electric Power Research Institute is expected to make a decision in early FY 1980 as to whether or not to proceed with a 10-MW_e-scale Brayton-cycle hybrid plant. Based upon the foregoing assessments, a decision will be made at that time whether or not to offer DOE participation in development of this plant.

SUBSYSTEMS AND COMPONENTS DEVELOPMENT

The Subsystems and Components Development segment of the Large Power Systems Applications encompasses the efforts to improve the technology and economics of the individual solar components which are unique to large central receiver solar thermal power systems. These components are the heliostats, receivers, and thermal storage, and they constitute the new technology, high capital cost elements of the solar power systems. It is as a part of this segment of the large power systems applications that the Central Receiver Test Facility (CRTF) is operated to provide the testing capability and large-scale experimental basis for the development of promising components and subsystems for use in current alternate and advanced Solar Thermal Power Systems.

Central Receiver Test Facility

The Central Receiver Test Facility (CRTF) is located on Kirtland Air Force Base near Albuquerque, New Mexico (Figure 132), and is operated by Sandia Laboratories for DOE. It is the primary facility for testing components and subsystems developed as a part of the Solar Large Power Systems Applications program. Specifically, different receiver designs will be mounted in the tower for evaluation testing and various heliostat design concepts will be characterized with regard to tracking, pointing accuracy, and quality of the reflected beams. The activities at the facility are thus closely coordinated with and are in direct support of most other elements of the Large Power Systems Applications program.

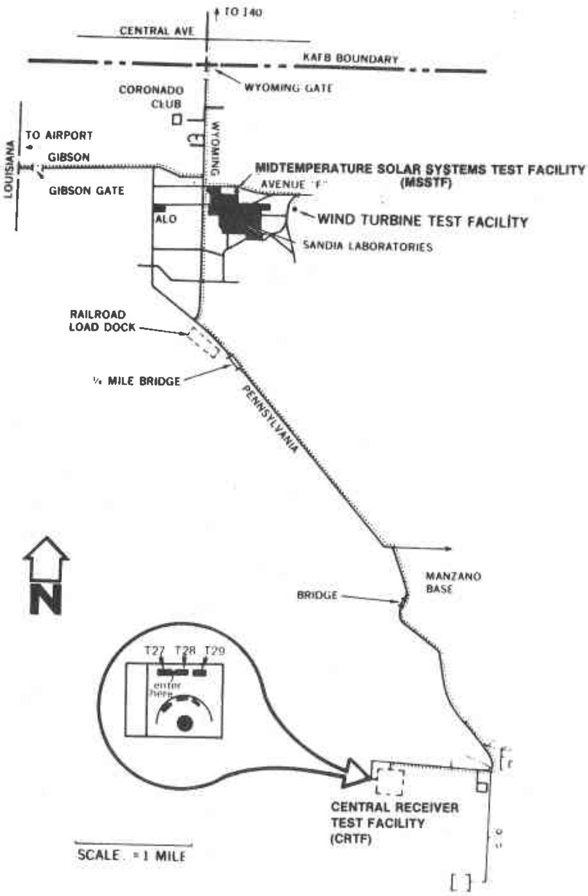


Figure 132. Map of Sandia Laboratories' Albuquerque CRTF Site at Kirtland Air Force Base

The primary objective of CRTF is to provide timely testing and evaluation of the receivers and heliostats. While this objective is given first priority in facility operation and scheduling, the facility is also useful to a broad class of experiments that may require its unique high-temperature, high-heat flux environment. The Solar Thermal Test Facilities Users Association (STTFUA) is interacting with CRTF to assist in coordinating the needs and requirements of other tests and experiments with those performed as a part of the primary program.

Conceptual design of the CRTF was initiated early in FY 1976 and site work, beginning with the installation of required utilities, was started in late FY 1976. During FY 1977, procurement and construction was initiated on all major elements of the facility. Construction of 312 heliostat foundations, fabrication and installation of 222 heliostats, and construction of the control building were all essentially completed during FY 1977. Figure 133 is a photograph of one of the completed heliostats. Construction of the tower and design and procurement of the Master Control and Data Acquisition systems (MCS and DAS) were initiated in early FY 1977. The site, during early stages of tower construction, is shown in Figure 134. By May 1977, sufficient heliostats and their controls had been installed to allow a partial demonstration of the operation of the facility. A 6.4-mm-thick steel plate was attached to the north side of the partially completed tower near the 36.6-m test level. Seventy-one heliostats, representing a portion of the heliostat field, were focused onto the steel plate. Calculations indicated that the thermal power reflected onto the tower was about 1.8 MW and that a solar concentration of about 1200 was achieved at the center of the beam. Photographs of this successful demonstration are shown in Figures 135a and 135b.

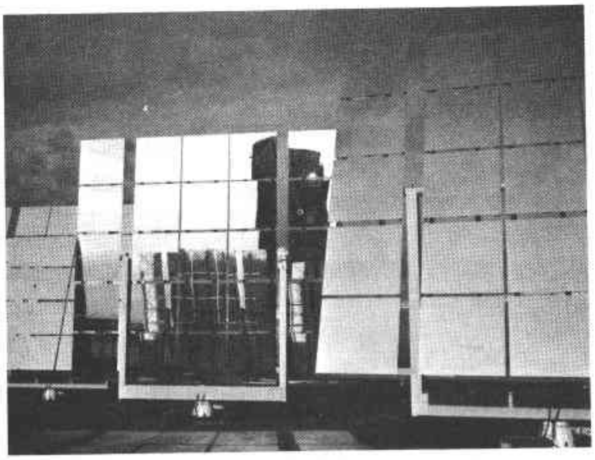


Figure 133. CRTF Heliostat

Figure 134. CRTF Tower Construction

During FY 1978, the major emphasis at the CRTF was directed to completing construction of the facility and preparing for operation in a testing mode. Early in FY 1978, the control building was officially accepted and the MCS and DAS systems were installed. Similarly, all heliostats were installed,

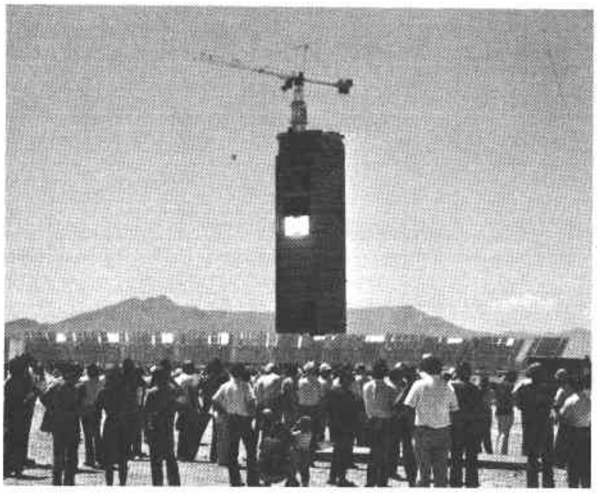


Figure 135a. CRTF Demonstration (May 1977)

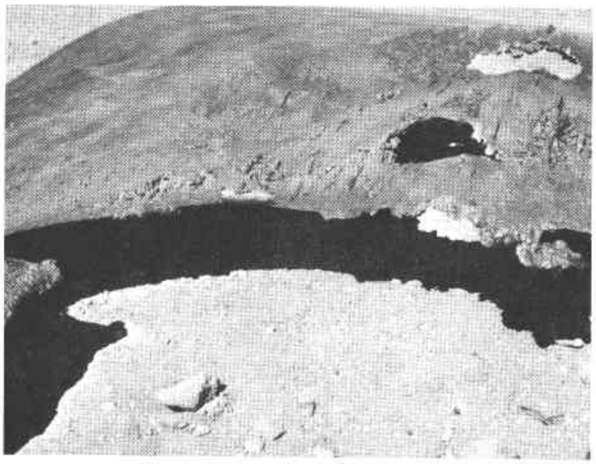


Figure 135b. Photograph of ¼-in. Steel Plate Used in Testing During May 1977 Demonstration at CRTF Site

the control wiring completed, and the supplier left the site after checkout and acceptance of the control system.

The major construction item, ongoing throughout FY 1978, was the tower system including the tower itself, the 100-ton elevating module, and the heat rejection system. The original heat rejection system was modified to include the capability of providing high-temperature, high-pressure water and high-pressure air to all test levels. All of these items were completed and the tower system officially inspected and accepted late in FY 1978. A photograph of the facility showing all major elements in place is shown in Figure 136.

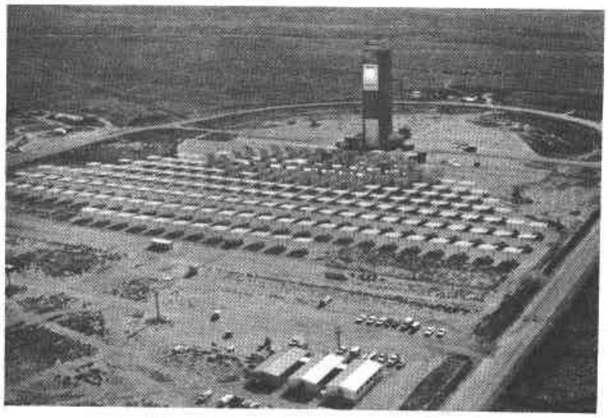


Figure 136. CRTF Site

As specific subsystems were completed during construction, operational tests were conducted. Beginning in April 1978, the heliostats were operated on weekends with the water-cooled working receiver as the target. During June and July, this operation was extended to weekday operation to obtain experience in operation of the entire system. Figure 137 shows the working receiver during a test.

Phase I of the formal acceptance tests for the facility were conducted on July 26 and 27. This phase was directed at acceptance of the heliostats, the control and data systems, the working receiver, and the meteorological and dual-power systems. From the 188 heliostats used during these operations, 3.64 MW of incident thermal power was measured on the working receiver. This agrees within 3 percent of the calculated value, and further calculations indicate that the facility will provide over 5 MW of thermal power when using all 222 heliostats.

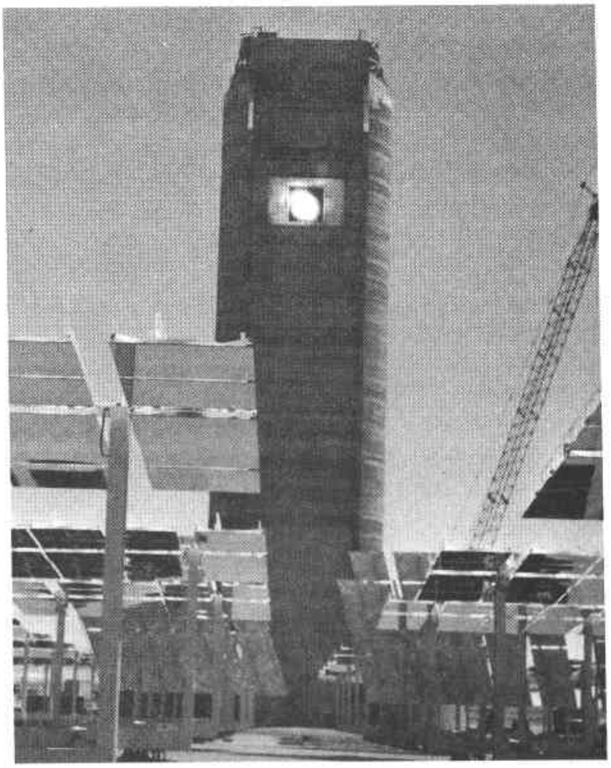


Figure 137. CRTF Operation With Working Receiver

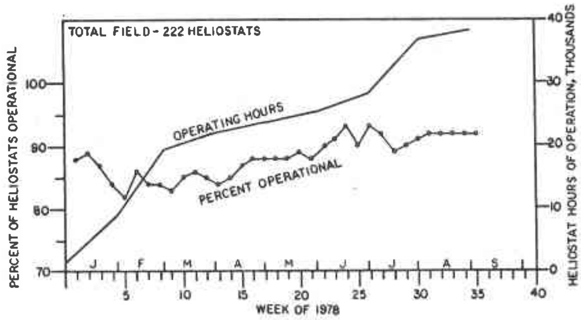


Figure 138. CRTF Heliostat Field Status

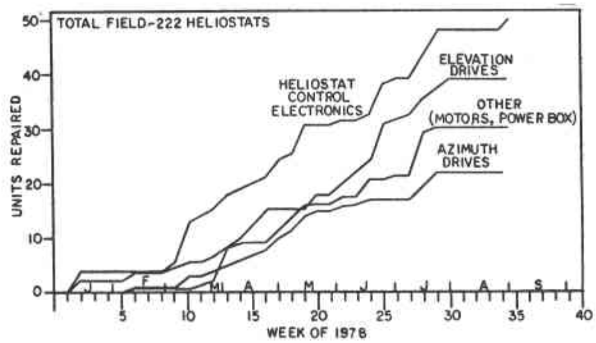


Figure 139. Repair History for Heliostats

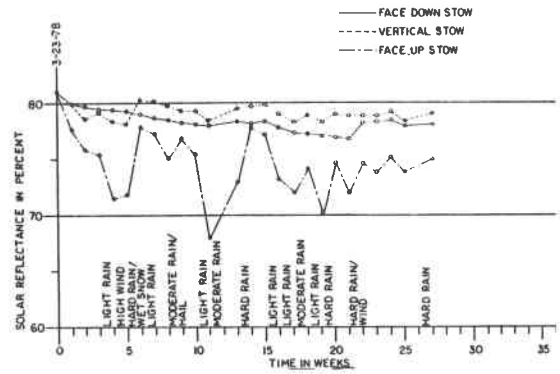


Figure 140. Reflectance vs Time for Different Storage Orientations in STTF Heliostat Field

During FY 1978, the heliostats were operated as much as possible to determine performance and maintenance characteristics. During this period, operational problems resulting from component failure in the heliostat control electronics and from encoder failure in the drive systems were observed. Figure 138 presents a summary of the cumulative operational hours and the percentage of the heliostat field which was operational. Figure 139 presents a summary of the repairs necessary to maintain the operational status shown in Figure 138. Weekly reflectivity measurements on samples of the heliostat mirrors were started in March 1978, and Figure 140 shows the results of these measurements. The effects of environmental conditions can be seen, and these data illustrate the effects of different storage modes.

Two test receivers were delivered to the CRTF during FY 1978. The first to arrive, the EPRI/Boeing 1-MW thermal gas-cooled bench model, arrived on August 6. The receiver and air supply system have been connected and checked out. Solar tests will begin early in FY 1979. The second receiver, the DOE/MDAC/Rocketdyne prototype panel from the 10-MW_e pilot plant design, arrived on site on September 20. Plans were underway to erect the panel on the elevating module when a contractor-supplied hoist failure caused damage to the elevating module. The accident occurred while the local contractor was testing his equipment with a 38,000-lb weight to verify the planned procedure for removing the MDAC receiver panel from a flat-bed truck and placing it on the elevator. The hoist had been tested with a 76,000-lb test weight--2.24 times heavier than the panel--and the 38,000-lb weight was 30 ft above the elevator when one flange of a cable spool broke. This failure caused the cable to spin off the spool and slacken. As the load dropped, the cable snapped, and the weight tore a 12-ft^2 hole in the roof of the second story of the elevator. The steel framing in both the elevator roof and the floor of the upper room and instrumentation cabling located near the ceiling in the top room of the elevator were damaged. Electronic equipment and instrumentation cabling in the computer room below where the weights came to rest were not damaged. The MDAC receiver panel was then placed in a hanger building at nearby Kirtland Air Force Base where instrumentation is being installed by MDAC/Rocketdyne personnel. Damage to the module was evaluated and repair initiated. Present projections indicate the module can be structurally repaired by early FY 1979. As soon as the module is structurally and electrically ready, the MDAC panel will be returned to the CRTF and positioned on the tower.

During FY 1978, interaction and cooperation with the STTFUA has occurred. This consisted of attendance and participation at meetings and seminars and review of proposals as well as briefings and tours as requested by STTFUA. This interaction helps to ensure that the facility will be available and accessable for tests initiated in the future by activities other than those in the Large Power Systems Applications program.

During FY 1979, the facility will be heavily involved in testing both receivers and prototype heliostats. Following completion of the MDAC receiver tests in the summer of 1979, the 61-m test level will be available for testing of additional designs. The first series of EPRI/Boeing tests are estimated for completion in January and the 42.7-m level will then be readied for testing of the EPRI/Black & Veatch gas-cooled receiver. Testing on this second gas-cooled receiver is expected to begin in the summer and continue for 4 months.

Testing of two photovoltaic panels is also planned for FY 1979. These tests are in support of the DOE National Photovoltaic Program and will involve testing of a panel of silicon cells at intensities up to 200 kW/m^2 and a panel of gallium arsenide cells at intensities up to 1500 kW/m^2.

Heliostat evaluation activities in FY 1979 will emphasize specific areas. The heliostat Beam Characterization System (BCS), a video camera-based, digital analyzer which will measure beam flux contours, and centroids on a tower mounted target will be completed and checked out. The first prototype to be evaluated will be one designed, fabricated, and funded by Westinghouse. This prototype will be supplied to the CRTF by Westinghouse and be evaluated at DOE expense. The second series of prototypes will be those supplied to the CRTF by STMPO as a result of the heliostat development contracts for the 10-MW_e pilot plant. The projected schedule for all of these activities, both heliostat evaluation and receiver tests, is shown in Figure 141.

Other FY 1979 activities at the CRTF in support of the Large Power Systems Application program will include planning for and starting any facility modifications or additions necessary to test and evaluate advanced receiver designs or advanced heliostat designs. No test items from either of these are expected in FY 1979, but modifications required to start tests early in FY 1980 will be initiated.

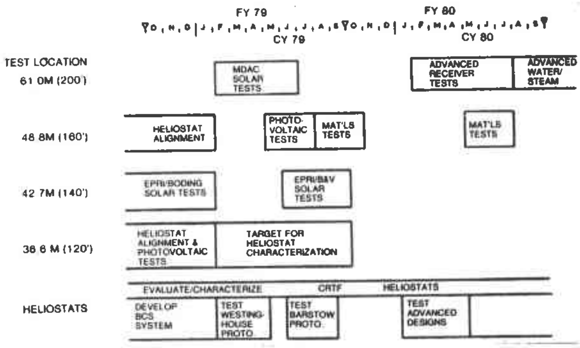


Figure 141. Tentative CRTF Testing Schedule (September 15, 1978)

Heliostats

The extensive heliostat collector field required to collect the low energy density sunlight constitutes the largest fraction of the costs for solar central power generation. For this reason, strong emphasis is being given to the cost reduction of these components. Heliostat cost goals have been established as a result of allocating overall power plant cost targets to the various subsystems. The present goal of the heliostat development program is to achieve an installed cost of \$100/m^2 (1978 dollars) of reflector area by 1990. The attainment of this goal, in conjunction with cost targets for other subsystems, will provide a competitive alternative to the use of oil and natural gas for electric power generating utilities in the late 1980s and 1990s.

A concentrated heliostat development effort was initiated in 1975 when four contractor teams (Boeing Engineering and Construction Company, Honeywell Incorporated, Martin-Marietta Aerospace, and McDonnell Douglas Astronautics) were funded to complete design studies for first-generation heliostat concepts. These 2-year efforts culminated in the fabrication and testing of prototype heliostats based on the concepts developed. An extensive design critique and costing evaluation for each of the designs was undertaken to select the best heliostat approach for the 10-MW_e pilot plant planned near Barstow, California. One of each of the prototypes developed by the four contractors was subsequently installed in Livermore, California, where continued testing and evaluation is being conducted. Figure 142 presents a view of the four first-generation heliostats.

Selection of the 10-MW_e pilot plant design contractors was recently announced. Both Martin-Marietta and McDonnell Douglas were selected for negotiation of a 1-year collector subsystem preproduction contract with options permitting the Government to select for fabrication the one(s) which best meets the requirements on perfor-

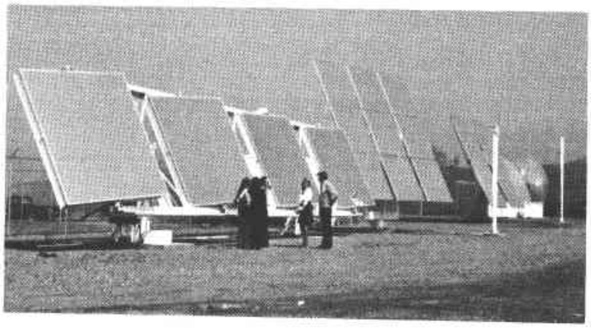
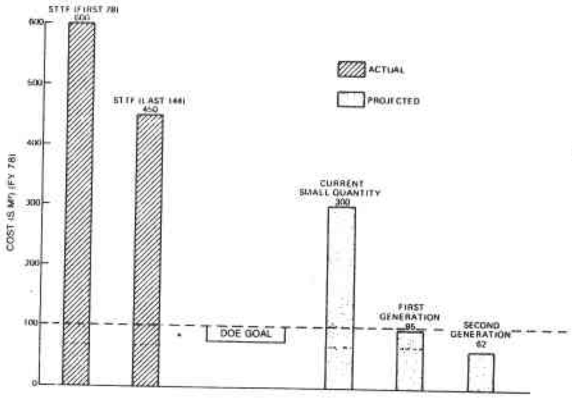


Figure 142. First-Generation Heliostats Installed at Sandia Laboratories, Livermore, California (Left to right: Honeywell, Martin-Marietta, McDonnell Douglas and Boeing)

mance and cost. Approximately 1900 will be built.

Prior to the development of heliostat designs for the 10-MW_e pilot plant, limited production of a special Martin-Marietta design for the unique requirements of the 5-MW_t CRTF was completed. A total of 222 heliostats were fabricated and installed during FY 1977 and FY 1978. Even though these heliostats have special features to serve the needs of the test facility, their recorded costs provide an upper benchmark against which cost estimates and ultimate goals can be compared. Figure 143 graphically illustrates the installed costs of the CRTF heliostats versus the anticipated future trends. These costs have been adjusted to 1978 dollars.

Conceptual designs for a second generation of heliostats were initiated in October 1977. Contracts were awarded to Boeing Engineering and Construction, General Electric, McDonnell Douglas Astronautics, and Solaramics Incorporated. The purpose of the program was to significantly reduce the cost of a heliostat field for a solar thermal power plant from the costs generated during the 10-MW_e pilot plant preliminary design. Each contractor developed a heliostat design with associated manufacturing, assembly, installation, and maintenance approaches. Capital and operations and maintenance costs were estimated for a one-time production of 2500 units and for continuous production rates of 25,000, 250,000, and 1,000,000 units per year. Schematic drawings of the heliostat designs are shown in Figure 144.



Note This cost goal is for unity reflectivity and corresponds to the $72/m² previously reported in 1975 $s for 0.9 reflectivity

Figure 143. Heliostat Costs (installed)

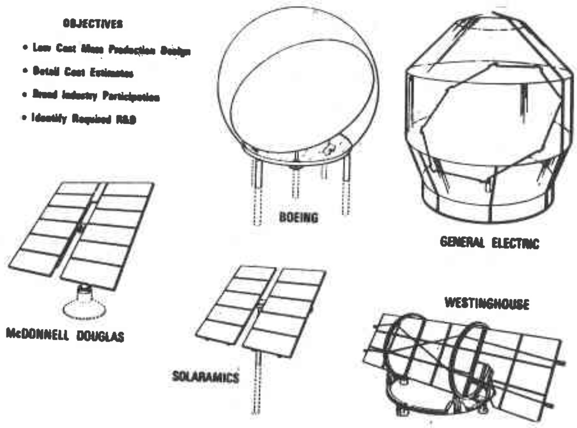
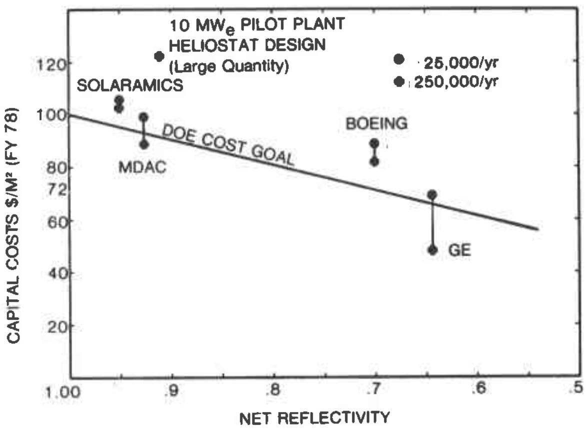


Figure 144. Large Power Systems Second-Generation Heliostats

In addition to the four designs entirely funded with federal dollars, an encouraging precedent in heliostat development is also illustrated in Figure 144. The design approach being pursued by Westinghouse is entirely funded with their internal funds. Under a no-cost agreement with Westinghouse, in exchange for critically reviewing their design progress and testing a resulting prototype at the Central Receiver Test Facility in Albuquerque, they will publicly disclose design features and cost numbers generated. As a result, five second-generation heliostat designs are being evaluated rather than just the four that are fully federally funded.

Each of the contractors participating in the second-generation heliostat development effort projected mass production costs below the DOE goal. Figure 145 illustrates the DOE cost goal versus net reflectivity. Considered in this manner, heliostats utilizing different technologies (i.e., plastic enclosed designs versus glass/metal designs) can be compared on a consistent basis. As Figure 145 shows, at the higher production rates, four independent assessments of different design approaches indicate that the cost goal is realizable. These costs represent 1978 dollars and assume stable production rates at the annual quantities plotted. These cost goals are reassessed annually to reflect the latest study results and economic trends.



Note: These cost goals correspond to the $72/m² previously reported in 1975 $s for 0.9 reflectivity

Figure 145. Prototype Second-Generation Heliostats (8% fee and 10% contingency)

The follow-on effort defined for verifying the design concepts and costing figures generated under the second-generation, phase-one studies will be limited to demonstrating the high leverage component and materials developments selected from the detailed evaluation of the submitted designs. A major tool used in the evaluation was a new computer model DELSOL developed during FY 1978. This field performance and design computer code was used to synthesize a cost-optimal field layout and annual performance for each of the competing designs. Sensitivities in pointing accuracy, receiver size, and tower height were investigated to ensure that the comparison was not biased in favor of one design. With the addition of DELSOL to DOE's analytical capabilities, rapid comparison of competing approaches to design solutions readily can be accomplished. Of equal importance, however, is the utility of this code for contractor users; they will have a better tool with which to provide trade-off studies when the code is documented and released in FY 1979.

Utilities have been faced with hard choices in the past few years in the selection of power plant types. All indications are that these decisions will become even more difficult in the future and hence the need for credible source data places increasing demands on competing technologies. Recognizing the need for cost figures based on verifiable estimates, and keeping in mind the ever present desire to foster competition, a new competitive solicitation is being prepared for release early in FY 1979. Called the Preproduction Heliostat RFP, this solicitation has the objective of funding up to four contractors for low-cost, mass-producible heliostat designs that can provide heliostats for early 1980 applications. Competitors for this procurement will be provided with all data generated under DOE funding to date as well as critiques and evaluations. The deliverables from this effort will be prototype heliostats for side-by-side comparison and firm cost numbers in a format specified by a utility user. The intent is to get utility participation early in the program to maximize the chance of serving their needs.

At the same time that detail design production oriented efforts are progressing, a New Ideas Heliostat RFP has been released to encourage new concepts and small business participation. Under the auspices of the New Ideas Heliostat RFP, new and novel approaches to solving heliostat problems are being pursued. The intent of this effort is to provide a precursor to third-generation heliostat efforts. The total heliostat development program is attacking several fronts in an attempt to provide aggressive forced development of this technology. By the end of FY 1979, competitive heliostats for the pilot plant near Barstow will be in side-by-side testing; approximately four competitors will be doing detail design on production heliostats for mass production in the early 1980s, and several innovators with new concepts will be attempting to reduce costs through conceptual innovation. Figure 146 shows the near-term time line for this integrated development effort.

With the development program outlined, the goals of the important cost driver in solar thermal central power systems can be met and data generated to demonstrate the viability of those goals.

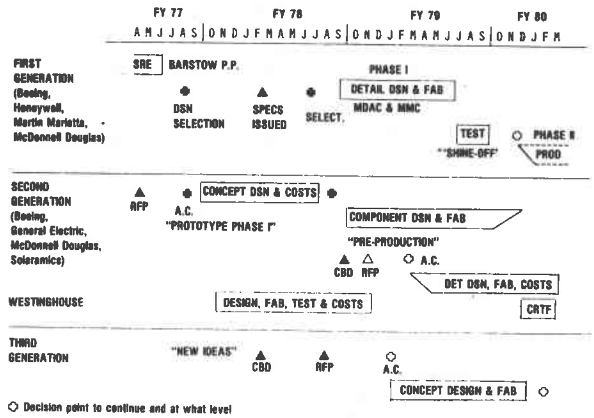


Figure 146. Heliostat Development Program

Receivers

In the summer of 1975, three contractors, Honeywell Inc., Martin-Marietta Corporation, and McDonnell Douglas Astronautics Company (MDAC), were selected to conduct preliminary design and subsystem research experiments on a Central Receiver Solar Power Plant using water/steam as the transport/working fluid and a steam-Rankine turbine as the heat engine. Two years of study, experimentation, and analysis by these contractors and exhaustive review by an ERDA evaluation team led to the selection of the MDAC configuration for the baseline design of the 10-MW_e pilot plant to be constructed near Barstow, California. This concept included an externally illuminated, vertical-tube, once-through-to-superheat boiler located on a tower in a surrounding field of heliostats. In the selection of the pilot plant configuration, the choice between the externally illuminated MDAC receiver and the cavity-type receiver by Martin-Marietta was relatively narrow. Conceivably, for other applications, the cavity receiver might be preferred. It was also recognized that restricting the central receiver to the steam-Rankine cycle may not provide the most cost-effective, long-term operations. Technical questions were raised which involved life cycles, hydraulics, heat distribution, etc., as well as the accompanying economics. Answers to these questions were not readily available.

The objective of the receiver program is to evaluate the merits of alternate technologies for absorbing the solar flux. Included in this activity are the in-depth studies being conducted to support the design and evaluation of the pilot plant water/steam receiver. The goals of the receiver program are to:

- Minimize receiver weight and cost,
- Maximize receiver efficiency, and
- Obtain receivers which will result in higher efficiency systems.

Initially, studies were conducted to evaluate the merits of alternate concepts. As a result of these studies, water/steam technology was selected for the 10-MW_e pilot plant. The program was then expanded to encompass gas (air and helium), salt, and sodium technologies.

In support of the 10-MW_e pilot plant, receiver design reviews were initiated. Combustion Engineering and the General Electric Company analyzed the thermal fatigue associated with the departure from nucleate boiling (DNB) and the flow stability of the pilot and commercial plant water/steam receivers designs. Their results indicate that the pilot plant size receiver will probably have a thermal fatigue life in excess of 30 years. The commercial plant size receiver may experience dynamic flow instabilities which may be correctable by orificing the tubes in each panel. There is an unresolved question regarding the stability of the pilot plant panels under the low-flow, low-heat flux conditions. This question will be answered by testing.

Two test programs have been planned for the MDAC configuration--a 5-tube panel and a 70-tube panel--and are well underway. The five-tube panel will be tested at the Sandia radiant test facility. The purpose of the test is to study the DNB phenomenon predicted to occur in the pilot plant boiler panels. The experimental data will be used to estimate the fatigue life of the pilot and commercial plants. The panel was fabricated by MDAC and is currently being prepared for testing. Assembly and checkout of the test set-up will be completed by March 1979. The testing will be completed before the end of FY 1979.

MDAC is under contract to retest their Subsystem Research Experiment (SRE) receiver (a 70-tube panel) at CRTF. The testing is designed to generate data typical of a portion of the pilot plant receiver at Barstow. The testing will emphasize the thermal hydraulic performance and the static and dynamic stability aspects of the design over the entire operating range. The test will include operation during normal start-up and shutdown, intermittent cloud conditions, and emergencies to determine transient and steady-state performance under conditions equal to or exceeding those expected in the pilot plant. The effects of variations in input and output conditions on receiver operation will also be investigated. During FY 1978, the test plan was prepared, further analysis was conducted on the panel, and the panel was modified to include the required instrumentation. The testing is expected to start early in FY 1979 and be complete in the summer.

To support the evaluation of the pilot plant, Sandia developed a computer code to evaluate elastic strains in circular tubes with one-sided heating thereby simulating the MDAC receiver design. It can be used for locating the region of highest strain due to diurnal cycles and estimating the effect of bending and bowing in reducing fatigue damage. Results so far indicate that bending will not play a significant role in reducing fatigue damage in the 10-MW_e pilot plant receiver.

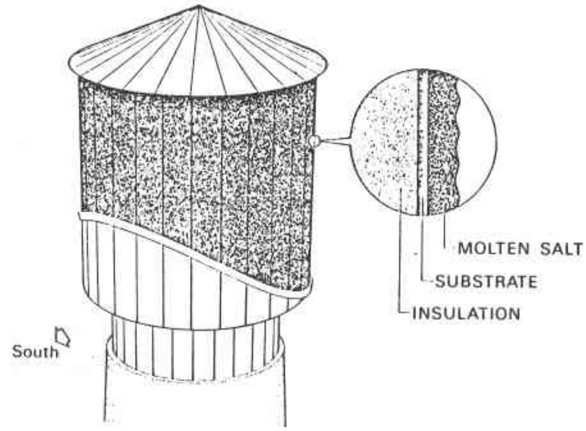
A number of advanced receiver studies are being conducted to establish the feasibility of developing a system that will significantly reduce the cost of electricity generated by solar central receivers. These systems utilize sodium, salt, air, or helium in the receiver. Four of the studies (Atomics International, Boeing, General Electric, and Martin-Marietta) include the entire solar plant, and three studies (Dynatherm, Sanders, and Sandia) are concentrating on the receiver. The sodium and salt receivers are coupled to a Rankine cycle turbine, and the air and helium receivers are coupled to a Brayton cycle turbine. The major limitations of the pilot plant water/steam are the low system efficiency which results because of the constraint imposed by the storage subsystem, the low maximum flux which the receiver can absorb. The advantage, however, is the enormous technical experience with water/steam. Other receiver coolants such as liquid sodium, molten salt, air, and helium can lead to higher efficiency systems requiring fewer heliostats. Thus, these advanced technologies may result in a more cost-effective central receiver solar power plant.

To ensure that the full potential of the water/steam technology is made available to the solar community, advanced water/steam receiver concepts are being investigated. These may prove to be more cost effective than current designs.

A summary of the major activities completed on the advanced receiver studies during FY 1978 is presented in Table 7. During FY 1979, the information developed during FY 1978 will be reviewed, the relative advantages of each of the technologies will be determined, and recommendations for future activities will be presented to DOE. The receiver designs which were selected as a result of the studies conducted during FY 1978 are presented in Figure 147.

Table 7. Major Activities for Advanced Concepts — FY 1978

Advanced Water/Steam	• Prepared RFQ package • Reviewed proposals and selected contractors
Brayton Technology	
Boeing	• Completed Phase I • Selected a multiaperature cavity receiver
Dynatherm	• Selected a baseline design and thermodynamic cycle
Sanders	• Completed the design and fabrication of the 250 MW_t receiver and initiated testing
Salt Technology	
Direct Absorption	• Demonstrated the high flux capabilities • Completed an extensive review of the direct absorption concept • Initiated a CRTF test program • Conducted material compatibility experiments
Martin Marietta	• Completed conceptual design phase of the program • Selected a multiaperture/cavity configuration • Conducted material compatibility experiments
Sodium	
Atomics International	• Completed conceptual design phase of the program • Selected external receiver configuration
General Electric	• Selected external receiver configuration



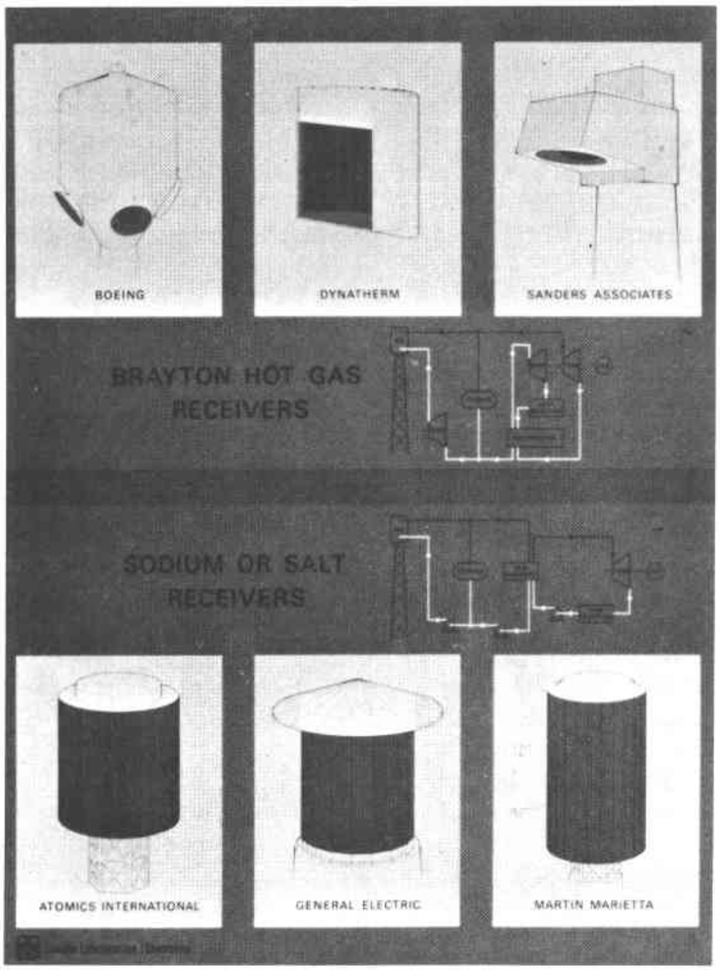


Figure 147. Advanced Concepts

At Sandia Laboratories, tests have been conducted in support of the direct absorption concept. To date, absorption properties of some representative doped molten salts have been measured, salt flow characteristics and salt/containment materials compatibility have been investigated, an analytical model of the direct absorption process has been developed, and a review of the direct absorption concept was completed.

As previously indicated, a number of general studies are being conducted to support the receiver development program. Foster Wheeler Development Corporation (FWDC) is working on a program to develop an "Interim Structural Design Standard for Solar Energy Applications." The overall objectives of this program are to:

- Develop and recommend an interim structural design standard applicable to the central receiver solar thermal power system components that generally fall under the scope of the ASME Boiler and Pressure Vessel Code, and

- Identify test programs and other additional work required to update the interim standard.

To date, FWDC has surveyed the available literature and prepared an initial draft of an interim design standard for water/steam systems. During FY 1979, they will complete and issue the interim design standard and initiate an in-depth study to establish the additional standards which will be required for the advanced systems. SERI will assume standards responsibility by FY 1980.

The magnitude of the convective loss from a central receiver exerts a significant influence on the thermal efficiency of a solar thermal-electric power generation system. The magnitude of this loss is difficult to estimate because the high operating temperatures and large sizes of the receivers make experimental verification difficult. In addition, the interaction between free and forced convection mechanisms is not well understood. The intent of a study at the University of Illinois is to experimentally and analytically investigate receiver convective losses.

The experimental apparatus consists of a small cryogenic wind tunnel which will be capable of generating the Grashof and Reynolds numbers typical of full-scale receivers. This tunnel, when completed and operational in FY 1979, will permit the quick and inexpensive comparisons of receiver configurations. This study will be complemented by the full-scale testing of the MDAC, Martin-Marietta, and EPRI receivers at CRTF. The ability to compare small wind tunnel model and full-scale receiver convective losses will greatly reduce the uncertainties in scaling model results to full-scale design for all the future central receiver concepts.

Because tall towers are common to all design concepts and represent an appreciable fraction of the total cost of a solar central receiver plant, a study was initiated to thoroughly analyze tower design/costs as a function of receiver weight, tower height, and environment. During FY 1978, the RFQ was prepared and released, and the contractor was selected. The study will be completed during FY 1979.

A summary of the receivers currently being developed and the impact they have on a solar central receiver is presented in Table 8. As is evident, the studies are showing that the advanced receiver concepts will substantially reduce the cost of electricity.

Storage

Storage capacity is an important parameter in the design of advanced solar thermal power plants because it provides flexibility for dispatching solar plants and enhances the plant capacity factor and economic worth to the utility. The amount of thermal storage varies from the minimum necessary to buffer the heat engines from the transient heat input from the sun-cloud effects, etc., to an amount which permits the solar thermal power plant to provide its rated output continuously, even throughout extended sunless periods, as a base load capacity plant.

The objective of energy storage technology development is to demonstrate commercially viable storage technology for possible Solar Central Power Systems Applications. These applications include solar stand-alone, repowering, or hybrid power plants. The level of technology to be considered must be consistent with commercial availability in the 1985 to 1990 time frame.

DOE is funding several studies to develop solar central receiver power systems which are economically competitive with conventional power generation energy sources. The systems under consideration include the water/

Table 8. Receiver Characteristics and System Cost

	Water/Stream (Barstow Technology)	GE	AI	MM	Boeing	Sanders	Dynatherm	Direct Absorption
Power								
MW_e	100	100	100	300*	140**	100	10.0	100
MW_t	506	373	390	1080	640	250	48.8	560
Type/Fluid	External/ Water	External/ Sodium	External/ Sodium	Cavity/ Salt	Cavity/ Air	Cavity/ Air	Cavity/ Air	External/ Salt
Size (in meters)								
Length	26	17	16	13	71	30	10 x 6 x 12	17
Diameter	17	22	16	8	50	38	—	17
Weight (kg x 10^{-3})	1900	406	225	114	2360	—	136	119
Maxiumum Temperature (°C)	510	704	595	550	840	1100	820	565
Efficiency	90	90	89	94	80	87	89	94
Flux (MW/m^2)								
Peak	0.85	1.6	1.4	0.78	0.20	0.30	2.2	1.9
Average	0.43	0.53	0.50	0.30	0.04	0.15	—	0.62
Cost†								
Capital ($ x 10^{-6})	210	110	140	400	216	83	—	96
Energy $\frac{MW}{kW_e\text{-}hr}$	95	—	82	34	100	—	—	32

*Three Modules **Two Modules †Preliminary Numbers steam receiver technology selected for the 10-MW_e pilot plant near Barstow and several advanced systems. In FY 1977, three storage concepts were proposed for the 10-MW_e pilot plant (Figures 148, 149, 150). All concepts use sensible heat for storing thermal energy. The concepts differ in that they employ various combinations of liquids and solids in series tanks as the storage media. The combinations give rise to different maximum storage temperatures and hence different maximum temperatures of steam produced from storage.

As part of these studies, storage designs were developed for both the 10-MW_e pilot plant and a larger-scale commercial plant. Subsystem research experiments (Figures 151 and 152) were conducted to investigate concept feasibility and the thermal stability, compatibility, and fouling of various storage media. Based on the results of these tests and cost/performance estimates for the commercial plant, the single-stage oil/rock thermocline concept was selected for the pilot plant design.

During FY 1978, DOE continued to fund studies directed toward the identification of economic storage fluids and

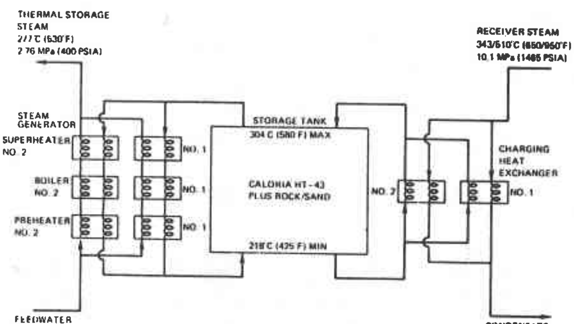


Figure 148. McDonnell Douglas Pilot Plant Thermal Storage

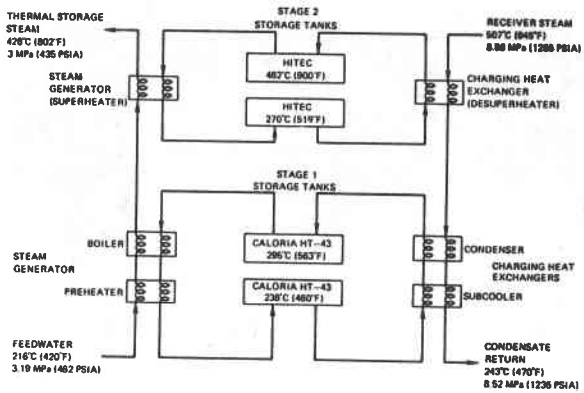


Figure 149. Martin-Marietta Pilot Plant Thermal Storage

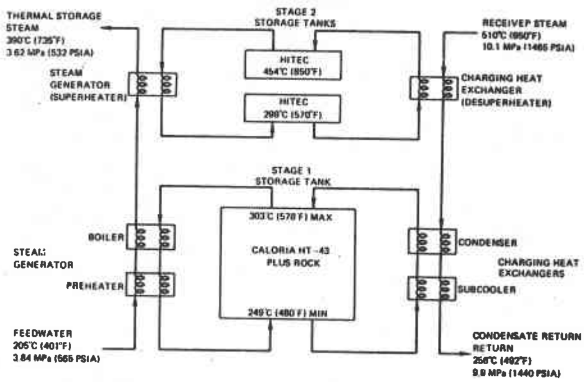


Figure 150. Honeywell Pilot Plant Thermal Storage

the understanding of oil/rock storage media stability, compatibility, and fouling. These studies included the design, development, and testing of a fluid maintenance unit to refurbish degraded oil (Figure 153), long-term laboratory testing of candidate oils and solid storage media (Figure 154), and operation of a laboratory flow loop to simulate pilot plant operation.

Significant achievements during FY 1978 included 1000 hours of fluid maintenance unit operation with up to 30 hours of unattended operation. A reduction in oil fluid degradation rate compared to that of a sealed system

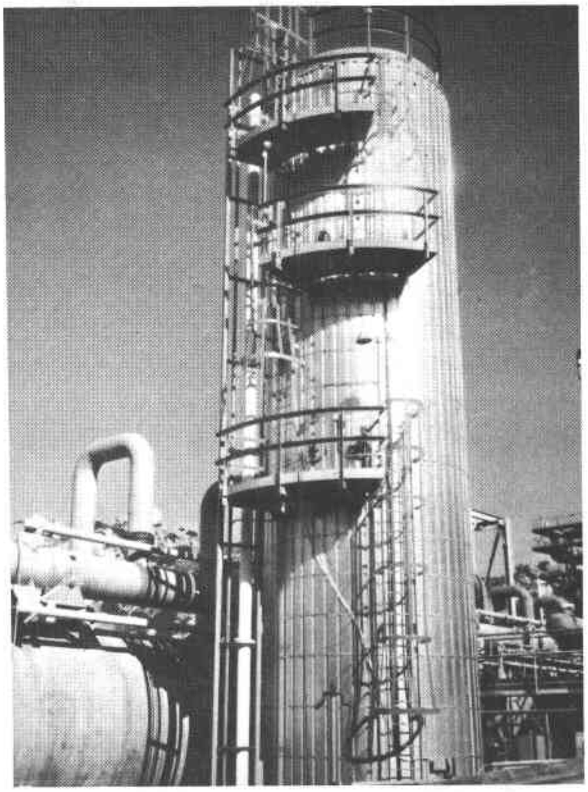


Figure 151. Completed Thermal Storage Unit

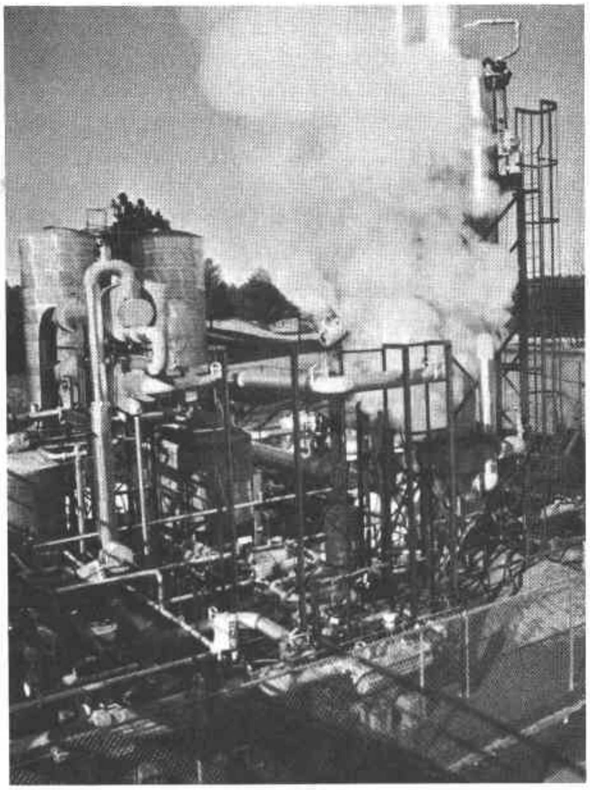


Figure 152. Thermal Storage Unit in Operation

without a fluid maintenance unit was observed. Long-term laboratory stability, compatibility, and fouling tests were conducted on several fluids at temperatures ranging from 550°F to 750°F. Several thousand hours of test data were obtained for oils both alone and in contact with solid media such as rock and taconite and materials of construction. Finally, a laboratory flow loop has been operated for several thousand hours to obtain data on surface fouling in convective flow, viscosity change, fluid sludging on rock, and sand migration.

During the next year, the long-term stability, compatibility, and fouling tests will be continued. A test will be performed to determine the effect of tank venting on the storage fluid degradation rate. Tests of additional candidate oils will be initiated.

As part of the DOE 10-MW_e pilot plant study, Honeywell completed fabrication and assembly of most of the components of a 1.3-MW_t latent heat salt storage experiment. Final assembly and testing of the experiment was deferred by DOE because this approach now appears of lesser promise. The equipments (Figure 155) are expected to be utilized for other experiments.

In FY 1978, DOE initiated conceptual design studies of advanced system concepts. In contrast to the pilot plant water/steam receiver technology, these concepts use sensible heat working fluids (liquid sodium, molten salt, or air). Advantages of these

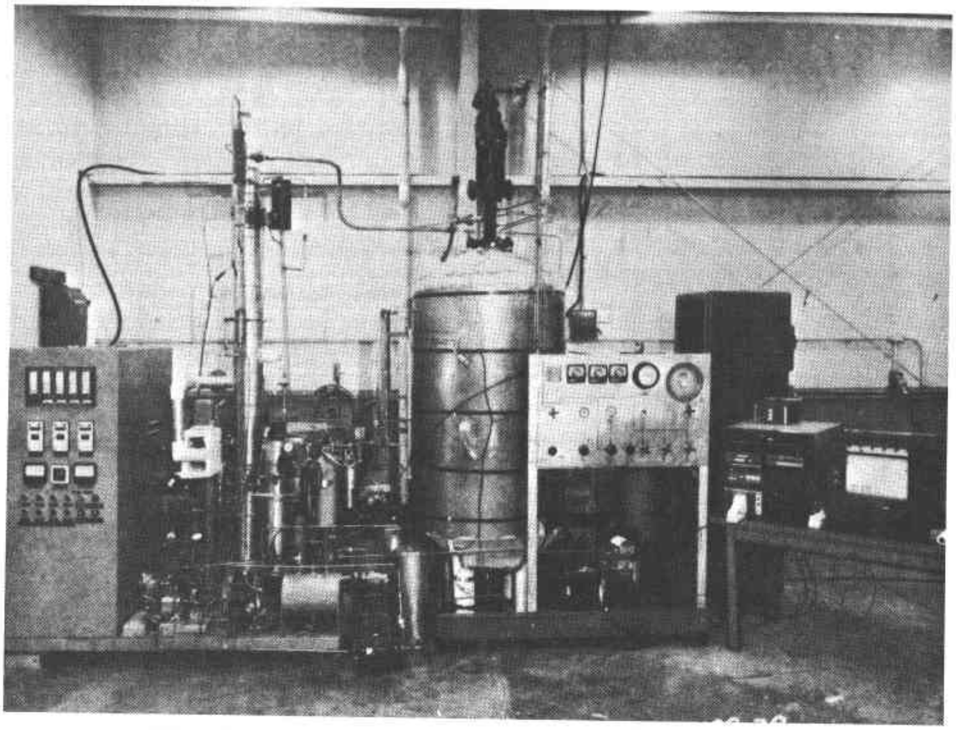


Figure 153. Fluid Maintenance Unit Testing to Refurbish Degraded Oil

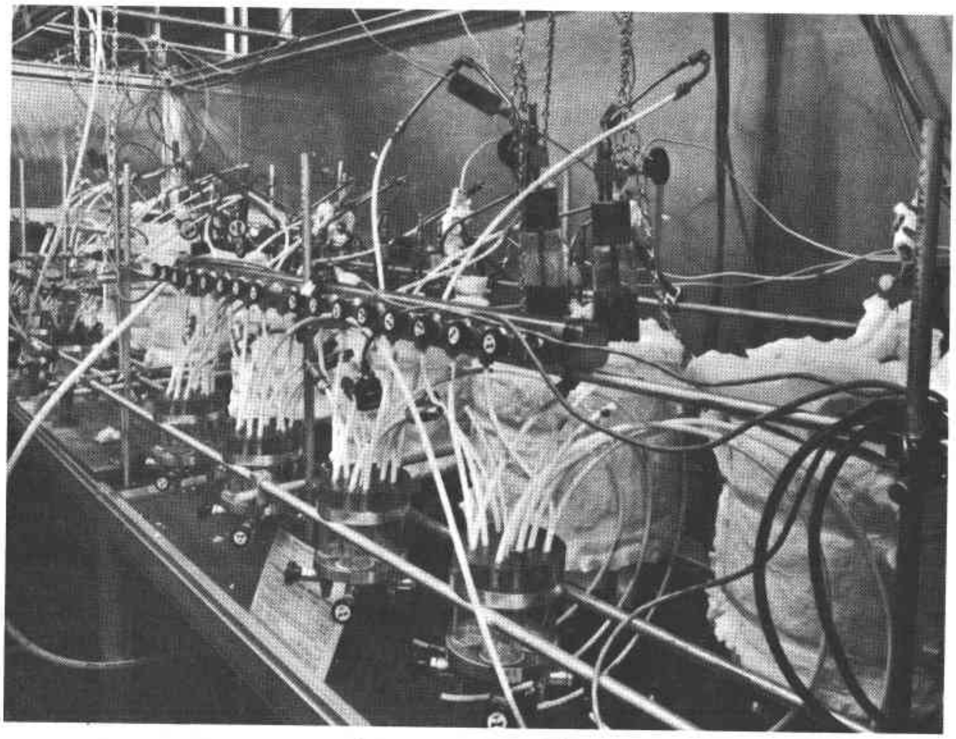


Figure 154. Candidate Oils and Solid Storage Media Testing

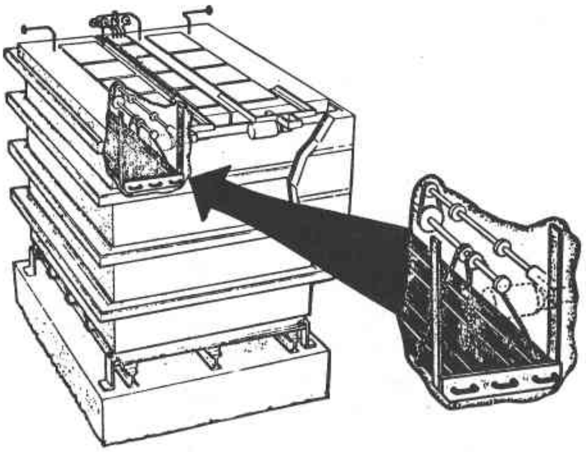


Figure 155. SRE Thermal Storage Tank

concepts over the pilot plant design are high cycle efficiencies due to increased operating temperatures and pressures, capability to generate the full plant electrical output when operating from storage and potentially reduced cost.

Because the energy storage systems for the advanced concepts operate at high temperatures, technical performance uncertainties are an important consideration. Testing of high-temperature storage media which may be compatible with several of these advanced systems was therefore initiated. These studies include investigations of the thermal stability of molten salts (HITEC, draw salt) and their compatibility with solid storage media such as rocks and taconite, and containment materials. Approximately 700 hours of test data were obtained for salt temperatures up to 1020°F.

In FY 1979, laboratory studies of potentially attractive high-temperature storage media will be continued. Studies of the effects of thermal cycling on rock fracture will be initiated. If funds are available, development of alternate storage concepts for advanced systems and central receivers will be undertaken. Conceptual design studies will be conducted in three categories based on receiver working fluid types and storage media maximum operating temperatures:

- Storage for advanced water/steam receivers--storage media maximum operating temperatures to 593°C (1100°F);
- Storage for liquid sensible heat receivers--storage media maximum operating temperatures to 704°C (1300°F); and
- Storage for gas sensible heat receivers--storage media maximum operating temperatures to 1093°C (2000°F).

Activities will be initiated in the three application categories with anticipation of funding at least one contract in each category.

ACRONYMS AND ABBREVIATIONS

ACTF	Advanced Component Test Facility
ADS-1	Advanced Systems No. 1
ADVS	Analog Design Verification System
ASTM	American Society for Testing Materials
BCS	Beam Characterization System
BPNL	Battelle Pacific Northwest Laboratories
CMTF	Collector Module Test Facility
CNTLG	Cromwell, Neyland, Truempter, Levy and Gatchet, Inc.
CRTD	Central Receiver Technology Development
CRTF	Central Receiver Test Facility
DAS	Data Acquisition System
DNB	Departure from Nucleate Boiling
DOE	Department of Energy
EE	Engineering Experiment
EPRI	Electric Power Research Institute
ERDA	Energy Research and Development Administration
ETM	Engineering Test Model
FMDF	Fixed-Mirror Distributed Focus (systems)
FWDC	Foster Wheeler Development Corporation
GIT	Georgia Institute of Technology
HVAC	Heating, Ventilating, Air Conditioning
JPL	Jet Propulsion Laboratory
LBL	Lawrence Berkeley Laboratories
MCCC	Mississippi County Community College
MCS	Master Control System
MDAC	McDonnell Douglas Astronautics Company
MSSTF	Midtemperature Solar Systems Test Facility
NBS	National Bureau of Standards
NSF	National Science Foundation
ORNL	Oak Ridge National Laboratory

PFDR	Point Focusing Distributed Receiver
PFSTS	Point Focus Solar Test Site
PNM	Public Service Company of New Mexico
PV	Photovoltaic
SERI	Solar Energy Research Institute
SFDI	Solar Facilities Design Integrators
SOLAR/CS	Division of Solar Applications under the Office of the Assistant Secretary for Conservation and Solar Applications
SOLAR/ET	Division of Central Solar Technology and Division of Distributed Solar Technology under Office of the Assistant Secretary for Energy Technology
SOLTES	Simulator of Large Thermal Energy Systems
SPSA	Small Power Systems Applications
SRE	Subsystem Research Experiment
STES	Solar Total Energy Systems
STF	Systems Test Facility
STMPO	Solar Ten-Megawatt Project Office
STOR	Division of Energy Storage Systems, DOE
STTFUA	Solar Thermal Test Facility Users Association
TEC	Transportation Energy Conservation
TMY	Typical Meteorological Year

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