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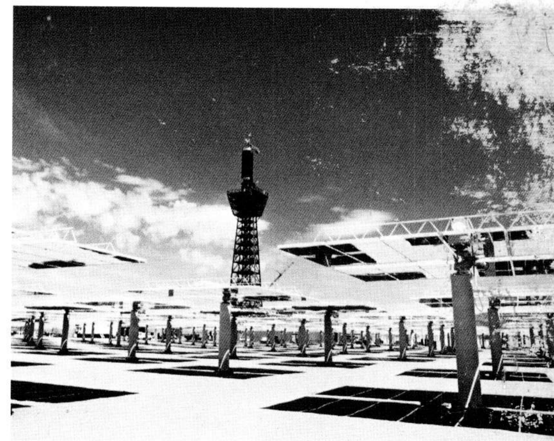

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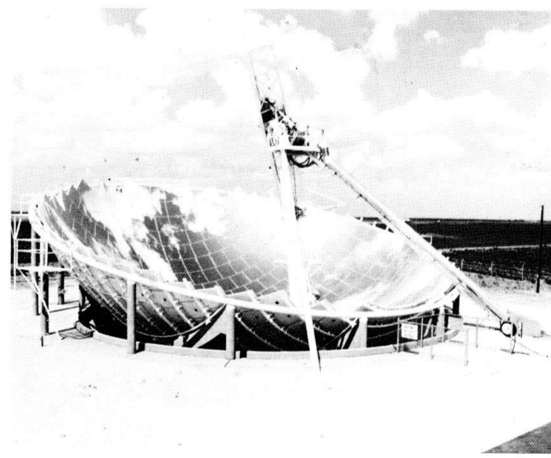

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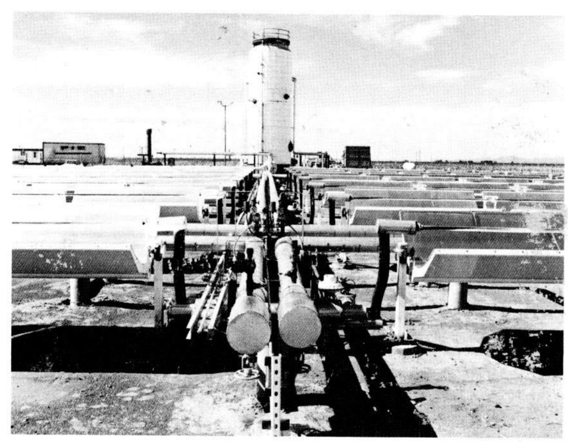

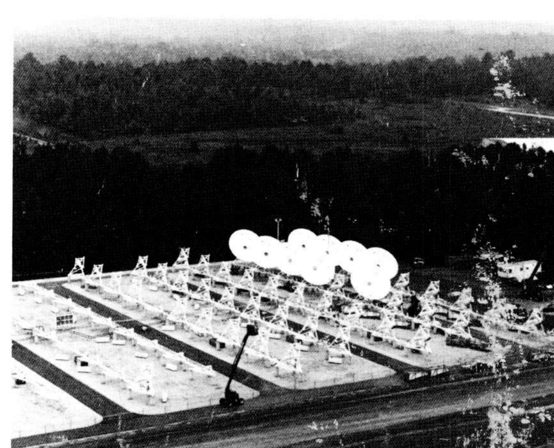

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Solar-Thermal Technology

Annual Technical Progress Report FY 1981

Volume II: Technical

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FOREWORD

This report, which is divided into two volumes, documents the accomplishments and progress of the U.S. Department of Energy (DOE) Solar Thermal Technology (STT) Program during fiscal year 1981, covering the period from October 1, 1980 to September 30, 1981. Volume I, the Executive Summary, contains a brief description of each technology, followed by highlights of the technical activities during the year. Volume II details the FY 81 accomplishments, and includes an annotated bibliography, list of contacts, and acronyms relevant to the program.

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SECTION I

INTRODUCTION

THE PROGRAM

Solar thermal technology converts the sun's radiant energy into basic heat energy ranging up to 1370°C (2500°F). This heat can be used for industrial, agricultural and other commercial processes; converted to electricity; or used in chemical reactions to produce transportable bulk fuels and chemical feedstocks. The Department of Energy's Solar Thermal Technology (STT) Program is developing five advanced solar thermal energy conversion concepts: four types of concentrating collectors (central receivers, parabolic dishes, parabolic troughs, and hemispherical bowls) and large-scale salt-gradient solar ponds. The concentrating concepts use mirrors to focus or concentrate the sun's rays on a small area where the radiant energy is converted into medium- to high-temperature heat. Solar ponds rely on salinity differentials to suppress convection, enabling the pond to collect and store heat at temperatures up to 100°C. Each of these five concepts is in a different stage of development.

The STT Program is divided into two branches (Figure 1-1): the Research and Technology Branch manages research and development (R&D) on materials, components, and subsystems; the Systems Test and Evaluation Branch is completing the deployment and evaluation of prototype systems. This is the only federal R&D program for advanced solar thermal energy conversion techniques. Private sector efforts, by the Electric Power Research Institute and the Gas Research Institute, are coordinated with the DOE program, making use of DOE support, then disseminating information to utilities and enlisting their participation in these experiments.

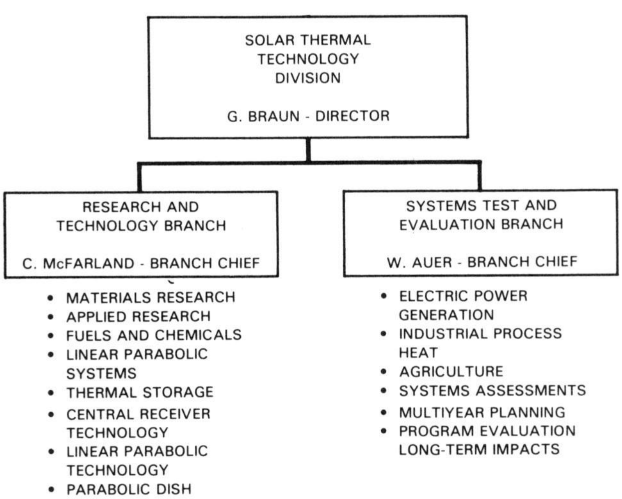

Figure 1-1. Solar Thermal Technology Program Structure

The Program is structured to stimulate research and engineering development of early generation components and subsystems. Since 1977 the majority of STT R&D funds have been allocated to large and small businesses; the remaining R&D funds have gone to universities, national laboratories, and not-for-profit organizations. This course of action has facilitated the transfer of technology from the public to the private sector. Program management has also been decentralized to include the national laboratories supporting the program, balancing resources and enabling DOE headquarters program managers to concentrate on strategic planning, resource allocation, and program evaluation.

GOALS AND OBJECTIVES

Federal laws enacted in 1974 mandated government support of the design, development, construction and operation of solar thermal energy systems. These laws were in response to Congress's recognition that attaining technical preeminence and energy independence involved risk-taking beyond the capabilities of the private sector acting alone.

The early thrust of the program was to develop solar thermal technology and to learn how complete STT systems work and how they function at the interface with industrial plants and electrical grids. By disseminating this data, the Program has provided a research infrastructure and technological base for a domestic growth industry in central receivers, dishes and troughs. Mass-producible concentrator designs and alternate thermal subsystem designs have been tested, and test facilities and system experiments are in place.

The goal of the STT Program is to expand the technology base for solar thermal energy. The Program emphasizes research to (1) increase system efficiency, (2) reduce system costs, and (3) develop the materials, components and subsystems essential to building reliable systems that can meet specific cost targets. The Program is providing the technical foundation for the private sector to produce systems that provide heat between 93° and 1370°C (200° to 2500°F), thus meeting the typical energy needs of American industry and utilities.

The specific functional objectives set for the STT Program by the 1974 Solar Energy Research, Development and Demonstration Act (P.L. 93-473) are:

(1) Production of electricity from a number of 1- to 10-MW powerplants.

(2) Production of synthetic fuels in commercial quantities.

(3) Large-scale use of solar energy in the form of direct heat.

(4) Utilization of thermal and all other solar facility byproducts.

(5) Design and development of hybrid systems involving the concommitant use of solar and other energy sources.

(6) Continuous operation of such plants/facilities for a time period.

A seventh functional objective was added by the Energy Research Act of 1977 (P.L. 95-39, Sec. 102 (d)): a 5-MW demonstration project for small community applications. These functional objectives translated into time-phased technology-specific activities, and cost-performance objectives were developed.

Progress has been made toward all the mandated objectives, as listed below:

1. Toward the production of electricity from several 1- to 10-MW power plants, a 150-kWe parabolic trough system is producing electricity in Coolidge, Arizona, and the Central Receiver Test Facility is operating in Albuquerque, New Mexico. A 10-MWe pilot plant, the largest of its kind in the world, will begin operation in California in FY 82.

2. Production of commercial-quantity synthetic fuels is a long-term objective. Research to date has focused on understanding and developing processes for producing synthetic fuels using solar thermal energy.

3. Large-scale use of solar energy in the form of direct heat has been demonstrated through several system experiments with parabolic troughs producing heat in industrial applications in the medium-temperature range. Areas where additional component R&D is needed were identified, and parabolic trough technology was shown to be nearly ready for commercialization.

4. Thermal and other solar facility byproducts will be used in the Total Energy Project at Shenandoah, Georgia. This first-of-a-kind field test cogenerating plant, simultaneously producing electricity and industrial process heat, will start operation in mid-FY 82.

5. The design and development of hybrid (solar/fossil) systems is progressing with advanced development efforts on Brayton and Stirling cycle engines for hybrid use with parabolic dishes.

7. The 5-MWe demonstration project for small community applications has reached the stage of preliminary design of a 0.25-MWe to 1-MWe parabolic dish system for small communities.

The 6th objective, continuous operation of such plants/facilities, applies to each other objective.

BENEFITS

The technical progress made in FY 81 increases the confidence that the program can be of significant long-term benefit to the U.S., providing both direct benefits to the economy and improved environmental quality.

Direct Benefits to the Economy

The ability to produce heat over broad temperature ranges and capacity levels makes solar thermal technologies useful in a variety of applications, such as electric generation, industrial process heat, and production of transportable fuels and chemical feedstocks. The unique ability of solar thermal systems to use thermal storage, the least expensive form of energy storage, gives them an additional competitive edge over other solar electric systems.

There does not seem to be an effective alternative to the STT Program which can ensure that the specific objectives mandated by P.L. 93-473 will be met. Projected energy cost savings from successful STT development can be attributed to the program. If STT is successfully developed, then the savings in the cost of energy to the consumer is estimated at $10 to $50 billion (Ref. 1-1).

Progress has already been made in building a technology base. As a result of program efforts, an industry is emerging for one medium-temperature concept, parabolic troughs. High-temperature systems, particularly central receivers and parabolic dishes, can be expected to follow suit. In addition, potential export markets for STT are expected to grow. This would increase the size of the STT manufacturing industry, and contribute to the U.S. balance of payments position, if the United States develops a healthy, assertive solar thermal industry.

Environmental Quality

Compared with conventional systems, STT systems reduce air pollutants. In the short term, SO_X and NO_X are reduced; in the long term, CO_2 emissions are reduced as are the mining, drilling and transport of fuel, improving environmental quality. Health and safety dangers appear minimal; none identified so far poses a major obstacle to accelerated STT development.

Furthermore, capital savings would be effected because of lowered expenditures for pollution control technologies required to achieve a given standard of air quality.

SECTION II

CENTRAL RECEIVER TECHNOLOGY

In a central receiver system, a field of computer-guided heliostats (mirrors) focuses sunlight onto a large tower-mounted receiver. The intensified heat energy absorbed by the receiver can be transferred to a circulating working fluid to power an electric generator or provide heat for industrial processes, or the energy may be used directly to provide heat for endothermic chemical processes. Part of the heated working fluid may be diverted to an energy storage subsystem; energy storage allows the power plant or factory to operate during nonsolar hours. Figure 2-1 shows a schematic of a central receiver system.

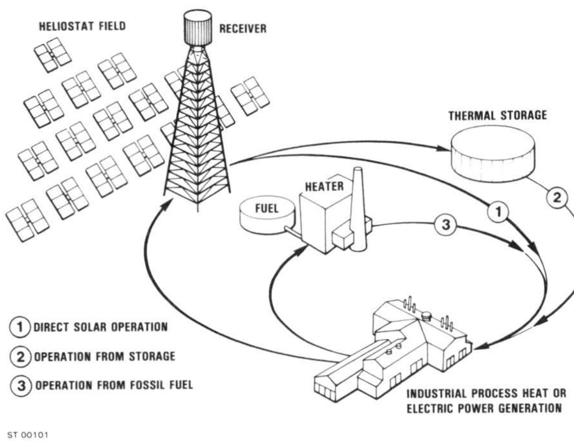

Figure 2-1. Schematic of Typical Central Receiver System Configuration

This chapter provides information on the status of central receiver technology for FY 81. Work during this year was continued in support of heliostat, receiver, and thermal storage design and development. Studies were funded that addressed the potential application of central receiver systems to cogeneration and repowering projects. Construction progressed toward the FY 82 start-up of the 10-megawatt electric (MWe) solar thermal central receiver pilot plant, one of the first solar-powered thermal electrical generation plants to be operated by a utility in the United States. Abroad, a smaller (500 kWe) central receiver system-solar thermal electric power plant began operation in Almeria, Spain. A diverse testing program was the basis for many of these accomplishments; experiments conducted at the Central Receiver Test Facility in Albuquerque, New Mexico, offered valuable solar test information to a variety of users.

Research efforts in FY 81 saw major advances in heliostat and receiver technology. Using the technology base, utilities and industries are beginning to consider building privately funded central receiver systems.

A. COMPONENT TECHNOLOGY DEVELOPMENT

1. Heliostat Technology Development

Two significant accomplishments in heliostat technology development occurred in FY 81: 1818 first-generation heliostats were installed at the 10-MWe central receiver pilot plant near Barstow, California (see Section B), and second-generation heliostat contracts were completed. The installation of the 1818 heliostats at the pilot plant was the culmination of efforts initiated in 1975 to develop first-generation heliostats. Martin Marietta designed and built the heliostats (Figure 2-2) for the pilot plant.

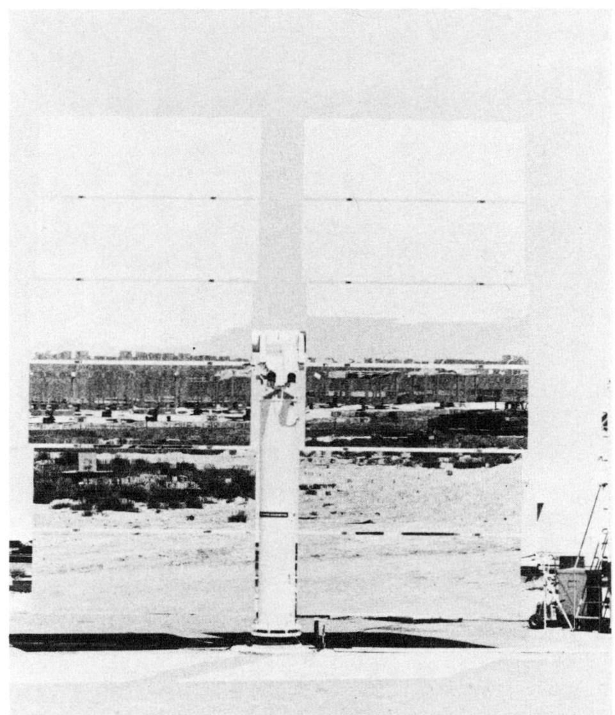

Figure 2-2. Martin Marietta's Pilot Plant Heliostat

Second-generation heliostat development was begun in 1979, soon after the final selection of the Barstow heliostat design. Contracts were concluded with five companies: ARCO Power Systems (formerly Northrop, Inc.), Boeing Engineering & Construction, Martin Marietta Corporation, McDonnell Douglas Astronautics Company, and Westinghouse Electric Corporation. Westinghouse subsequently dropped out of the effort. When the contracts were completed, each of the four remaining contractors had provided two prototypes of its heliostat design (Figures 2-3 and 2-4); a detailed design for a production heliostat; a conceptual design for a factory that would produce 50,000 heliostats per year; and cost estimates. These estimates covered production, installation, operation, and maintenance costs. All the contractors have published development reports (Refs. 2-1, 2-2, 2-3, 2-4).

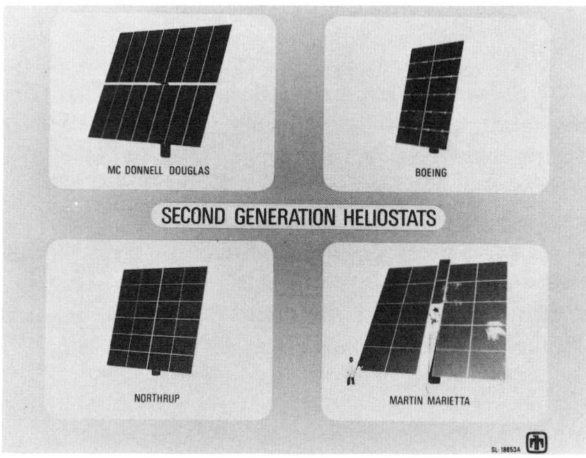

Figure 2-3. Front Views of Second-Generation Heliostats

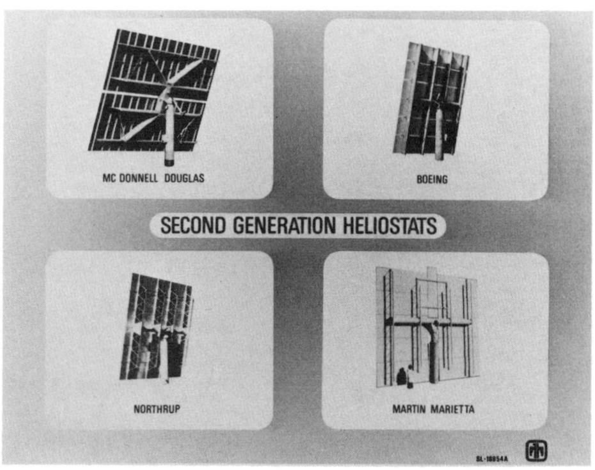

Figure 2-4. Back Views of Second-Generation Heliostats

Sandia National Laboratories conducted side-by-side testing and detailed analyses of the second-generation prototypes and subsystems both at the Central Receiver Test Facility (CRTF) in Albuquerque, New Mexico and at the heliostat test facility in Livermore, California. Although the four prototype heliostats are all of the same generic design, each contractor provided a unique approach to problems discovered in earlier heliostat designs. Modifications made at this stage eliminated inherent weaknesses of previous designs. In addition, the contractors' cost estimates for installed heliostats indicated that the heliostat cost goal ($\$80/m^2$ in 1980 dollars) could be met at relatively low production rates after a few years of manufacture. The second-generation heliostat designs could benefit from varying amounts of low-risk design changes and additional development. A public presentation of the Sandia testing and analyses was made in September 1981; this information will be published early in FY 82.

Other major efforts pursued during FY 81 include the following: methods to clean heliostats were studied; the concept of a rotating heliostat field was investigated by Stilson Associates; new methods to evaluate heliostat performance were developed; materials for plastic-enclosed heliostats were tested; and new mirror module concepts were explored.

2. Receiver Technology Development

The primary goal of receiver technology development activities is to identify and develop those receiver concepts that are the most promising in terms of both function (absorbing solar flux) and feasibility (as indicated by systems analyses). Secondary goals of the receiver program include reducing receiver weights and costs to practical minimums; improving receiver efficiency by understanding the major thermal loss mechanisms; and developing receivers that are well integrated with the other plant components, thereby maximizing overall plant efficiency.

FY 81 receiver activities supported the operational testing and evaluation of the water/steam receiver at the Barstow pilot plant. The majority of other work focused on the development of the molten salt and sodium receiver concepts. Using nitrate salts as the heat-transport fluid has the potential to reduce the cost of producing energy and to minimize storage cost compared to other central receiver approaches. Table 2-1 summarizes this year's work in molten salt receiver technology. A more detailed description of activities in this area is presented below.

a. Molten Salt Receiver Experiment. A Martin Marietta molten salt receiver was tested at the CRTF in Albuquerque, New Mexico, from August 1980 through March 1981 (Figure 2-5). Table 2-2 lists the characteristics of this receiver. The complete experimental loop consisted of the receiver, a pump, a sump, a salt-to-air heat exchanger, interconnecting hardware (piping, valves, etc.), and an experimental control system.

Instrumentation consisted of 506 thermocouples, five pressure monitors, eight solar flux gauges, eight

Table 2-1. Major Activities of the Molten Salt Receiver Program During FY 81

Initiated	Completed
• Phase I contracts with Babcock and Wilcox and Foster Wheeler to design and fabricate molten salt receivers based on concepts developed during the repowering systems studies.	• Testing of the Martin Marietta molten salt receiver at the CRTF.
• Phase I contracts with Babcock and Wilcox and Foster Wheeler for the design of molten steam generators.	• Workshop on the Martin Marietta salt receiver for users/suppliers at the CRTF.
	• Synthesis of receiver design and systems for saturated steam for industrial process heat applications.

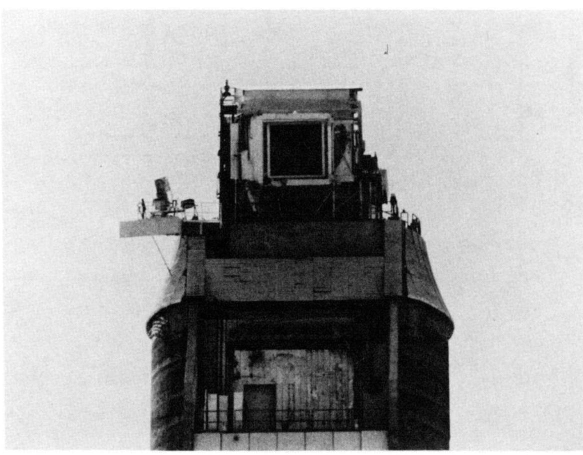

Figure 2-5. Martin Marietta Salt Receiver on the CRTF Tower

displacement gauges, and two flow meters. The experiment was controlled by various methods: manual, analog, and a computer-calculated algorithm. Nearly half of the 500 hours of solar testing were completed at maximum power (~5 MWt, >200 heliostats), during which the peak flux level in the plane of the aperture was approximately 1.65 MWt/m^2. The peak flux and average flux on the salt-cooled absorber tubes were 0.65 and 0.32 MWt/m^2, respectively.

This test program successfully demonstrated the suitability of molten nitrate salt as a receiver coolant; the safe, reliable operation of a molten nitrate salt receiver; and the abilities and limitations of the different control systems. More information on this experiment may be found in Section II.C.1.

Table 2-2. Martin Marietta Molten Salt Receiver Characteristics

Nominal thermal rating	5 MW
Heat transfer fluid	Molten nitrate salt
Active surface dimensions	3.35 m × 5.49 m
Cavity aperture	2.7 m × 2.7 m
Material	Incoloy 800
Tube size	19.1-mm diameter × 1.6-mm wall
Number of series passes	18
Tubes per pass	16
Total number of tubes	288
Inlet/outlet temperatures	561K/839K
Average solar flux	0.32 MW/m^2
Peak heat flux	0.65 MW/m^2
Salt flow rate (nominal)	27.3 m^3/hr

In conjunction with the molten salt receiver tests, Sandia National Laboratories and Martin Marietta hosted a two-part Molten Salt Receiver Test Results Workshop. During Part I of the workshop, which took place at the CRTF in January 1981, personnel from Martin Marietta and Sandia presented data summarizing the receiver's design and the test results. In Part II, held during February and March 1981, participants obtained "hands-on" experience during the solar operations of the receiver, including start-up, steady-state, simulated or real cloud passage, and normal or emergency shutdown. The workshop was attended by more than 60 individuals representing 14 user and 12 supplier firms. Results of the experiment were published in May 1981 (Ref. 2-5).

b. Advanced Molten Salt Receiver Design. The Martin Marietta molten salt receiver experiment represented the first step toward developing economically viable molten salt receivers. Toward this end Foster Wheeler and Babcock and Wilcox are designing advanced molten salt receivers based on concepts from the previously conducted repowering system studies. These preliminary designs are being prepared in conjunction with fabrication process development.

c. Molten Salt Steam Generator Design Studies. For solar central receiver plants to use molten salt for the receiver and thermal storage working fluids, molten salt steam generators must be developed. The design, fabrication and test of solar plant steam generators able to provide industrial process heat or generate power will be a first-of-a-kind effort.

Foster Wheeler and Babcock and Wilcox are studying the development of a cost-effective molten salt steam-generating subsystem that can produce high-temperature, high-pressure main and reheat steam for a turbine-generator. The development effort has been planned in two phases: preliminary design in FY 81, and detailed design, construction, test, and evaluation of this experiment continuing in FY 82. The final subsystem, which will be tested at the CRTF, is expected to resolve most of the design, fabrication, operational, and performance uncertainties associated with the full-scale subsystem.

d. Sodium Receiver Subsystem Research Experiment. The Energy Systems Group (ESG) of Rockwell International has provided at their own cost a sodium-cooled prototype receiver which will be tested at the CRTF. The ESG receiver consists of three 21-tube panels operating in parallel, each panel having an independent control valve (Figure 2-6). In preparation for the test, the receiver has been mounted on a test stand made up of an electromagnetic pump, a surge tank, a sodium-to-air heat exchanger, and interconnecting piping. Solar testing of the ESG receiver was expected to begin in October 1981 and to be completed in February 1982. A ''hands-on'' workshop for users and suppliers will be held in March 1982.

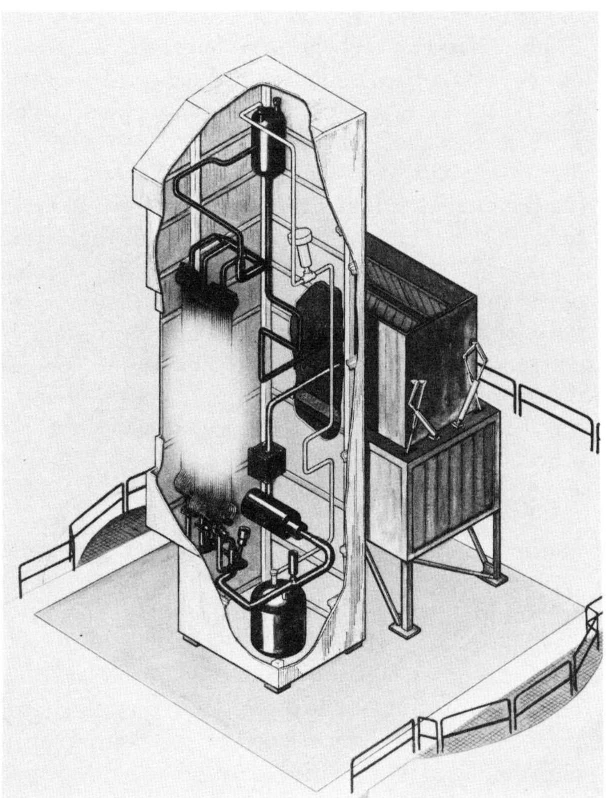

Figure 2-6. Rockwell Energy Systems Group Sodium Receiver Test at the CRTF

e. Receivers for Industrial Process Heat Applications. During FY 81, various central receiver technologies for supplying 177 °C (350 °F) and 288 °C (550 °F) saturated steam for industrial process heat applications were compared. Conceptual designs of systems based on molten salt, water/steam, and oil receivers were derived, where possible, from earlier work within the central receiver program. These systems include either molten salt or oil/rock storage subsystems. Costs were estimated for delivered energy over a capacity-factor range from 0.27 to 0.67 (Figures 2-7 and 2-8).

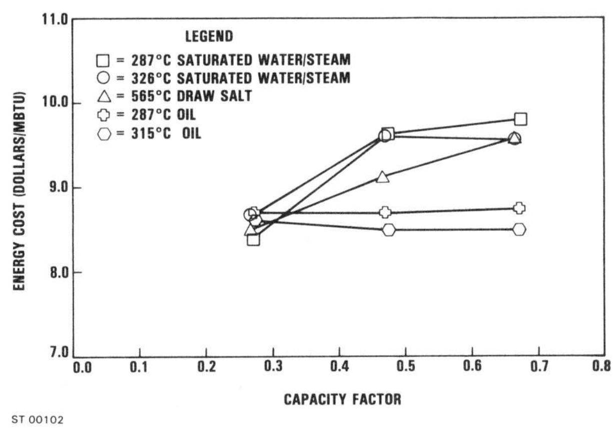

Figure 2-7. 176 °C (350 °F) Saturated Steam Levelized Energy Costs

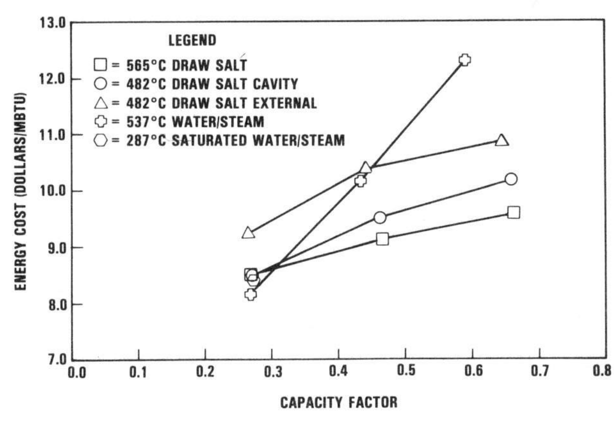

Figure 2-8. 287 °C (550 °F) Saturated Steam Levelized Energy Costs

The studies show that for systems requiring little or no storage, several different technologies can supply saturated steam at roughly equal costs. But for systems that need large amounts of storage, collecting energy at temperatures higher than the application temperature is warranted.

Process steam therefore represents an additional market for the 566°C (1050°F) molten salt receiver system that the program is currently emphasizing for electrical power production.

3. Storage Technology Development

The central receiver storage program has emphasized supporting storage subsystem designs for those receiver systems that are projected to be cost-effective. According to analyses, systems that use water/steam or molten salt receivers are the most promising. Storage work in FY 81, therefore, concentrated on developing alternative storage conceptual designs for water/steam systems; fielding a major storage experiment for molten salt; and developing a materials technology data base for molten nitrate salts.

a. Storage For Water/Steam-Cooled Receivers. During FY 81, two second-generation storage concept designs were completed, one by Babcock and Wilcox, the other by Combustion Engineering. Both contracts involved evaluating candidate second-generation storage concepts, selecting the most promising concept, and designing an entire conceptual subsystem. The final designs were costed and compared to a reference oil/rock sensible heat storage subsystem.

For a superheated steam receiver, Babcock and Wilcox selected a moving-bed storage subsystem that uses a free-flowing refractory particulate, such as very fine sand, as a heat transfer and storage medium. The sand is contained in bin-like structures with heat exchangers mounted on top (Figure 2-9). A helical screw conveyor or Archimedes lift transfers sand from the base of one bin to the heat exchanger on top of an opposing bin. The sand flows through the heat exchanger over a bank of tubes containing water or steam, thereby transferring heat, and exits into the bin below. Compared to the reference oil/rock subsystem, the moving-bed concept exhibits insufficient cost improvement to warrant further development for water/steam receivers; however, it shows promise for integration with liquid-metal-cooled receivers where temperatures are too high for an oil/rock system because sand is less costly than liquid metal as a storage medium.

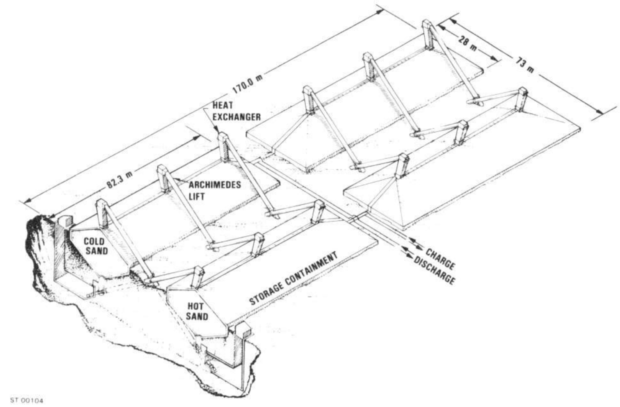

Figure 2-9. Moving Bed Thermal Energy Storage

Combustion Engineering designed a latent heat storage subsystem for a saturated steam receiver. In this passive design, 15 serpentine-shaped tubes are bundled into single-tube assemblies using aluminum, friction-fit fins (Figures 2-10 and 2-11). Five of these assemblies

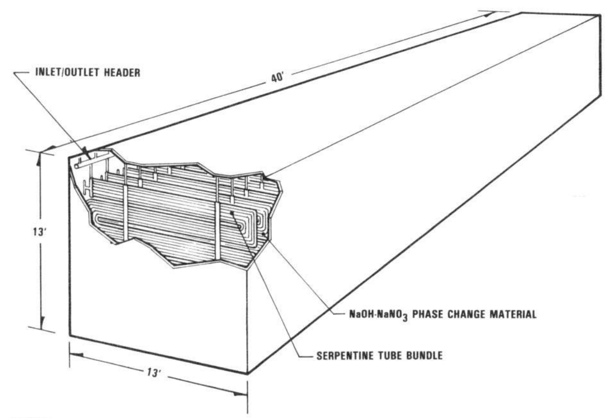

Figure 2-10. Latent Heat Thermal Storage Module

are placed in a rectangular tank that contains a eutectic salt mixture of $NaNO_3$ (18.5 mole %) and NaOH (81.5 mole %). Steam passing through the tubes gives up its heat and melts the salt. When the stored heat is needed, water is passed through the tubes and turned into steam. Further development of this particular subsystem is warranted, because it could save approximately 20% in storage costs over those incurred by the reference oil/rock subsystem.

b. Storage For Molten-Salt-Cooled Sensible Heat Receivers. Work on the development of a low-cost molten nitrate salt storage subsystem in FY 81 included critical component development, preliminary design studies, and a subsystem research experiment. Later, the test results and the preliminary design will be evaluated.

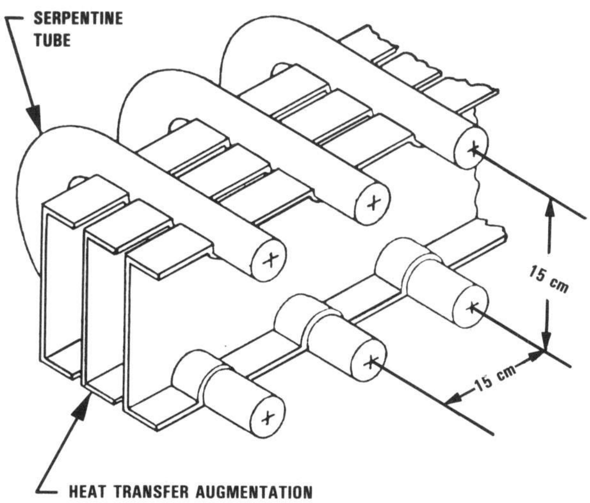

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Figure 2-11. Detail of Tube Assembly

Martin Marietta was awarded a contract in FY 80 to perform the development tasks. In its design, the high-temperature (566°C/1050°F) salt is contained in a lined and internally insulated hot tank, and the low-temperature (288°C/550°F) salt is contained in a separate insulated tank made of less-expensive carbon steel (Figure 2-12). The liner is an Incoloy-800 alloy, a liquid-tight waffled membrane similar to that used in

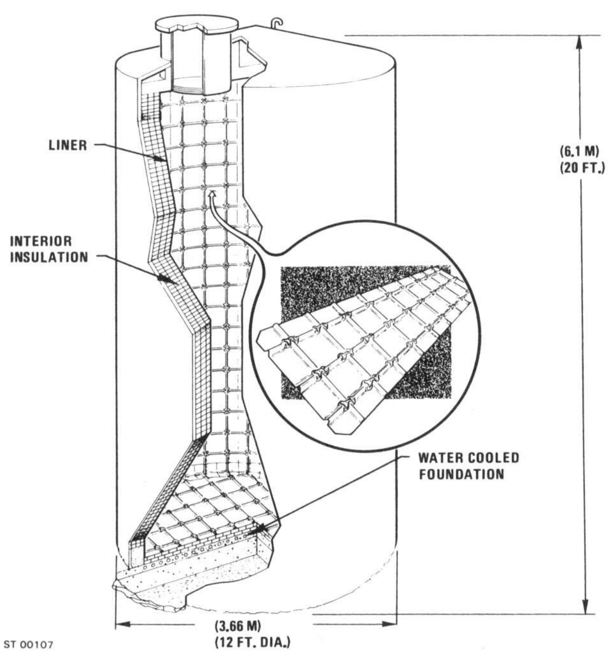

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Figure 2-12. Molten Salt Subsystem Research Experiment Hot Tank

liquid natural gas tanker applications. To date, the following progress has been achieved:

(1) Critical component development included successful testing on the Incoloy 800 knot-and-angle (corner) pieces of the liner. The testing has determined the welding parameters for joining the liner sections; the effects of strain and pressure cycling on the life of the knot-and-angle pieces; the effect of pressure cycling on a liner tested under actual operating conditions (i.e., in contact with salt at 566°C/1050°F); and the compressive strength properties of the insulating brick under both pressure and temperature cycling conditions.

(2) Preliminary design studies of full-scale tank insulation, size optimization, and preliminary thermal performance analyses are completed. Materials and thicknesses have been specified for both the external and internal components of the tank design. Tank size optimization studies identified key dimensions for the hot and cold tanks for 1240 MW_th of storage.

(3) Subsystem Research Experiment (SRE) design and layout, long-lead procurements, and component design have been completed. The experiment, which is to be conducted at the Central Receiver Test Facility, will test a 65-m^3 internally insulated hot tank and an externally insulated cold tank with a storage capacity of about 7 MW_th (Figure 2-13). A document that contains the design information and interface requirements for each test item has been issued.

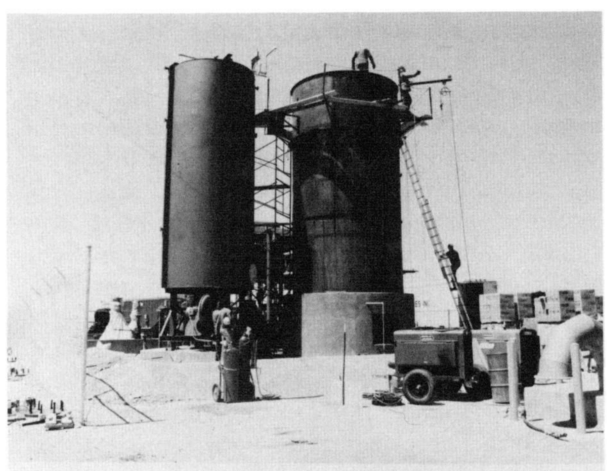

Figure 2-13. Molten Nitrate Salt Storage Subsystem Research Experiment at the CRTF

Many materials studies on molten nitrate salt storage systems took place in FY 81. Work by EIC Laboratories, Inc. shows that water does not react with molten nitrates to produce corrosive products; however, carbon dioxide does react with the salt to produce carbonates that, in sufficient amounts, could prove deleterious. Methods to exclude carbon dioxide or remove carbonates are available.

During FY 81 the viscosity, surface tension, density and heat capacity of molten mixtures of $NaNO_3$ and KNO_3 were determined. Oak Ridge National Laboratory has evaluated the corrosive behavior of high-temperature structural alloys in molten nitrate salts. The results, which supplement many experiments at Sandia National Laboratories, Livermore (SNLL), show little corrosion of the tested alloys: 304 and 316 stainless steel and Incoloy 800. Experiments at SNLL and General Atomic investigating the strength of Incoloy 800 at high temperatures under cyclic loading of the alloy show the alloy performs better in molten nitrates than in air or water/steam environments. Preliminary results of a contract with the University of New York at Buffalo suggest that at high temperatures the surface oxide initially formed on Incoloy 800 is stronger and more protective than that formed at lower temperatures in molten nitrates. Future experiments at Buffalo through FY 82 will focus on this phenomenon.

B. SYSTEMS EXPERIMENTS AND ANALYSES

1. Solar Central Receiver Pilot Plant

The 10-MWe Solar Central Receiver Pilot Plant will apply the results of many development experiments to a solar-powered electrical generation plant. Until now, solar central receiver technology has not been integrated into a full system for power generation within the United States. The primary objectives of the pilot plant are threefold: (1) to establish the technical feasibility of a solar thermal central receiver plant, including collecting data for industrial process heat and utility applications; (2) to obtain sufficient development, production, and operating data to indicate the potential for economical operation of commercial plants of similar design; and (3) to determine the environmental impact of solar thermal central receiver plants (Ref. 2-6).

Responsibility for the project has been assigned to the DOE Division of Solar Thermal Technology, Office of Solar Heat Technologies (formerly Division of Solar Thermal Energy Systems, Office of Solar Industrial Applications). A Solar Ten-Megawatt Project Office (STMPO) was established by the DOE San Francisco Operations Office (SAN) to handle the day-to-day planning, direction, execution, and control of the construction phase.

The pilot plant project is funded jointly by the DOE and the "Associates," a group composed of the Southern California Edison Company, the Los Angeles Department of Water and Power, and the California Energy Commission. In accordance with a cooperative agreement between DOE and the "Associates," the latter is involved in the engineering management, construction, and technology transfer activities of the project. Figure 2-14 shows a photograph of the plant, located on Southern California Edison property east of Barstow, California, at Daggett. Figure 2-15 illustrates how the Barstow plant will convert radiant energy to electricity.

DOE and the "Associates" share the overall project cost. DOE is funding construction of the solar facilities portion of the plant; the "Associates" (principally Southern California Edison) is funding the turbine-

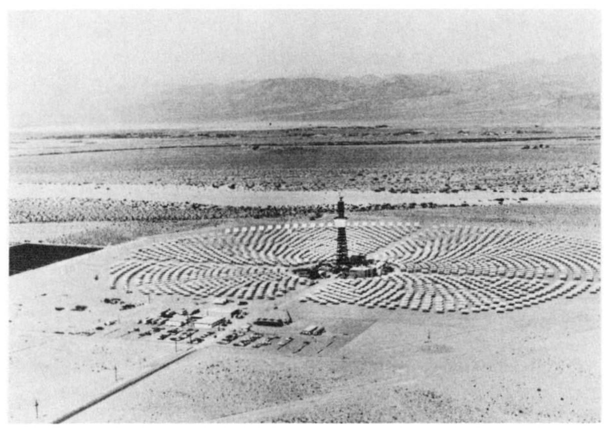

Figure 2-14. Completed Collector Field at Barstow Pilot Plant, September 1981

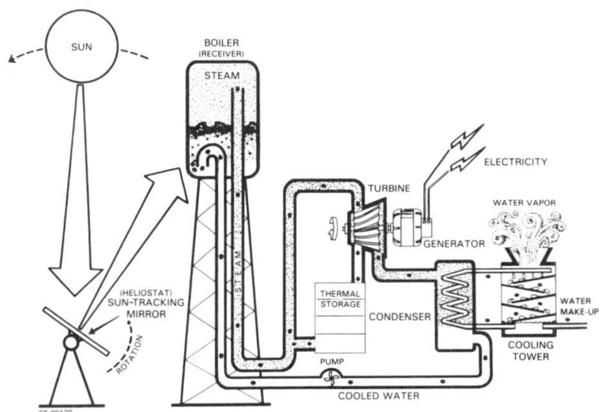

Figure 2-15. Schematic of 10-MWe Pilot Plant

generator facilities. The plant will be operated and maintained by Edison personnel, but costs will be divided between DOE and Edison. The plant is scheduled to first provide steam to the turbine early in 1982; then, following a period of checkout and testing, a 5-year test operations phase is scheduled.

During FY 81, the detailed design of the plant was finished; the major components were procured and installed; and point-to-point field wiring and piping were completed. Control system software has been evaluated on simulators and is installed in the plant's advanced digital control and data acquisition system. Table 2-3 summarizes the highlights of FY 81.

Heliostat installation was completed in FY 81. Figures 2-16, 2-17, and 2-18 show construction progress on the Barstow collector field, receiver, and core area, respectively, as of July 1981. Figure 2-19 presents a photo of the Visitors' Center, which opened in July 1980.

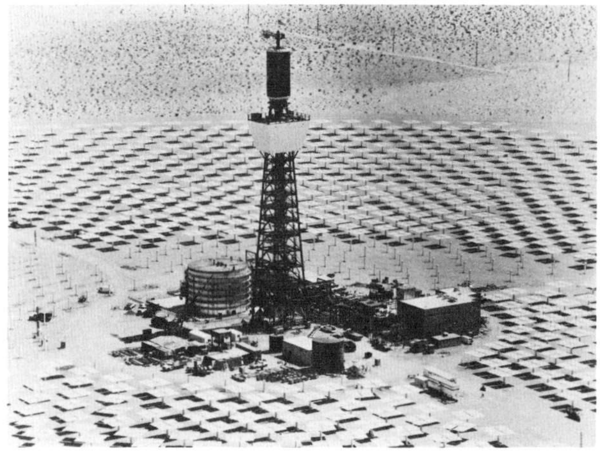
Figure 2-16. Aerial View of Barstow Pilot Plant Under Construction, July 1981

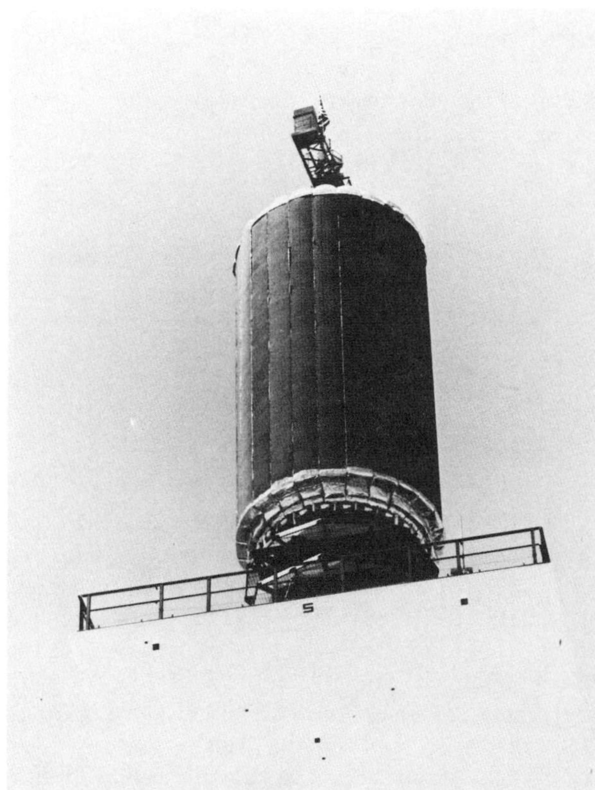
Figure 2-17. 10-MWe Plant Receiver Under Construction, July 1981

2. International Energy Agency Project

The Small Solar Power Systems (SSPS) project to design and build a solar thermal power plant was begun in 1977 by members of the International Energy Agency (IEA). Nine IEA member countries are cooperating in the effort: Austria, Belgium, Germany, Greece, Italy, Spain, Sweden, Switzerland and the United States. The site chosen for the two side-by-side systems is near Almeria, Spain. The systems are a central receiver system (CRS), and a distributed collector system (DCS).* These systems are based on existing

Table 2-3. Highlights and Accomplishments in FY 81

Installed and dedicated first heliostats	October 1980
Completed tower assembly	December 1980
Completed receiver panel fabrication	May 1981
Installed receiver panels on tower	June 1981
Received steam turbine	June 1981
Began operator training	June 1981
Completed thermal storage system tanks	July 1981
Installed control room equipment	July 1981
Filled thermal storage system with oil	August 1981
Completed control room-to-component wiring	August 1981
Completed heliostat field (1818 heliostats installed)	September 1981
Began control system checkouts	September 1981

*For a full discussion of the DCS, see Section IV.B.3.

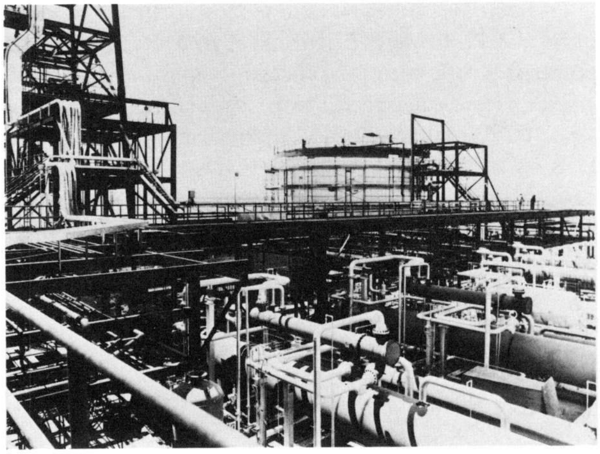

Figure 2-18. 10-MWe Plant Core Area Under Construction, July 1981

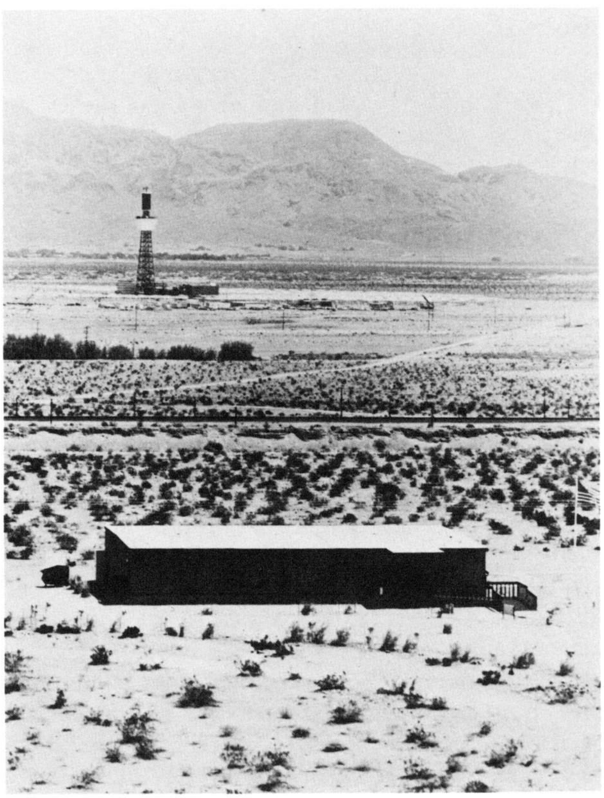

Figure 2-19. Visitor's Center at the Pilot Plant, July 1981

available technology, with a minimum of research and development effort. The SSPS plant was completed and was put in operation by the end of FY 81; the test and operations phase has begun and will proceed through the end of 1983 (Ref. 2-7).

The CRS uses liquid sodium as the primary heat transport fluid in the receiver as well as for storage. Liquid sodium is one of the heat transport fluids currently being evaluated in the U.S. Solar Thermal Central Receiver Program. Because there are no sodium central receiver power plants under construction in the U.S., the IEA/SSPS Project will provide the central receiver program with plant operations and maintenance data. Figure 2-20 presents a photograph of the IEA/SSPS CRS taken in July 1981.

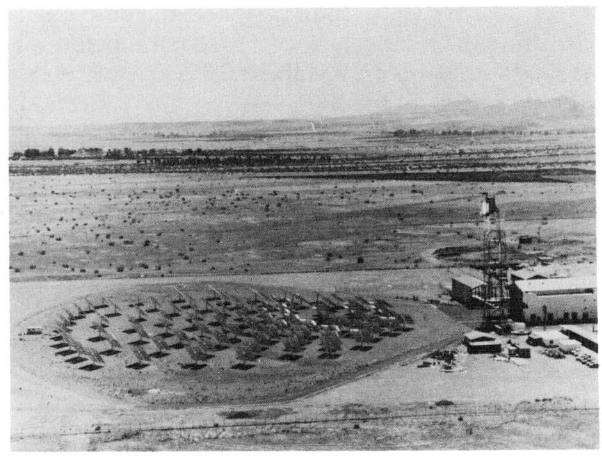

Figure 2-20. International Energy Agency SSPS Central Receiver System at Almeria, Spain

The three major systems of the 500-kWe CRS plant are the heliostat field, the sodium heat transfer system, and the power conversion system. The south-facing heliostats direct reflected solar energy to a tower-mounted cavity-type receiver. Thermal energy from the receiver is piped to a hot storage tank and then to a steam generator for the production of superheated steam, which in turn is fed to a steam motor to produce mechanical energy to drive an electric generator.

a. CRS Heliostat Field. The Martin Marietta heliostats are of the type developed for the central receiver pilot plant near Barstow, California, and evaluated as part of the test program for the Barstow plant. The 93 heliostats have been modified for use at the IEA site with four different focal length zones, ranging from 77 to 162 m. The mirror module is a vented sandwich of hot-bonded glass mirror, honeycomb core, and steel pan enclosure. The heliostat array controller transmits commands to the heliostats by means of four subordinate heliostat field controllers.

b. CRS Receiver. The German-designed north-facing sodium receiver is mounted atop a steel tower. This cavity-type receiver has a vertical octagonal 9.7-m^2 aperture with a centerline 43 m above the ground. Sodium flows in six horizontal parallel tubes that wind back and forth from the bottom to the top of the cavity.

Sodium enters the inlet header at 270 °C (518 °F) at the bottom of the panel and exits the outlet header at 530 °C (986 °F) near the top. The peak flux is approximately 62 W/cm^2 at equinox noon as 2880 kWt enter the receiver aperture.

c. CRS Storage, Steam Generator, and Power Conversion Unit. A cold sodium vessel and a hot sodium vessel, each having a volume of 70 m^3, provide storage for the CRS. Sodium enters the hot storage vessel from the receiver at 530 °C (986 °F), is pumped to the helical-tube once-through steam generator, then is returned to the cold sodium vessel at 275 °C (527 °F).

The power conversion unit is a steam-driven, five-piston motor and a three-phase current generator. The generator is equipped with an automatic voltage control device for non-parallel (isolated) operation, and a reactive current control for parallel (grid-connected) operation.

d. Test and Operations. The plant will be run under actual operating conditions to the maximum possible extent while test and operations personnel collect reliable data on the viability of the selected technical solutions, the behavior of the plant, and the economics of plant operation. To ensure that this data is available to U.S. industry and utilities, the U.S. DOE has a representative on the Test and Operations Advisory Board, the group that provides recommendations on the planning and evaluation of operations. DOE is chairing the SSPS International Test and Evaluation Team that will conduct tests and experiments in parallel with routine operations, and will report the results of all tests and operations.

3. Repowering/Retrofit Projects

''Repowering'' is the addition of a replacement or auxiliary steam generation system, e.g., a solar central receiver system, to an existing power plant. ''Retrofit'' refers to adding such a power source to an existing industrial operation such as process heat.

Over the past 2 years, 13 site-specific conceptual repowering and retrofit designs have been developed for electric utility and industrial process heat applications. Designs for utility applications covered oil- and natural-gas-powered plants varying in size from 25 to 111 MWe. These repowering proposals used water/-steam, molten salt, or sodium as the heat transport fluid in either external or cavity receivers, and had up to 6 hours of storage capability. All the plants have conventional steam Rankine conversion cycles.

The IPH studies considered such diverse applications as oil refining, enhanced oil recovery, natural gas processing, uranium ore processing, gypsum board drying, and ammonia production. Smaller than the utility repowering plants, the IPH plants ranged in size from 11.8 to 43.5 MWt. Both external and cavity receiver designs were studied; oil, water/steam, air, and a mixture of steam and natural gas were considered as potential receiver fluids. Tables 2-4 and 2-5 summarize the conceptual designs for utility and IPH applications, respectively.

Subsequently and concurrently with these studies, significant advances have occurred in the state of the art of solar central receiver components and subsystems. Current efforts have been focused on incorporating advances in design and consolidating the repowering and retrofit experience with the cogeneration design results.

Work in FY 81 included preparation of the RFP for Advanced Design studies and the evaluation of responses; it culminated with the issuance of DOE/SAN contracts. Five studies—four utility applications (Arizona Public Service, El Paso Electric Co., McDonnell Douglas/Sierra Pacific Power Co., and Rockwell International/West Texas Utility Co.) and one cogeneration application (Bechtel Group, Inc./Amfac Sugar Co.)—were funded to begin in September 1981.

These studies will attempt to refine previously completed conceptual designs in the repowering and cogeneration categories by (1) incorporating within them the most recent technical developments in solar central receiver components and subsystems (e.g., heliostats, receivers, storage units, steam generators), and (2) verifying that the performance estimates for the initial designs are based, to the maximum extent possible, on the performance characteristics of commercially available equipment. Results of all these studies will be summarized and documented in FY 82.

4. Solar Cogeneration Projects

Cogeneration is the term for producing electrical and/or mechanical energy in combination with other useful thermal energy. Because a cogeneration system delivers electrical energy and process heat more efficiently than systems that deliver this energy separately, cogeneration conserves fossil fuel. Fuel usage is further reduced if solar thermal capabilities are added to a fossil fuel cogeneration facility.

Table 2-4. Repowering Electric Utility Applications

Prime Contractor	Arizona Public Service (APS) (Eric Weber)	El Paso Electric Co. (EPE) (Jim Brown)	Black & Veatch Consulting Engr. (Sheldon Levey)	McDonnell Douglas Astronautics Co. (C.R. Easton)	General Electric (Jim Elsner)	Rockwell Intl. Energy Sys. Group (Tom Springer)	Rockwell Intl. Energy Sys. Group (Tom Springer)	Public Service of New Mexico (J.D. Maddox)
Subcontractors	Martin Marietta Badger Energy Gibbs & Hill	Stone & Weber Westinghouse	Public Service Co. of Oklahoma (PSO) Babcock & Wilcox Baily Controls Co.	Sierra Pacific Pwr. Foster Wheeler Dev. Stearns-Roger Desert Research U. of Houston Westinghouse	Southwestern Public Service (SPS) Kaiser Engineers	Stearns-Roger McDonnell Douglas U. of Houston Texas Electric Svc. Co.	West Texas Utilities U. of Houston Boeing Sargent & Lundy	Stearns-Roger Westinghouse
Site Location	Saguaro Power Station, Tucson, Arizona	Newman Station, El Paso, Texas	Northeastern Stn., Dologah, Oklahoma, near Tulsa	Ft. Churchill Plant, Yerington, Nevada, near Reno	Plant X - Earth, Texas, near Lubbock	Permian, Basin Station, Monahans, Texas, near Odessa	Paint Creek Stn., Stanford, Texas, near Abilene	Reeves Stn., Bernalillo, New Mexico, near Albuquerque
Plant Data Net Output, MWe Turbine Inlet Temp., °C (°F) Pressure, MPag Type/Date	 113.2 537 (1000) 10 Nonreheat/1954	 82 537 (1000) 10 Reheat/1960	 145 537 (1000) 12.4 Reheat/1961	 115 537 (1000) 12.4 Reheat/1967	 100 537 (1000) 10 Reheat/1955	 115 537 (1000) 10.1 Reheat/1958	 110 537 (1000) 12.4 Reheat/1972	 46 510 (950) 8.6 ________ /1957
Receiver Technology and Output Temp., °C (°F)	Molten Salt Quad Cavity 565 (1050)	Adv. Water/Steam External/548 (1020) (Separate Reheat Receiver)	Adv. Water/Steam External [115 (240) Sector/544 (1012)]	Molten Salt Partial Cavity 565 (1050)	Liquid Sodium Cylindrical, External 593 (1100)	Liquid Sodium Cylindrical, External 593 (1100)	Liquid Sodium Cylindrical, External 593 (1100)	Water/Steam Rocketdyne Once-Thru - Based on Barstow/565 (1050)
Receiver Output Power, MWt	350	92/13	73.3	330	142	158.5	226	111
No. Heliostats/m^2 Total Mirror Area, m^2 Land Area, Acre	10500/49.05 515,025	2776/81.8 227,077	2255/49.05 110,617	8411/56.42 474,549	4809/49 235,881	4742/56.42 267,544 280	7882/49 386,218	40086/38 155,268
Field Configuration	Surround	160° North	Near React. North	130° North	Surround	Surround	Surround	Surround
Solar Output Design Point, MWe (Net)	111	41	30	77	57	50	60	25
Annual Energy Produced, GWht	719.5	206.8	115.2	759	290.5	355.5	482.5	—
Storage	3.8 h @ 305 MW	None	None	6 h	10 min full power	1 h	4 h full power	None
BBL of Oil (equiv.) Saved Annually	493,000	133,000	88,000	490,000	200,000	237,000	351,000	—
Capital Costs (Heliostat Unit Price/m^2)	$166.8 M ($230)	$93.1 M ($230)	$55.1 M ($260)	$196 M ($224)	$116 M ($230)	$112 M ($260)	$145 M ($230)	$125 M
$/kWt	—	—	—	—	—	—	—	—
Annual Energy/Area	1.397 MWht/m^2	0.98 MWht/m^2	1.04 MWht/m^2	1.6 MWht/m^2	1.23 MWht/m^2	1.346 MWht/m^2	1.249 MWht/m^2	—
Cost/Fuel Displaced	$199/MWht	$397/MWht	$368/MWht	$258/MWht	$399/MWht	$313.9/MWht	$234.6/MWht	—
Solar Fraction (Annual)	0.273	0.60[2]	0.08	0.23	0.23	0.28	0.32	0.5

Table 2-5. Industrial Process Heat Applications

Prime Contractor	Northrup Inc. (Roy Henry)	Martin Marietta Denver (Dave Gorman)	McDonnell Douglas Astronautics Co. (L.W. Glover)	Foster Wheeler Development Corp. (R. Raghaven)	Boeing Engr. and Constr. Company (D.K. Zimmerman)	PFR Engineering Systems, Inc. (Tzvi Roseman)
Subcontractors	Arco Oil & Gas Co.	Exxon Research & Engr. Foster Wheeler Dev. Corp. Black & Veatch	Gulf Research & Development Co. Foster Wheeler U. of Houston	Foster Wheeler Energy Corp. Provident Energy Co., Inc.	United States Gypsum Inst. for Gas Tech. Shawinigan Engr. Corp. North Amer. Turbine	Valley Nitrogen McDonnell Douglas U. of Houston
Site Location	North Coles Levee Plant 8 (22 mi west of Bakersfield, California)	Edison Oil Field, Bakersfield, California	Mt. Taylor Uranium Mill, San Mateo, N. M. (60 mi west of Albuquerque)	Provident Energy Refinery, Mobile, Arizona (near Phoenix)	Sweetwater Plant Sweetwater, Texas (40 mi west of Abilene)	El Centro Ammonia Plant, El Centro, California, (100 mi east of San Diego)
Plant Data Process Process Fluid Temp., °C (°F)	Natural Gas Proc. Hydrolight Cycle 301 (575)	Enhanced Oil Recov. Wet Steam 232-354 (450-670) (80% quality)	Uranium Processing Saturated Steam 185 (366)	Refinery Steam 371 (700) (separate fossil superheater)	Gypsum Board Drying Hot Air 426 (800)	Ammonia Production Solar Heated Steam Methane Refining 187 (1450)
Receiver Technology and Output Temp. °C (°F)	Oil Fluid, Once-thru Cavity 293 (560)	Water/Steam Twin Cavity, Wet 297 (567) - 82%	Water/Steam External, Drum Type 203 (399)	Water/Steam External, Flat Panel 271 (520)	Air Cavity, Forced Circ. 724 (1335)	Reradiation Inner Cavity 787 (1450)
Receiver Output Power, MWt	11.8	29.32	15.7	43.5	11.92	34.5
No. Heliostats/m^2 Total Mirror Area, m^2 Land Area, Acre	320/52.6 16832	818/49.05 40123	383/56.4 21601	1174/56.4 66214	469/44 20636	1040/56.4 58656
Field Configuration	North	150° North	North	North	North	North
Solar Output Design Point, MWt (Net)	9.5 (32.5 x 10^6 Btu/h)	29.3 (100 x 10^6 Btu/h)	13.9 (47.4 x 10^6 Btu/h)	43.2 (147.4 x 10^6 Btu/h)	10.54 (1.3 MWe Cogenerating Electricity)	34.0 (115.8 x 10^6 Btu/h)
Annual Energy Produced, GWht	23.2	55.9	31.8	105	16.8	84.5
Storage	None	None	None	3 min Press. Water	None	None
BBL of Oil (equiv.)	21,336	44,058	21,135	76,724	11,743	Additional 10,500 Tons of Ammonia Produced
Capital Cost (Heliostat Unit Price/m^2)	$8.34 M ($301)	$14 M ($230)	$12 M ($230)	$27.6 M ($272)	$9 M ($230)	$24.9 M ($230)
$/kWt	707	478	764.3	634.5	755	713.04
Annual Energy/Area	1.34 MWht/m^2	1.39 MWht/m^2	1.47 MWht/m^2	1.59 MWht/m^2	0.814 MWht/m^2	1.44 MWht/m^2
Cost/Fuel Displaced	$368/MWht	$188/MWht	$332/MWht	$212.3/MWht	$427/MWht	$261/MWht
Solar Fraction (Annual)	0.90 (0.24)	(2.6)	(0.21)	(0.208)	0.07 (doesn't include 0.221 MWe)	0.66 (0.226)

Figure 2-21 depicts a solar cogeneration facility based on the central receiver concept. Recognizing the value of this system, for its increased efficiency as well as its potential industrial process heat markets, DOE initiated conceptual design work using specific plants to serve as typical sites for study purposes. Seven contracts were awarded; the first one began in September 1980, the last one in January 1981. All of these design contracts were completed in FY 81 and results are being published.

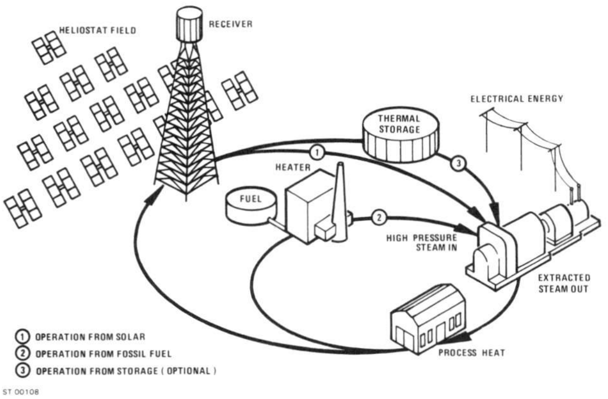

Figure 2-21. Schematic of a Solar Cogeneration Facility

The selected proposals cover a wide range of geographical areas (Figure 2-22) and address several potential applications, including sugar mill operations,

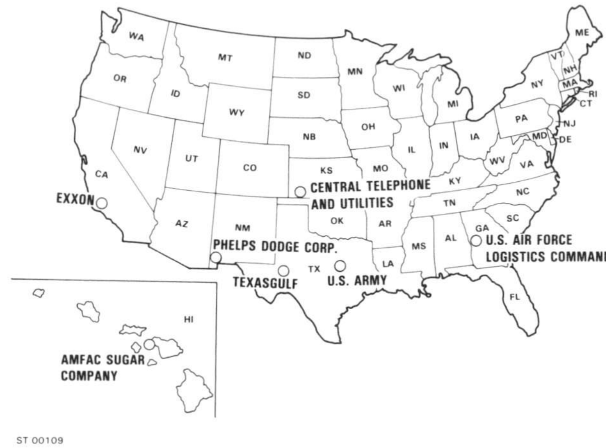

Figure 2-22. Cogeneration Plant Sites

natural gas processing, enhanced oil recovery, sulfur mining, copper smelting, and space heating and cooling. Each designer/user submitted its proposal for a particular industrial or commercial application. Table 2-6 summarizes the key aspects of the seven projects that are described below.

(1) Pioneer Mill Company, Ltd. (Lahaina, Maui, Hawaii)

Prime Contractor: Bechtel Group, Inc.

Subcontractors: Amfac Sugar Co.; Foster Wheeler; Northrup

Table 2-6. Solar Congeneration Conceptual Design Summary

	Central Receiver						
User	Power Output, MWt	Temperature, °C Pressure, MPa	Type	Tower Height, m	Number of Heliostats (mirror area x 10^3 m^2)	Solar Power[a] (Thermal Storage)	Annual BBL Oil Equiv. Saved
Amfac Sugar Co.	26	438 6.85	cavity-water	76	815 (43.0)	17.0 MWt 3.4 MWe 0.3 MWm	37,000
Central Telephone & Utilities-Western Power	37	520 11.07	external-water	74	1,057 (55.8)	3.7 MWt 15 MWe	48,100
Exxon Research & Engineering Co.	115	566 2.5	cavity-salt	140	3,295 (189.1)	13.2 MWt 20.4 MWe (380 MWh)	140,000
Texasgulf Chemical	19.8	272 5.65	external-water	70	588 (31.0)	16.1 MWt 2.2 MWe	40,100
Phelps Dodge Co.	270	816 0.37	cavity-air	190	10,441 (521.0)	54 MWt 46 MWe (4080 MWh)	436,000
Fort Hood, U.S. Army	8.7	454 0.10	cavity-salt	53	242 (13.8)	3.5 MWt 0.6 MWe (20 MWh)	9,700
Robins AFB	8.8	400 5.9	external-water	60	251 (13.2)	7.9 MWt 0.7 MWe	8,300

[a]Proportion of net output from solar.

Pioneer Mill Company, Ltd., a subsidiary of Amfac Sugar Co., operates a sugar factory and has an existing cogeneration facility supplying steam for mechanical drive turbines and process evaporators, and electric power for irrigation pumps. The mill consumes #6 oil to supplement the use of bagasse (the cellulose residue of the processed sugar cane) in the existing dual-fired boiler in order to produce steam at 5.87 MPa and 400 °C (752 °F).

The object of this project is to retrofit a solar central receiver system to the existing cogeneration facility. The solar retrofit will require the addition of a north collector field of 815 heliostats, a tower-mounted receiver, and a steam and condensate pipeline approximately 1000 meters long to connect the receiver with the existing plant. The two-cavity, natural-circulation water/steam receiver will operate in parallel with the existing boilers and will supply about 45% of the total steam demand for the factory at design point. Bagasse will be diverted from the boilers to the storage house where it can be reclaimed when solar-produced steam is not available. Using bagasse eliminates the need for thermal storage and allows about 73% of the oil currently consumed during the harvest season to be displaced (Figure 2-23).

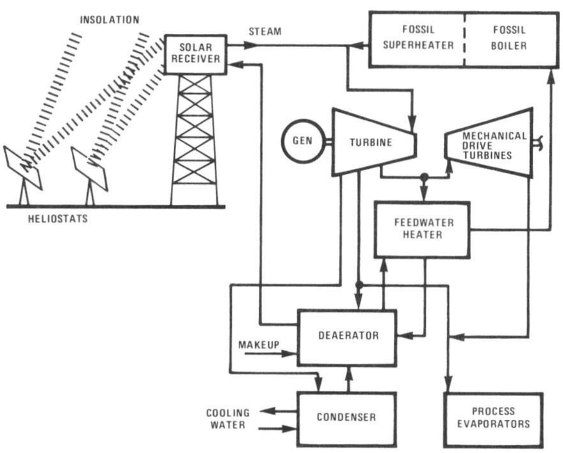

Figure 2-23. Schematic of Pioneer Mill Company Sugar Factory Solar Cogeneration Project

A site test program is currently monitoring direct normal insolation.

(2) Central Telephone & Utilities-Western Power, Cimarron River Station (near Liberal, Kansas)

Prime Contractor: Black and Veatch

Subcontractors: Central Telephone & Utilities-Western Power; Babcock and Wilcox Co.; Foxbow Co.

The cogeneration facility of the Central Telphone & Utilities-Western Power (CTU-WP) Cimarron River Station provides a net output of 55 MWe for its customers of the CTU-WP grid, and normally 20 MWe and 15 MWt of process heat to the natural gas processing plant of National Helium Corporation.

A site-specific conceptual design has been selected to demonstrate the technical feasibility and identify the economic potential of a central receiver cogeneration facility. The heliostats will redirect and concentrate solar energy onto an external, water/steam type receiver mounted on a 74-meter tower. The thermal energy absorbed by the receiver will be transferred to the feed water and steam, thus producing superheated steam at a pressure and temperature compatible with turbine inlet conditions. Steam from the gas-fueled boiler will be mixed with steam from the solar receiver and delivered to the turbine. The turbine generator will convert the thermal energy in the steam to electric energy. A portion of the steam flowing through the turbine will be extracted as process steam for National Helium Corporation. This conceptual design (Figure 2-24) does not include energy storage.

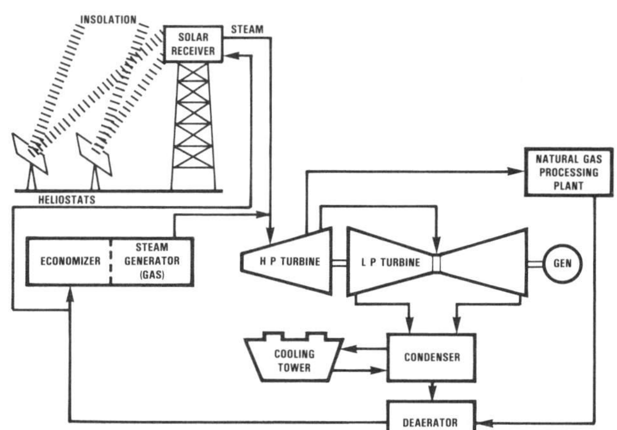

Figure 2-24. Schematic of CTU-WP Cimarron River Station Solar Cogeneration Project

Currently, a site test program is monitoring direct normal insolation and potential contamination of heliostat mirror surfaces.

(3) Exxon Corporation Edison Field (near Bakersfield, California)

Prime Contractor: Exxon Research and Engineering Control Research Office

Subcontractors: Martin Marietta, Aerospace; Badger Energy, Inc.; Pacific Gas and Electric Co.*

*PG&E participated at its own expense and was not funded under DOE contract.

Exxon's Edison Field uses steam injected into wells interspersed between oil-producing wells for enhanced oil recovery. The steam increases the field pressure and heats the oil, lowering its viscosity, thus permitting the oil to be pumped out of the ground faster and more economically. It also permits the recovery of oil that could not be retrieved by conventional pumping.

Exxon has proposed a design concept using a solar central receiver system to generate steam both for enhanced oil recovery, and to generate electricity to be sold to Pacific Gas and Electric (PG&E). A north field of heliostats will redirect the solar energy to a dual-cavity molten salt receiver mounted atop a 140-meter tower. Hot molten salt will be stored in the hot tank of a two-tank storage system, then pumped to a steam generator producing 13 MWt of steam for injection into the oil field 24 hours a day. Excess hot salt will produce steam to generate electricity at a rate of 15 MWe during PG&E's peak demand period. The spent salt will be returned to the cold tank for reuse (Figure 2-25).

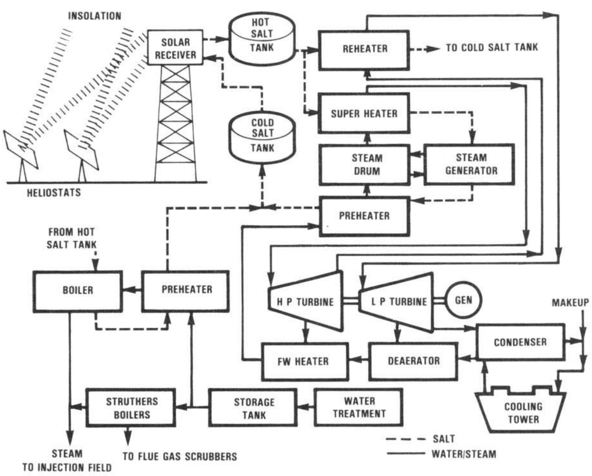

Figure 2-25. Schematic of Exxon Corp. Edison Field Enhanced Oil Recovery Solar Cogeneration Project

(4) Texasgulf Comanche Creek Sulfur Mine (near Fort Stockton, Texas)

Prime Contractor: General Electric Company, Energy Systems Programs Department

Subcontractors: Texasgulf, Inc.; Brown and Root Development, Inc.

The Comanche Creek Sulfur Mine is in continuous operation, 24 hours per day, 365 days a year. The mine has eight gas-fired water heaters that generate the process heat required for mining sulfur; electricity is purchased from West Texas Utilities. The solar cogeneration facility will be operated in parallel with a gas-fired package boiler to provide 100% of the mining operation's electrical requirements and 16.5% of the process heat requirements.

The conceptual design consists of a north field of heliostats redirecting the solar energy onto a flat, external receiver mounted on a 70-meter tower. The planned receiver is a natural-convection, saturated water/steam boiler. The outputs of the receiver and a gas-fired boiler will be fed in parallel to an accumulator. The accumulator output will be directed into a separate gas-fired superheater that raises the saturated steam to superheated conditions for entry into the turbine. An extraction port on the steam turbine will feed a high-pressure heat exchanger to raise the process water temperature to 177 °C (350 °F) for transport to the sulfur wells. The solar steam cycle is a closed loop operation: the process water, being of poor quality, will not be recycled after it is pumped into the sulfur wells (Figure 2-26).

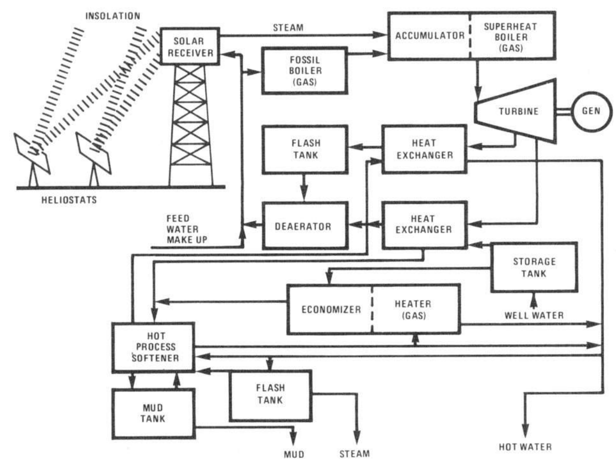

Figure 2-26. Schematic of Texas Gulf Inc. Comanche Creek Sulfur Mine Solar Cogeneration Project

(5) Phelps Dodge Corporation, Hidalgo Copper Smelter (near Playas, New Mexico)

Prime Contractor: Gibbs & Hill, Inc.

Subcontractors: Phelps Dodge Corporation; Boeing Engineering & Construction Co.

The Hidalgo Copper Smelter processes 2880 tons of dried and fluxed ore concentrate daily, producing 700 tons of copper a day. With a solar central receiver system, the smelter should increase its copper output by 90%.

A solar central receiver will supply up to 270 MWt of heated air for use in the smelting process, displacing about 75% of the present oil consumption. It will also provide the input to the gas turbines, thereby cogenerating up to 45 MWe. Waste heat from the smelter will produce steam to generate an additional 25 MWe and 12,000 hp of motor power.

In the conceptual design, compressed air from cogenerating gas turbines is heated in a cavity receiver to 816 °C (1500 °F) by a surrounding field of heliostats. After heated air is expanded in the gas turbines, it will be ducted to a thermal storage reservoir, which consists of a mound of waste slag from the smelter. The slag will be covered with a layer of soil for insulation, and operate similarly to a rock-bed storage system. As ambient air is circulated through the slag, it will be heated and then ducted to the flash furnace of the smelter and to the superheaters. Waste heat will be recovered from both operations by use of waste heat boilers and ore concentrate dryers (Figure 2-27).

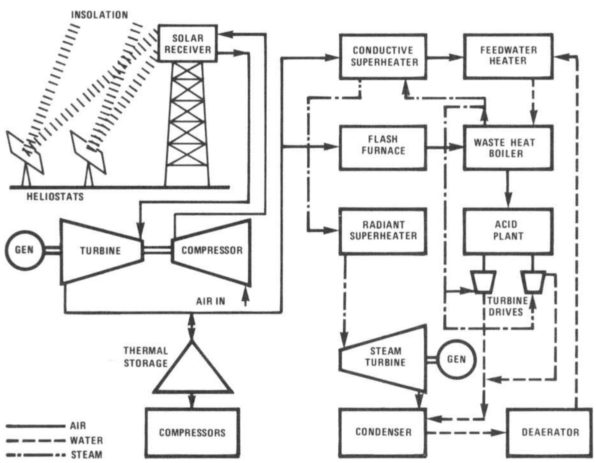

Figure 2-27. Schematic of Phelps Dodge Corp. Hidalgo Copper Smelter Solar Cogeneration Project

(6) Fort Hood Army Base (Killeen, Texas)

Prime Contractor: McDonnell Douglas Astronautics Co.

Subcontractors: Stearns-Roger; University of Houston

The Fort Hood Army Base solar cogeneration facility will benefit Complex 87000, a group of 20 buildings serving the housing, dining, and other needs of approximately 1650 soldiers. Texas Power and Light Company currently supplies the electrical energy for the complex. Thermal energy for room heating and domestic hot water is provided by gas-fired boilers in the central plant building. The proposed solar cogeneration facility will supply the complex with over 60% of its annual thermal energy needs and with over 100% of its yearly electrical energy requirements. The excess electricity will be distributed through the electrical grid for other Fort Hood uses.

In this design, heliostats will redirect up to 10 MWt of solar energy to a single-aperture, partial-cavity receiver. The absorbed heat will be transferred by molten salt to the hot tank storage system; during prolonged periods of low or no insolation, a gas-fired salt heater will generate heat for the system. From the storage tank, the hot salt will be pumped through a natural circulation type steam generator to produce the operating steam for a 600-kWe-rated turbine/generator unit. Extracted steam from the turbine will be sent to an aborsption water chiller for space cooling; turbine exhaust steam will be used for space and water heating. In times of peak demand, water is available from chilled water and hot water storage tanks (Figure 2-28).

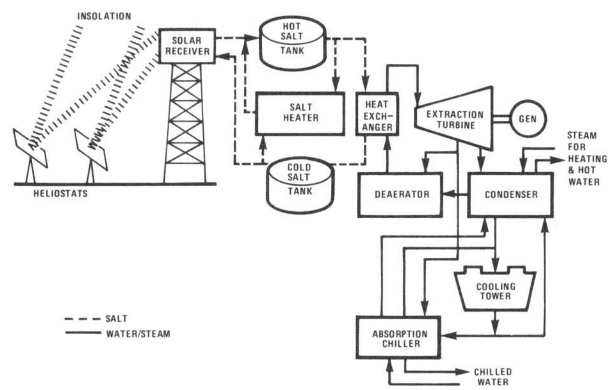

Figure 2-28. Schematic of Fort Hood Army Base Solar Cogeneration, July 1981

(7) Robins Air Force Base (Warner Robins, Georgia)

Prime Contractor: Westinghouse Electrical Corporation

Subcontractors: Heery & Heery, Inc.; Foster Wheeler Solar Development Corp.; Mechanical Technologies, Inc.

The solar cogeneration facility will serve the section of Robins Air Force Base that is currently supplied with central steam for space conditioning and water heating by four boiler plants. Steam is used for space heating in the winter, absorption cooling in the summer, and some industrial process loads. A Georgia Power Company substation located nearby provides a 10-MW electrical distribution system.

In the conceptual design, the heliostats focus solar energy on an external, flat-panel receiver. This water/steam central receiver, based upon natural-circulation receiver boiler technology, will provide main steam to the turbine generator, which has an output of about 750 kWe. Exhaust from the turbine is directed into the base steam trunk, supplementing the output of the boiler plant (Figure 2-29).

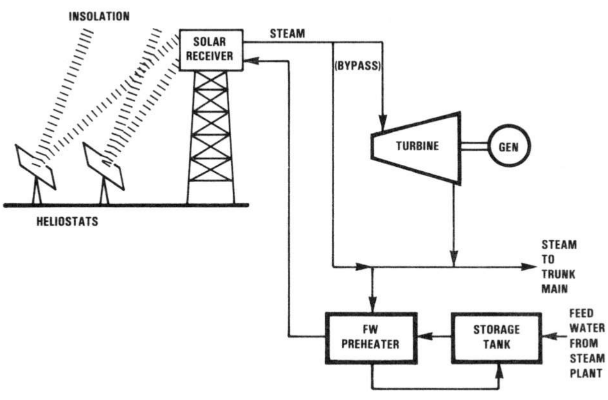

Figure 2-29. Schematic of Robins Air Force Base Solar Cogeneration Project

C. CENTRAL RECEIVER TEST FACILITY

The Central Receiver Test Facility (CRTF), located in Albuquerque, New Mexico, continued in FY 81 to support the development of both receiver and heliostat designs for future industrial applications. Managed by Sandia National Laboratories, Albuquerque, for DOE, the facility consists of a 61-meter tower, 222 sun-tracking mirrors (each 37 m^2), a computerized control and data acquisition system, and a video-based system for evaluating heliostat performance (Figure 2-30).

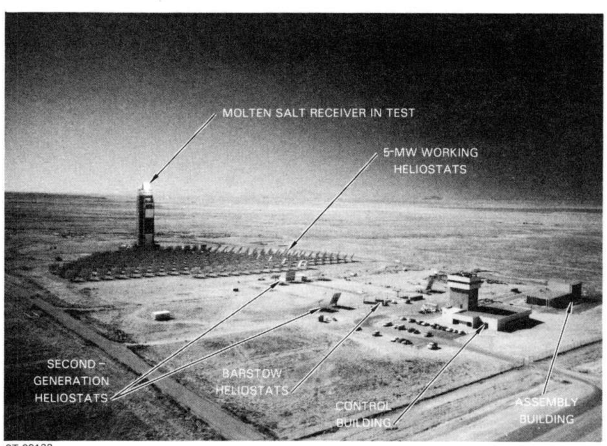

Figure 2-30. 5-MWe Central Receiver Test Facility

Since the CRTF began operation in October 1978, three major receiver test programs have been completed and seven heliostat designs have been evaluated. The FY 81 CRTF test program results contributed significant information for central receiver technology development.

1. Molten Salt Receiver Test Program

The Denver Division of Martin Marietta Aerospace Corporation designed and built an advanced design solar receiver that uses a molten salt (60% $NaNO_3$-40% KNO_3 mixture) heat-absorbing fluid. The receiver consists of 288 tubes made of Incoloy 800 alloy. The tubes, each having a 1.9-cm diameter and 0.17-cm wall, are arranged in a serpentine flow pattern; 16 tubes in parallel make up the 18 vertical passes.

The 5.5-meter-wide-by-4.0-meter-high flat panel is mounted inside an insulated cavity that has a 3- by 3-meter aperture (which can be closed with hydraulically operated doors). The working fluid enters the panel at 288 °C (550 °F) and is heated to 566 °C(1050 °F) at the design operating conditions. Test results indicate that the molten salt absorbs up to 4.7 MW of thermal power at a light-to-heat conversion efficiency of up to 90%.

Subjected to nearly 500 hours of solar testing, this experimental receiver was operated at full power and rated temperatures for approximately one-quarter of the test time. Valuable information about the performance and operation of molten-salt-type receivers was obtained. The CRTF evaluation also provided representatives of utility and industrial organizations with an opportunity to gain hands-on experience with receiver operation.

2. Liquid-Sodium-Cooled Receiver Test Program

A sodium receiver designed and built by the Energy Systems Group of Rockwell International, using private corporate funds, was installed at the CRTF in the last half of FY 81. By mid-FY 82, the testing and evaluation of this receiver should be completed. A hands-on operations workshop for utility and industrial representatives is planned for the final phase of the operations program.

The receiver panel is comprised of three flat tube-bundles, each formed by 21 tubes made of 316 stainless steel. The irradiated portion of the panel is 1.2 m wide by 3.0 m high. The receiver, which will be solar-tested in an exposed (non-cavity) configuration, is designed to have a 450-1/min sodium flow rate. Inlet and outlet temperatures are 290 °C (554 °F) and 595 °C (1103 °F), respectively. The receiver can absorb up to 2.5 MW of thermal power at peak flux densities of 1.5 MW/m^2.

3. Heliostat Performance Test Program

The performance characteristics of two second-generation heliostat prototypes from each of four manufacturers were evaluated in FY 81. The basic test plan included criteria on optical and structural performance, environmental survival, operation modes, and life-cycle considerations.

Evaluation of the test results thus far indicates that (1) the designs are basically sound, with some improvement still needed in mirror module design; (2) the previous design deficiencies have been overcome, resulting in improved weight efficiency and beam quality, and fewer life-cycle problems; and (3) operation and maintenance costs will be small compared to heliostat costs. The detailed results of this test program were presented to potential industrial and utility users in September 1981. This test program will continue in FY 82 with emphasis on obtaining additional life-cycle information and on evaluating improved mirror module and other component designs.

4. Thermal Storage Test Program

A 7-MWh thermal storage demonstration test was constructed at the CRTF in FY 81. The experimental system, which uses a molten salt (60% $NaNO_3$-40% KNO_3) working fluid, will undergo a 5-month-long test operation in FY 82. The test will demonstrate a variety of charge and discharge performance strategies and will evaluate a unique storage-tank liner, insulation, and fabrication technique.

5. Non-Central Receiver Test Program

Besides providing facilities for the evaluation of receivers, heliostats, and thermal storage subsystems, the CRTF hosts experiments that take advantage of its special high solar flux density environment. During FY 81 two tests were coordinated for the CRTF by the Solar Thermal Test Facilities Users Association, an organization founded in 1977 to promote the use of the major solar thermal test facilities by users other than those with direct solar thermal program interests.

In one instance, a series of tests was conducted for the Applied Physics Laboratory of Johns Hopkins University. This study, sponsored by the U.S. Navy, used the CRTF beam to simulate the aerodynamic heating that a rocket nose cone experiences during flight. Because there is minimal radio frequency (RF) electromagnetic radiation present with the CRTF solar beam, the rocket-tracking radar accuracy was determined without RF interference and optimized during the aerodynamic flight simulations. The second program, initiated for Science Applications, Inc., simulated the effect on soils of the light pulse from a nuclear weapon blast. The initial phase of this program depended on the evaluation of a simple beam concentrator that enhanced the flux density of the CRTF beam by a value between 1.6 and 1.8. Improved beam concentrator designs are now under consideration for use in future studies.

SECTION III
PARABOLIC DISH TECHNOLOGY

Point focus parabolic dish technology is being developed for the U.S. DOE by the Jet Propulsion Laboratory (JPL) under an interagency agreement with the National Aeronautics and Space Administration (NASA). The status of this work is described below in terms of the major subsystem hardware elements, the integration and test effort, and the field experiment preparation. Testing is done at the Parabolic Dish Test Site (PDTS) to assist in the development of dish subsystems and to verify the performance of a dish module before deploying dish hardware in field experiments in user environments.

Parabolic dishes are inherently modular. Achievable temperatures may exceed 1,370 °C (2,500 °F). As a result, heat engines can be operated at the highest practical temperatures, and thus at maximum efficiencies. Dishes can be used in either thermal or electrical modes and in cogeneration applications, including a wide range of industrial applications at temperatures down to about 315 °C (600 °F).

Because dishes are modular, a single dish can be used autonomously in a remote application, or a field of dishes can be deployed with their outputs in parallel. Power can be added incrementally, as required, and individual dishes serviced without disturbing other units in the field. Modularity also offers manufacturing and installation advantages, because a large number of identical devices are dealt with.

A. COMPONENT TECHNOLOGY DEVELOPMENT

The major components of a parabolic dish module are the concentrator (including support structure and sun-tracking systems), receiver, engine, and alternator. The engine and alternator are referred to here as the power conversion subsystem. The grouping of receiver, engine, and alternator is termed the power conversion assembly (PCA). A typical dish module is shown in Figure 3-1.

1. Concentrators

The concentrator consists of a reflective paraboloidal surface, its supporting structure, and tracking provisions. The measures of performance derive from the geometric accuracy of the reflective surface, the specular reflectivity of the surface, and the sun-pointing accuracy. The concentrator of a dish is a relatively large part of the total system cost, so the development effort centers on attaining the lowest cost consistent with the desired performance (Ref. 3-1).

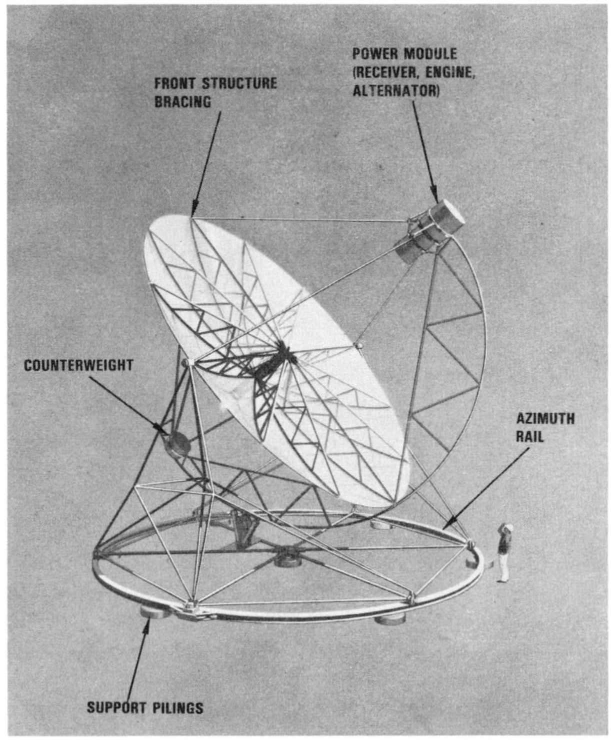

Figure 3-1. Parabolic Dish Module

Contracts for concentrator development were in effect for General Electric (GE) and Acurex during the reporting period. (The GE-designed concentrator will be constructed by Ford Aerospace Communications Corporation in FY 82.) The GE concentrator, designed to provide an output of 80 kilowatts thermal (kWt) at an insolation of 1,000 W/m^2, has the following nominal characteristics:

Diameter	12 m
Rim angle	53 degrees
Tracking accuracy	± 1/8 degrees
Reflective surface area	113 m^2 (1,216 ft^2)
Reflectivity (specular)	0.78
Concentration ratio (geometric)	1,000 (for 31-cm-diameter aperture)

The detailed design of the concentrator was completed early in FY 81. The paraboloidal dish, shown in Figure 3-1, is composed of 12 radial gores, each comprising an inner, center, and outer panel. (The outer panel is 3.05 m [10 ft] wide by 1.06 m [3-1/2 ft] deep.) A precision master mold was made for each of the three panel configurations by subcontractors. The support panels consist of a fiberglass sandwich with a balsa wood core. The reflective surface is a second surface mirror on a Llumar film. Three panels making up one gore were fabricated and shipped to JPL at the end of FY 81 for evaluation and optical testing.

Early in FY 82, panels for a complete dish module will be fabricated, including support structure and articulation subsystem. A complete concentrator with its control system will be shipped to the PDTS for performance evaluation and subsequent systems testing with PCAs attached at the focal plane.

In October 1980, work began on an Acurex contract to design an alternate point focus concentrator. In initial conceptual studies of an advanced concentrator, Acurex developed a triangular concentrator design configuration with triangular panels. The substructure panel material was changed to plastic to accommodate the sheet-molding technique used by the subcontractor, the Budd Company. Acurex selected a chemically tempered glass from Glaverbel in Germany for the second surface mirrors. It is low-iron, soda lime glass 0.7 mm (0.028 in.) thick.

Early in the contract, Acurex determined that a circular planform would be as much as 30 percent more economical in small numbers of concentrators than the original triangular shape, so this configuration (shown in Figure 3-2) was selected. For the concentrator support system, the single-pedestal design selected consists

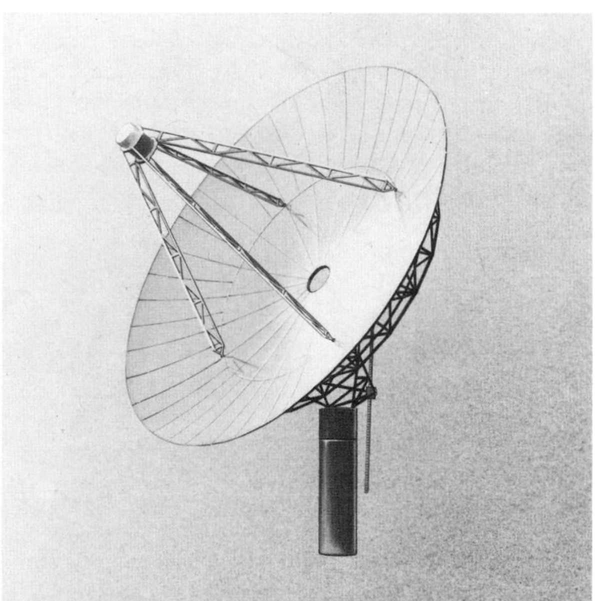

Figure 3-2. Acurex Concentrator (Artist's Rendition)

of a 43.2-cm- (17-in.) diameter pipe extending 3.2 m (10-1/2 ft) above ground and embedded in a 0.9-m- (3-ft) diameter concrete pier 5.5 m (18 ft) deep. The estimated performance for the Acurex dish is 78.6 kWt at an insolation of 1,000 W/m^2 and a 24-cm (9.4-in.) receiver aperture. Other characteristics of the Acurex concentrator are:

Diameter	11 m (36 ft)
Rim angle	45 degrees
Tracking accuracy	± 1/8 degree
Reflective surface area	95 m^2 (1,022 ft^2)
Reflectivity (specular)	0.95
Concentration ratio (geometric)	2,000 (for a 24-cm-diameter aperture).

Acurex completed the major portion of the detailed design of its concentrator near the end of FY 81. Developmental panels were fabricated in two configurations: one with a glass-reinforced plastic structure, and one with a cellular glass substrate similar to the facets on the two Test Bed Concentrators (TBCs) at the PDTS. Both had bonded second surface glass mirrors. In all, six cellular glass and one glass-reinforced plastic develomental panels were fabricated and optically tested. Initial optical tests of the glass-reinforced plastic panels indicated structural problems requiring additional development, but the cellular glass tests showed excellent optical quality.

The two TBCs have been in operational use at the PDTS since October 1979. Although they were designed as test instruments, much of the test experience applies to concentrator operation and maintenance. These two identical dish concentrators (Figure 3-3) are nominally 11 m in diameter and can

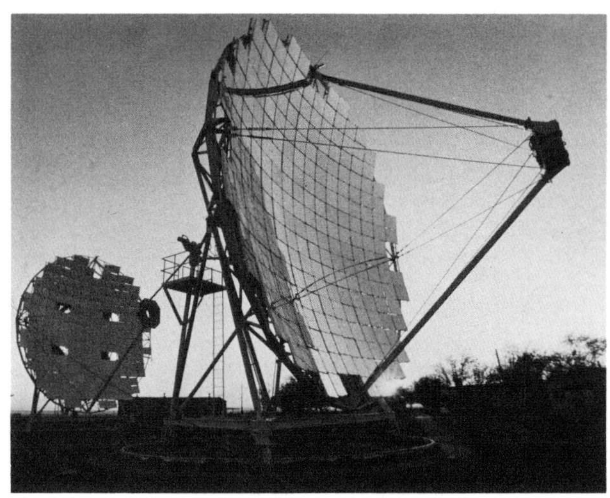

Figure 3-3. Test Bed Concentrators at Parabolic Dish Test Site

produce a maximum of 82 kWt with an insolation input of 1,000 W/m^2. The pointing error with closed-loop sun sensor tracking is less than 0.05 degrees.

There are 224 individually adjustable mirror facets on each TBC; these can be defocused as required to match the power limitations of devices being tested in its focal plane. With the mirror segments set for sharpest focus, a peak flux of 1,500 W/cm^2 is obtained through an aperture 20 cm (7.8 in.) in diameter. For most receiver testing to date, the center mirrors are defocused to reduce peak flux intensity to about 600 W/cm^2. As mentioned below, a Sanders receiver with a quartz window was tested on a TBC during FY 81 at a sustained temperature of 1,425 °C (2,600 °F).

Of the many concentrator design concepts examined, one of the more promising approaches, in terms of production economy and adequate performance, is the bonding of thin film on steel panels. This approach is being pursued by the Boeing Engineering and Construction Company in Seattle, Washington. When sample panels were tested at JPL, measured slope errors were only 1.2 mrad, an accuracy approaching the specifications of the TBC. This indicates that if high reflectivity can be coupled with long life, a concentrator of thin film on steel may be cost-effective. This design has sufficiently high potential to warrant further development.

2. Receivers

Receivers are identified with the heat engine cycle to which they provide thermal input. They can also be classified by the working fluid they use, or by whether or not they contain phase change materials for buffer storage. Cavity-type receivers under development for the organic Rankine, Brayton and Stirling cycles are discussed below. Comparative characteristics are presented in Table 3-1.

Table 3-1. Receiver Characteristics Summary

Engine Cycle	Rankine		Brayton		Stirling
Manufacturer	Ford	AiResearch	AiResearch	Sanders Assoc.	Fairchild
Working Fluid	toluene	steam	air	air	helium
Fluid Outlet Temperature, °C (°F)	400 (750)	705[a] (1,300)	815 (1,500)	1,370 (2,500)	815 (1,500)
Aperture Diameter, cm (in.)	38 (15)	22.8 (9)	25.4 (10)	19.7 (7.75)	27.9 (11)
Integral Hybrid Design	no	no	no	no	yes
Efficiency (%)[b]	70 to 90	80 to 92	70 to 80	up to 90	85 (est.)
Maximum Pressure, MPa (psi)	5.5 (790)	14 (2,000)	0.25 (38)	0.7 (100)	14 (2,000)
Material	metal	metal	metal	ceramic	metal
Buffer Storage	yes[c]	no	no	yes	no

[a]This is the capability for the receiver; a typical engine as described in Table 3-2 (Carter) would use a lower flux.

[b]Temperature-dependent.

[c]135 kg_m (300 lb_m) of copper acts as integral buffer storage.

a. Organic Rankine Receiver (Ford Aerospace & Communications Corporation). The receiver for the organic Rankine cycle (ORC) is being developed by FACC to supply toluene vapor at about 400 °C (750 °F) to the turbine of the Barber-Nichols power conversion subsystem. The receiver and power conversion unit is shown in Figure 3-4.

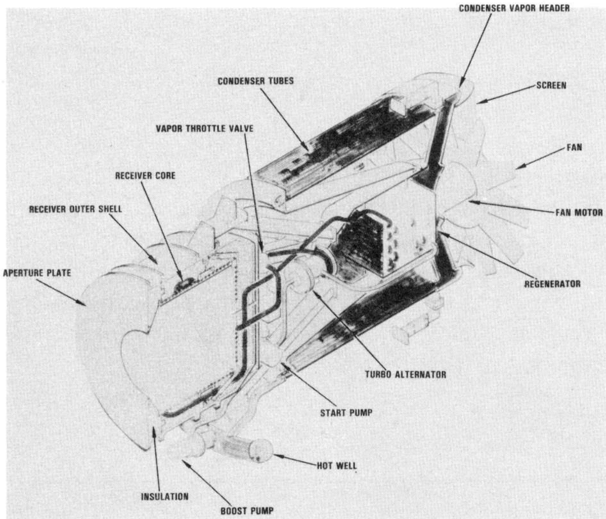

Figure 3-4. Cross Section of Power Conversion Assembly Showing Receiver, Alternator, and Organic Rankine Engine

FACC began testing the ORC receiver in February 1981, under steady-state conditions using a test loop to simulate the Rankine heat engine. Runs were made at both sub- and super-critical toluene pressures and the thermal output of the receiver was varied over a range of 25 to 100 kW during qualification testing, which was completed at FACC in June 1981 (Ref. 3-2). The engine/alternator subsystem, completed in August 1981, was tested using a fossil-fired boiler. Then it was shipped to FACC for the receiver to be attached in preparation for testing on TBC-1 at the PDTS in November 1981.

b. Steam Rankine Receiver (Garrett AiResearch). A contract for a Rankine steam cycle power converter was awarded to Garrett AiResearch for the design and fabrication of a steam receiver. The cylindrical cavity is 43.2 cm (17 in.) in diameter by 54.6 cm (21.5 in.) deep and contains a tubular helix wound with Inconel 625 tubing. The aperture plate and back closure plate are water-cooled aluminum and stainless steel, respectively. It is suitable for industrial process heat applications as well as for driving Rankine cycle heat engines. Testing, completed in March 1981 at the PDTS; demonstrated stable, uniform receiver operation over the full performance range. No flow instabilities were evident even at very low mass flow rates. The receiver is in frequent use as a steam source for making fuels and chemicals, and testing engines and components. It will be used in the future for developing receiver aperture and cavity designs and for evaluating their resistance to thermal shock.

c. Air Brayton Receiver (Garrett AiResearch). An open-cycle air Brayton engine under development has a rated turbine inlet temperature of 815 °C (1,500 °F). An all-metal receiver for the air Brayton engine, shown in Figure 3-5, was delivered to JPL in December 1980

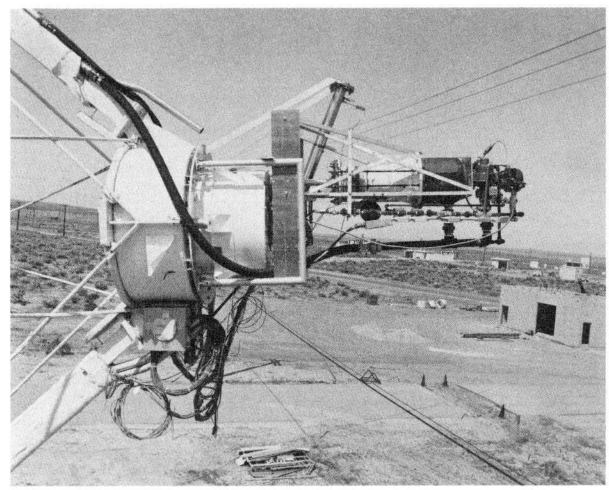

Figure 3-5. Receiver for Open-Cycle Air Brayton Engine

by the Garrett Corporation, Torrance, California. It was instrumented and installed on TBC-2 with testing completed in May 1981. The maximum operating envelope of the receiver, including temperature, pressure and flow rates, was established. All performance goals were met, but the high thermal gradients in the Inconel heat exchanger produce stresses that reduce the lifetime of the receiver to unacceptable levels. A number of solutions to this problem, which could be incorporated in any future hardware with the necessary changes, have been developed.

Garrett Corporation is also under contract to develop a preliminary design for a higher temperature receiver employing latent heat buffer storage. Performance maps for typical insolation conditions at the PDTS were produced from computer simulations. Seven design concepts were screened for performance and cost, and a ceramic slip-cast design was selected for a fabrication feasibility study, to be performed by the Norton Company. The slip-cast concept allows the heat exchanger element to serve as the pressure container for the working fluid, thus eliminating the need for a transparent window to seal the aperture.

d. Air Brayton Receiver (Sanders Associates). Sanders Associates was awarded a contract in early 1980 to design and fabricate a 1,370 °C (2,500 °F) air Brayton receiver using a ceramic honeycomb designed for a pressure of 2 atm. The receiver, shown in Figure 3-6, uses a sintered beta silicon carbide honeycomb matrix as the heat exchanger and mullite to provide buffer storage. Because the receiver cavity is pressurized, the aperture is sealed by a quartz window. Fabrication was completed in September 1980 and Sanders conducted in-house testing.

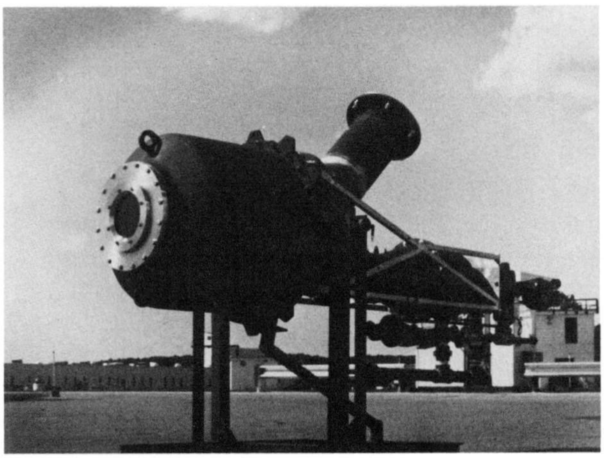

Figure 3-6. Hybrid Air Brayton Receiver

The receiver was then shipped to the PDTS for a series of pre-solar performance tests and interface compatibility tests. The first phase of the Sanders receiver testing at the PDTS indicated air exit temperatures ranging from 870° to 1,425 °C (1,600° to 2,600 °F). Preliminary estimates of efficiency are 60% at 1,200 °C (2,200 °F) ranging up to 90% at 870 °C (1,600 °F) when aperture solar beam spillage losses are accounted for. These tests demonstrated the feasibility of this high temperature receiver concept for exit air temperatures exceeding the existing state-of-the-art of metal designs. The temperatures exceed those required to power the ceramic advanced gas turbine (AGT) engine currently being developed, and will support the solarized version of the AGT, now under development by NASA.

e. Stirling Cycle Receivers (General Electric and Fairchild Stratos). Receivers for Stirling cycle engines differ from those previously described because close conductive coupling is required. These receivers were studied by General Electric (GE) and Fairchild-Stratos. The GE hybrid receiver concept uses heat pipes to conduct the energy to the engine heater head through encapsulated salts which provide buffer storage. The fabrication of a test unit was cancelled, however, due to funding reallocations by DOE.

The Fairchild receiver contract, awarded in 1979, was for design, development and fabrication of a metal receiver for the United Stirling (Sweden) engine. Its hybrid capability allows thermal augmentation by a gaseous fossil fuel, providing continuous power and eliminating the need for energy storage. The heater head and preheaters were fabricated from copper and Inconel by Solar Turbines International (STI). The receiver was shipped to JPL in December 1980 for combustor and preheater tests in preparation for a fully integrated test of the power conversion assembly in Sweden.

In June 1981, the receiver was shipped to United Stirling where the heater heads leaked when tested under pressure. The receiver, power converter, and control system were shipped from Sweden to the PDTS in July 1981; prior to delivery to the PDTS, the heater heads were repaired at STI. After undergoing a series of initial tests in the fossil-fired combustor mode at the PDTS in August, the complete PCA was mounted on the TBC for solar-driven testing in September 1981.

3. Engines and Power Converters

Brayton, Rankine and Stirling cycle heat engines were investigated for use with dish systems. Two versions of the Rankine cycle, one using steam as the working fluid and one using toluene, were previously studied under this program. The principal characteristics of these engines at this stage of their adaptation for dish use are presented in Table 3-2.

a. Organic Rankine Cycle. Organic Rankine cycle (ORC) technology is well understood and considered to be low-risk. In December 1979, Ford Aerospace and Communications Corporation (FACC) received a contract to develop the ORC receiver and to serve as integrating contractor for the power conversion assembly (PCA). FACC subcontracted with Barber-Nichols for the engine and Barber-Nichols subcontracted with Simmonds Precision for the permanent magnet alternator.

The PCA, consisting of receiver, engine, and alternator, is illustrated in Figure 3-7. In ORC operation, toluene working fluid flows in a closed loop and is expanded through a single-stage axial flow turbine. The exhaust vapor then passes through a regenerator (heat exchanger) to preheat the toluene entering the receiver. From the regenerator, the exhaust vapor flows through a forced air-cooled condenser, constituting the outer annulus of the converter, and then to the pump.

Table 3-2. Heat Engine Characteristics Summary

Engine Type	Steam	Organic Rankine	Air Brayton	Stirling
Manufacturer	Carter	Barber-Nichols	Garrett	United Stirling
Source Temperature °C (°F)	510 (950)	400 (750)	815 (1,500)	650-820 (1,200-1,500)
Sink Temperature °C (°F)	100 (210)	45 (115)(1)	25 (80)(2)	50 (125)(3)
Pressure (max) MPa (psig)	17 (2500)	—	0.2 (31.8)	 (2,200)
Engine Efficiency, %	≥20	26	32	38
Efficiency Speed, rpm	1,800	60,000	80 to 86,000	1,800
Power Conversion Assembly Output, kW	7	18(4)	24(5)	25(5)
Mass Flow, kg/hr (lb/hr)	27 (60)	430 (945)	930 (2,050)	NA
Engine Operating Time Between Overhauls, hr	NA	7,500	TBS	7,000 (Minor) 50,000 (Major)(6)
Working Fluid	water	toluene	air	helium
Engine Weight, kg (lb)	295 (650)	335 (740)	190 (420)	205(7) (450)

Notes: (1) Condenser exit.
(2) Ambient.
(3) Heat exchanger inlet.
(4) With 94.5% efficient alternator.
(5) With 94% efficient alternator.
(6) Assumes a metal heater head. A ceramic head would prolong the interval.
(7) Engine only.

A high-speed permanent magnet alternator is integral with the engine. The output is rectified for transmission to a central collection station.

Receiver qualification tests were completed in June 1981 at FACC. Barber-Nichols shipped the engine and generator set to FACC where the PCA, with control system, was assembled and will be tested in late October in preparation for shipment to the PDTS in November 1981. After the PCA is installed on a TBC, system level tests will be conducted. The tests will determine operating characteristics of the PCA, including performance, stability, and efficiency in all operating modes, and verify the mutual compatibility of the constituent subsystems.

b. Air Brayton Power Converter. A power converter for parabolic dishes is being developed by Garrett AiResearch, Phoenix, Arizona, based on their automotive advanced gas turbine (AGT-101) work. The solarized AGT-101 (SAGT), shown in Figure 3-8, is an open-cycle machine with a 815°C (1,500°F) turbine inlet temperature. The solar input to a typical receiver is

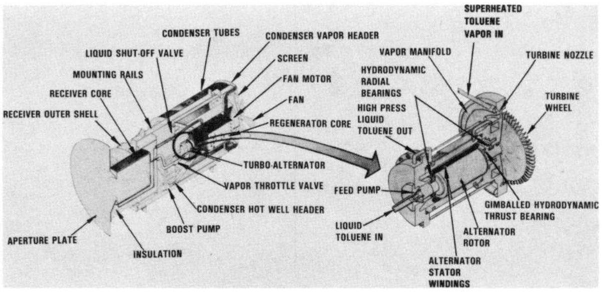

Figure 3-7. Organic Rankine Cycle Power Conversion Assembly

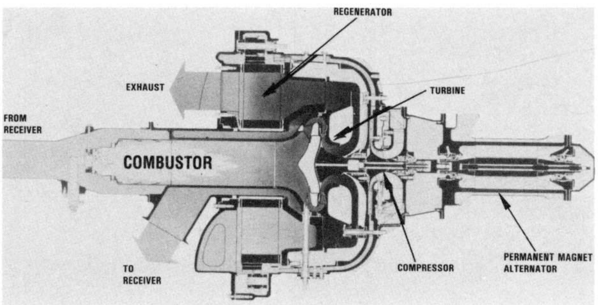

Figure 3-8. Solarized Automotive Gas Turbine

85 kW for an insolation of 1,000 W/m^2. The air entering the receiver from the recuperator is at a temperature of 565 °C (1,050 °F) at a pressure of 0.25 MPa (37 psia). The flow rate is 930 kg/hr (2,050 lb/hr). At these conditions the turbine inlet temperature is 815 °C (1,500 °F) and the mechanical shaft output power is 24 kW at an efficiency of about 32%. Advanced versions incorporating ceramic parts should be capable of turbine inlet temperatures up to 1,370 °C (2,500 °F) for which the shaft power would be 71 kW at an efficiency of 48%.

The schedule for the air Brayton effort calls for testing the initial SAGT engine in November 1981, followed 8 months later by the delivery of the engine, gear box, and alternator assembly to the PDTS. Either the Garrett or Sanders receiver will be used.

c. Dish Stirling Engine. Like the air Brayton engine, the dish Stirling engine is being developed as a "solarized" version of an automotive Stirling engine. (The integration of the PCA and the TBC form a Stirling dish module.) The solarized engine (shown in Figure 3-9) is referred to as the United Stirling 4-95 engine. In December 1980, it was modified to accommodate the changing attitudes of the engine relative to the ground as the dish tracks the sun, and it was tested for operation in an inverted position. The four-cylinder kinematic engine was tested at 1,500 rpm, with a heater head temperature of 710 °C (1,310 °F), a coolant temperature of 50 °C (120 °F), producing a shaft power

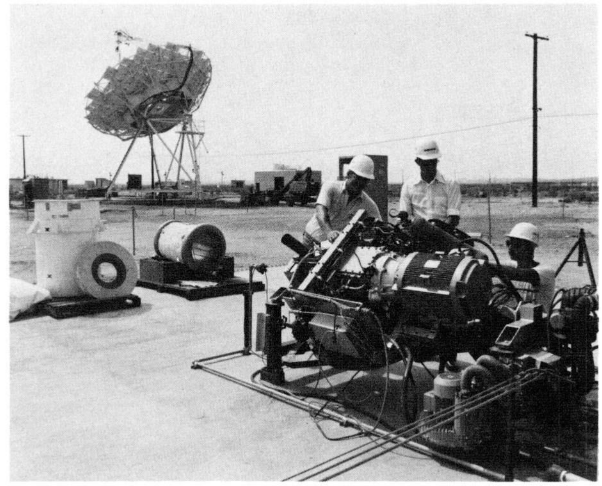

Figure 3-9. Solarized Dish Stirling Engine at Parabolic Dish Test Site

of 18 kW with a corresponding thermal-to-mechanical net engine efficiency of 35% at a mean helium pressure of 11 MPa (110 atm). At 15 MPa (150 atm), a shaft power of 24 kW was developed with an efficiency of 38 %. A total of 300 hours of operation have been accumulated on this engine. The engine was delivered to the PDTS in July 1981 and mated to the Fairchild receiver.

During the first half of 1981, United Stirling took delivery of the Fairchild receiver, the receiver body combination pre-heater and aperture plate built by STI, and the control console and GE utility interface unit. By April 1981, United Stirling had completed all test operations on the power converter using the combustor to power the engine. The engine is illustrated in Figure 3-10. In July, 1981, the converter assembly had arrived at the PDTS and was assembled and checked out. The power unit will be mounted on the TBC and all water, natural gas, electrical controls and instrumentation will be connected beginning in early October, with functional and performance tests to follow.

4. Thermal Transport

Cost-effective thermal transport for parabolic dishes was examined for applications using industrial process heat (IPH). The two major areas of concern are the match between dish characteristics and IPH applications, and the thermal piping networks and methods which will minimize installed costs.

Application studies were conducted by Science Application, Inc. (SAI) and FACC under contract to JPL (Ref. 3-3 and 3-4). These studies examined the integration of solar process steam units into four industries: (1) an ore processing plant for U.S. Borax;

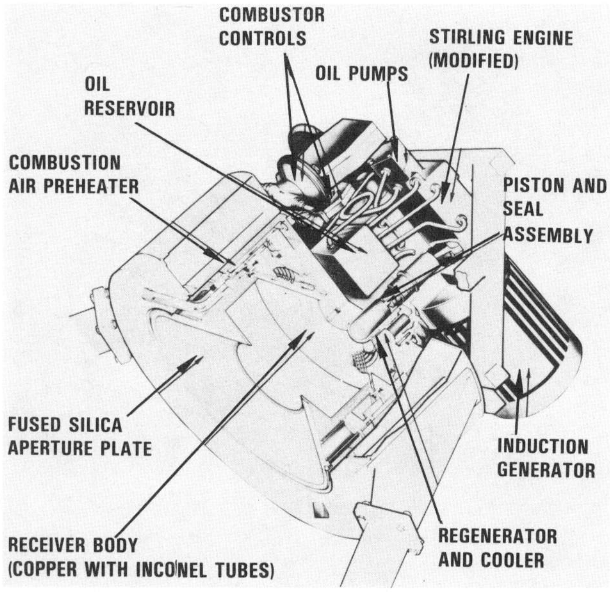

Figure 3-10. United Stirling Engine/Receiver Unit

(2) oil pumping for low production stripper wells; (3) farm production of furfural from agricultural wastes; and (4) drying of gypsum wallboard. Elements such as available space, the processes involved and user economics were considered.

A computer optimization code was developed to evaluate thermal piping networks and methods, and to determine the most cost-effective thermal transport layout. The code incorporates data on collector spacing, operating temperatures, heat losses, fabrication techniques, pumping losses, and costs. Evaluating thermal transport subsystem costs for 510°C (950°F) steam, the subsystem cost was $\$27/m^2$ of collector area plus $\$7/m^2$ for the factory-fabricated riser and down comer.

5. Storage

Thermal storage for solar thermal systems is most cost-effective when its application is limited to buffer storage (short-term storage on the order of an hour or less) as required to maintain power output during intermittent cloud passage. Buffer storage for dish systems can be incorporated effectively in the receiver, as shown by studies conducted by both GE and FACC.

In the GE heat pipe receiver for powering a Stirling engine, shown in Figure 3-11, sodium conveys heat to a phase-change storage section containing salts that surround the heat pipes. The receiver incorporates a hybrid feature that permits the use of gaseous fuel when insolation is unavailable for longer periods than can be accommodated by the buffer storage.

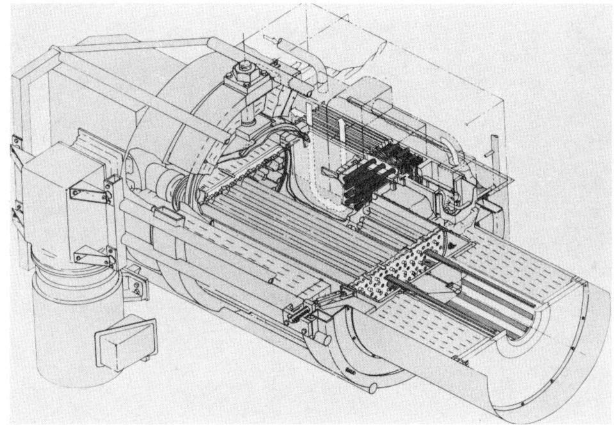
Figure 3-11. GE Heat Pipe Receiver for a Stirling Engine

B. SYSTEMS EXPERIMENTS AND ANALYSES

1. Solar Total Energy Project, Shenandoah, Georgia

The Solar Total Energy Project (STEP) at Shenandoah, Georgia, will use parabolic dishes to generate both electricity and process steam for a knitwear factory, including plant space heating and chilled water for air conditioning. The energy will be supplied to the Georgia power utility grid and to a nearby knitwear factory of Bleyle of America, Inc. The objectives of this project are: (1) to assess the interactions of solar total energy technology in an industrial application with an electric utility interface; (2) to acquire data to compare with cost and performance predictions; (3) to promote engineering and development experience within industry with complete solar total energy systems; and (4) to ensure that technical data are disseminated. The project encompasses design, construction, operation and technical and economic evaluation of the solar total energy system providing power to the knitwear factory. This project is a major element in the solar thermal program; it will provide data to support the development of point-focus, distributed collector technology and is a major milestone in solar cogeneration technology.

The system uses 114 parabolic dish collectors, 7 m (23 ft) in diameter, with a silicone base heat transfer fluid circulating through the receiver tubes. Solar radiation is focused on the receivers by the collectors and heats the transfer fluid to 400° C (750° F). A steam turbine provides 400 kW of electrical energy, and steam is cascaded from the turbine at 117°C (350°F) for knitwear processing. The exhaust steam at 100°C (230° F) is used to provide thermal energy for space heating and chilled water for air conditioning.

Construction was started in January 1981, and was essentially complete by fall 1981. Full operational status is expected by spring 1982.

Figure 3-12 shows an overall view of the project in August 1981. The construction of the collector field is nearly complete. Collector assembly is proceeding from east to west. A collector is shown in stowed position in Figure 3-13 with protective film covering the reflective surface. Major tanks and equipment are shown emplaced in Figure 3-14, including the thermal energy storage tank and the roof-mounted steam condenser. Figure 3-15 shows the turbine generator, which was shipped to the site in September 1981.

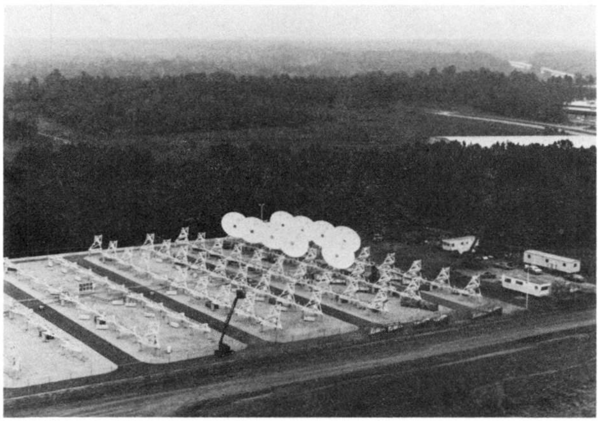

Figure 3-12. Shenandoah Collector Field, August 1981

Performance testing of the production version of the Shenandoah collector was completed in July 1981. Measured thermal efficiency over the day (energy collected in fluid, divided by energy over collector surface) was 60%. The production collector displaced one of four Shenandoah prototype collectors at Sandia National Laboratories for testing. This small sample of the Shenandoah collector field also provided performance data on the heat transfer fluid and verification data of the collector control system. Following successful completion of the performance tests, approval was given in June 1981, for full production and assembly.

2. Small Community System/Module Development

The objective of the Small Community Experiment is to utilize proven dish modules in a user environment to generate 250 kWe of grid-connected electric power. The systems contractor for this experiment is FACC, with JPL serving as technical manager. For the Small Community Experiment, an organic Rankine power converter was chosen over the potentially more efficient

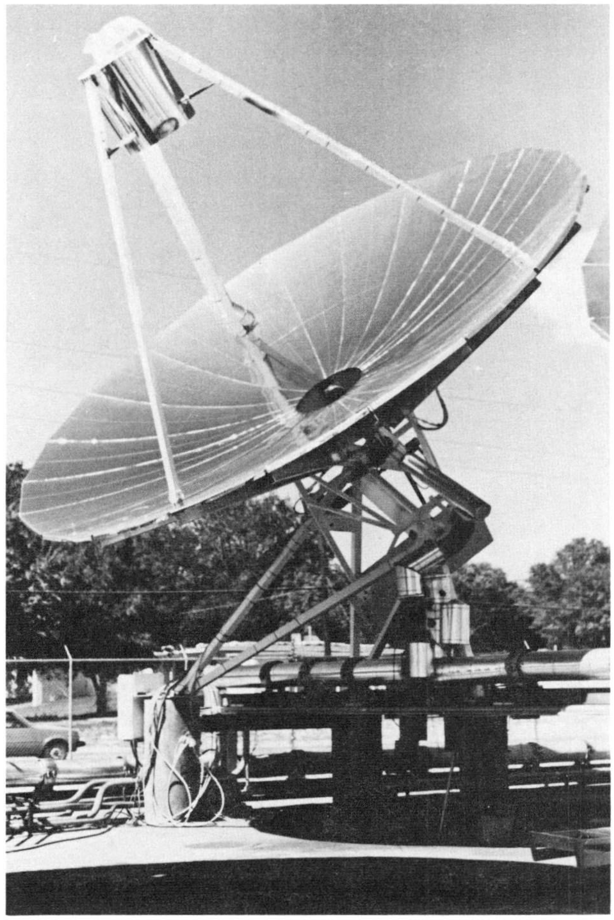

Figure 3-13. Shenandoah Collector Module, August 1981

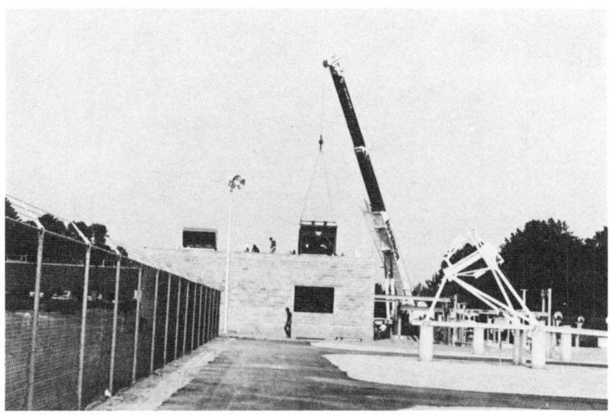

Figure 3-14. Shenandoah Building and Mechanical Area, August 1981

Brayton or Stirling cycles because it will be technologically ready before the other two (Ref. 3-5).

U.S. communities interested in solar thermal power were identified through the issuance of a DOE Program Research and Development Announcement

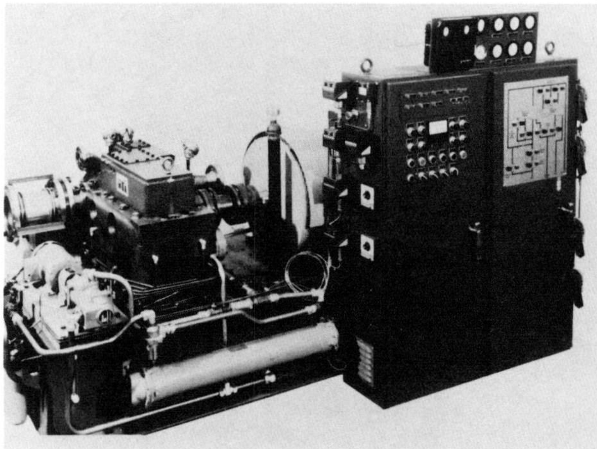

Figure 3-15. Shenandoah Turbine Generator

(PRDA). This solicitation was aimed at small communities having a peak electric load of less than 20 megawatts and served by a distribution network owned and operated by the local utility. Communities with larger utilities were acceptable if they were remotely located or could demonstrate a need for an alternate energy source based on economic considerations. The response pattern is shown in Figure 3-16; the communities preferred, based on engineering considerations only, are starred. Final site selection will be made in early FY 82.

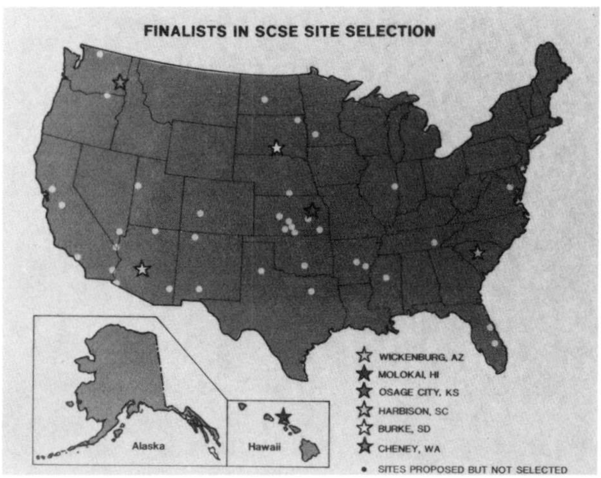

Figure 3-16. Small Community System Experiment Response Map

3. Field Test at Capitol Concrete Products Company

In December 1980, Applied Concepts Corporation was selected through a JPL procurement for a field test at Capitol Concrete Products Company in Topeka, Kansas. Applied Concepts Corporation will provide the site, user, system and all equipment and services necessary to design, fabricate, install, operate, maintain, and evaluate for 12 months an experimental solar plant in a typical industrial environment. The selected test involves operating a slat-type point-focus collector, manufactured by Power Kinetics, Inc. (PKI) in a fuel displacement mode.

The PKI collector is shown in Figure 3-17 undergoing verification testing at Sandia National Laboratories,

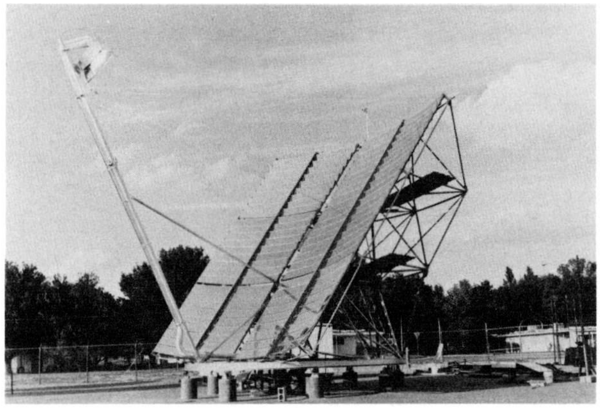

Figure 3-17. Power Kinetics, Inc. Collector

Albuquerque. The concentrator has a reflective surface area of 80.3 m^2. The curved slats are attached to the support structure via pivot points at their ends and are rotated about their center of mass for elevation tracking. The structure is attached to a circular track which rotates on pier-mounted casters for tracking in azimuth. The receiver consists of an insulated stainless steel housing with enclosed straight-tube boiler. The large aperture, used to increase interceptance of reflected light, is surrounded by a metal skirt to prevent excessive thermal losses due to convection.

Verification testing of the PKI collector at Sandia Laboratories began in September 1981. Preliminary test results indicate that collector peak efficiency (insolation converted to a net increase in the thermal energy of the working fluid) is about 80%, measured at an insolation level of 0.98 kW/m^2 and a steam receiver exit temperature of 149 °C (300 °F). At these conditions, the collector produces about 60 kW of thermal energy. Collector operations at Capitol Concrete are expected to begin in November 1981. The experimental plant will provide 77 kg/hr (170 lb/hr) of 149 °C process steam at 207 to 414 kPag (30 to 60 psig) to two autoclaves for curing masonry blocks. A final report to be submitted by the Applied Concepts Corporation in February 1983 will summarize technical performance and operational feasibility based on operational experience at both the industrial and the test sites.

C. PARABOLIC DISH TEST SITE SUPPORT TO DISH DEVELOPMENT

The activities at the Parabolic Dish Test Site (PDTS) at Edwards Air Force Base, California, have been implied earlier in much of the text devoted to receiver and power converter development. However, it is appropriate to summarize here the salient activities at the PDTS that have supported the development of parabolic dish modules:

(1) Tested the Sanders Associates high temperature solar receiver to exit air temperatures up to 1,425 °C (2,600 °F).

(2) Completed tests of the Garrett AiResearch air Brayton receiver at air exit temperatures up to 815 °C (1,500 °F).

(3) Tested the Garrett AiResearch steam receiver at 704 °C (1,300 °F) and 14 MPa (2,000 psi) with stable operation verified. Completed testing of the J. Carter Enterprises 1- and 2-cylinder steam engines using steam from the Garrett steam receiver mounted on TBC-1.

(4) Utilized TBC-1 and the Garrett steam receiver in the experimental production of furfural from corn cobs.

(5) Tested the receiver/combustor for the Stirling engine in preparation for fully integrated tests of the Stirling PCA. Refocused the TBC-1 mirrors to meet power requirements of the upcoming test.

(6) Conducted calibration tests and mirror alignments for each TBC as required to characterize these test concentrators and to satisfy the required power levels of a particular experiment or test usage. A cavity calorimeter and a flux mapper were used.

(7) Completed flux mapping of the Omnium-G concentrator. Tested the Omnium-G steam engine using TBC-1. Mounted and aligned new concentrator petals.

(8) Completed test verification of the Omnium-G system for the Southern New England Telephone Company application.

SECTION IV

PARABOLIC TROUGH TECHNOLOGY

A parabolic trough system comprises a field of trough-shaped collectors, lined with highly reflective material such as mirrored glass, that concentrate the sun's rays along a linear absorber tube situated at the focal point of the trough, thus heating the fluid contained in the tube. Collector efficiency is increased by designing the trough to track the daily movement of the sun. Parabolic troughs are referred to as distributed receiver systems because a heat receiver is coupled with each collector, creating a distribution of receivers throughout a field of collectors. Figure 4-1 shows a schematic of a typical parabolic trough system.

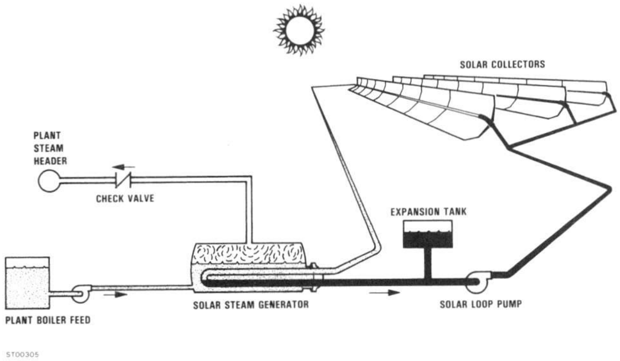

Figure 4-1. Schematic of Typical Parabolic Trough

These systems offer a key advantage: modularity. The minimum useful unit is a ΔT string (also called a collector loop), which is the number of collector modules needed to give the required temperature rise between the inlet and outlet manifolds in the field. Generally, systems are composed of several ΔT strings with motors. The size of the field is given in terms of the total square meters (or ft^2) of collector surface in all the troughs.

This chapter discusses parabolic trough technology developments for FY 81. Work continued on improving the thermal performance, durability and reliability of components; developing mass-producible modular subsystems and modular components; and testing of an engineering prototype thermocline storage subsystem. Several systems providing industrial process heat were brought on-line; overseas, a distributed receiver system, employing two types of parabolic troughs, began generating electricity for the grid in Almeria, Spain.

Performance and operation data from these currently operating plants will provide a technology and experience base from which a viable private industry can grow.

A. COMPONENT TECHNOLOGY DEVELOPMENT

The aim of this program element is to develop components and subsystems for midtemperature line-focus solar collection and conversion technologies. The objectives are to bring the applicable technologies to a final state of development and to determine the performance, durability, and operation and maintenance characteristics of components and subsystems. Specific summaries of FY 81 activities and FY 82 plans are presented for the Line-Focus Program Research and Development Announcement (PRDA), the performance prototype trough, and thermocline storage.

1. Line-Focus Program Research and Development Announcement for Parabolic Troughs

Final development efforts for trough collectors and components will concentrate on improving thermal performance, achieving greater durability and reliability, and developing mass-producible modular units that can be installed with a minimum of outside labor and materials. Therefore, a PRDA was sent out in 1980 to accelerate the development of mass-producible collectors by manufacturers of existing trough collector systems, and to give collector component manufacturers the opportunity to develop an improved product that can be mass-produced. The 1985 goals for these systems are as follows:

Peak thermal performance:
71% efficiency at 205 °C (400 °F);
65% efficiency at 315 °C (600 °F).

Cost before installation:
$100/m^2 ($10/ft^2) in 1980 dollars at 500,000 m^2 (5,000,000 ft^2)/yr.

Lifetime: 10 to 20 yr.

Cost-sharing contracts were awarded in early FY 81 to Acurex Corporation for collector development, tracker development, and control system development; to Solar Kinetics and Suntec Systems for collector development; and to Winsmith for speed reducer development.

a. Collector Development. The Acurex prototype drive string (36.5 m/120 ft) is to be constructed by November 1981, and tested by SNLA at the Acurex plant by December 1981. The Solar Kinetics drive string (36.5 m/120 ft) is scheduled to be completed in December 1981, and should be tested by SNLA at the Solar Kinetics plant by January 1982. The 18.3-m (60-ft) Suntec prototype drive string is scheduled to be completed by February 1982, and tested by SNLA at the Suntec plant by April 1982.

b. Acurex Tracker and Control System Development. This program, which integrates the collector tracking and control functions into a single mass-producible package, is in the final development prototype stage. Significant design improvements include: (1) fail-safe logic requiring only auto-track, hold, or stow commands, (2) tracking light sensor on a single mass-produced chip, (3) control interface for either a conventional multiwire system or a serial data system using telephone tone technology/hardware, and (4) elimination of the collector slew/search for sun acquisition (or aimless wandering associated with shadow band trackers) in favor of a system using a single solar tracking angle reference (STAR); the STAR systems sense course, sun position and insolation level to direct the "tracker controller," which then tracks for the entire field using the high resolution light band sensor. Prototypes of the hardware were completed in FY 81.

c. Winsmith Speed Reducer Development. Winsmith will design and fabricate a gearbox for parabolic trough collectors. During FY 81, Winsmith performed cost/performance trade-off studies and completed preliminary design of two-stage gearboxes for collector drive string lengths of 24.4 m (80 ft) and 36.5 m (120 ft). The gearboxes use a planetary first stage for high efficiency and a worm second stage to provide lock-up. Prototype fabrication, testing and evaluation will occur in early FY 82.

2. Performance Prototype Trough

The Performance Prototype Trough development began in 1979 to apply information gained from the development of first-generation parabolic trough collectors. The goals were to improve peak performance to 60% (from the 40% to 50% achieved by first-generation troughs) and to improve durability and component life from less than 3 to 20 years. First-generation designs did not lend themselves to mass production, a feature necessary for achieving low cost, so the new effort emphasized designs that use mass production materials and processes.

In 1980, an Engineering Prototype Trough which achieved 60% peak efficiency was developed. At the same time, different manufacturing concepts to adapt trough design to mass production processes were being investigated. Controls, drives, pylons, foundations, plating and four different structural designs were obtained from industry. Prototypes of the designs were fabricated from soft tooling and were tested. The final step in the Performance Prototype Trough Project is the assembly during FY 82 of the four designs into 24-m (80-ft) drive strings, then integrating them in a ΔT string with a tracking and control system, and performing system tests. Such a process will provide reliable performance, operation, maintenance, and cost data.

Work performed on this project during FY 81 is summarized in the following sections.

a. Sheet Metal Reflector Structure. Solar collector reflector structures were fabricated with stamped sheet metal panels, establishing that high performance reflector panels can be obtained with this type of mass-production technology. During FY 81, The Budd Co. produced prototype units (Figure 4-2) and evaluated them through accelerated environmental testing, structural deformation load testing, and optical inspection with a laser ray trace system. Contour accuracy of individual 1- by 2-m panels was well within specified tolerances. The Budd Co. has now produced several 2- by 6-m collector assemblies, which consist of six reflector panels mounted on a 6-m torque tube structural frame. This torque tube frame is also used for the sheet molding compound and laminated glass structures discussed below.

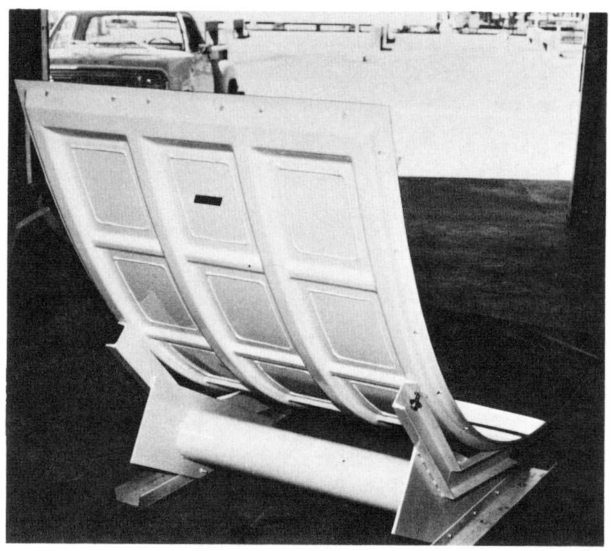

Figure 4-2. Sheet Metal Reflector Structure Prototype

b. <u>Sheet Molding Compound Reflector Structure.</u> Mass-production automotive molding technology was used to fabricate solar collector reflector structures, demonstrating that highly reflective mirrors of chemically strengthened glass can be molded into sheet molding compound structures. Materials and coatings required for successful integral molding were developed. Prototype units (Figure 4-3) produced by The Budd Co. were evaluated, including accelerated environmental testing and optical inspection with a laser ray trace system. Test results were satisfactory, and four 2- by 6-m collector assemblies were fabricated and installed for performance and system testing.

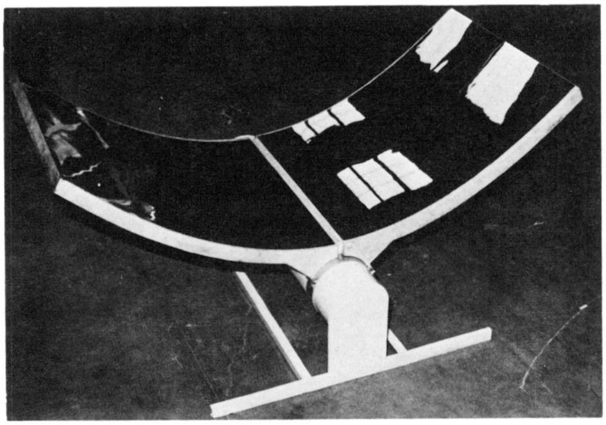

Figure 4-3. Sheet Molding Compound

c. <u>Glass/Space Frame Reflector Structure.</u> When glass with low absorptivity is used, a single sheet of glass can meet both structural and optical requirements, reducing cost compared to laminated glass designs. Schott America fabricated glass mirrors that meet the reflectivity requirements and are near the accuracy goals. The Budd Co. fabricated the space frame and assembled the trough. Individual 1- by 2-m reflector modules were made by bonding two stamped sheet metal ribs to two sagged glass mirrors, and the parts were bonded with a fast-curing polyurethane adhesive. A full 2- by 6-m trough was then assembled by bolting six reflector modules to the torque tube.

d. <u>Sandwich Reflector Structure.</u> During FY 81, sandwich modules fabricated earlier by Hexcel have remained exposed in the field. After 2 years, the epoxy-bonded, chemically strengthened mirrors remain unbroken: the epoxy is sound and only one small silver delamination zone has appeared in 40 panes.

Parsons of California is investigating the fabrication of 2- by 6-m, adhesively bonded, steel-skinned/aluminum honeycomb sandwich reflector modules (Figure 4-4). To be cost-effective, this lightweight structure requires simple four-point attachment to a torque tube and high density shipping capability. The effort to laminate glass mirrors with aluminized steel-face skins in the flat was unsuccessful. The temperature-cured epoxy adhesives were selected to obtain long field life while the laminate was formed to the parabola; the laminate was too stiff for layup in vacuum bagging. Instead, a one-shot assembly of mirrors, skins, honeycomb, and edge closure, using MA229 sheet epoxy throughout, has been successful in 2- by 2-m trial segments. Contour accuracy and resultant slope error goals appear to be achievable based on results obtained for these initial segments. This technique, now being used for full 2- by 6-m modules, provides the basis for practical volume production.

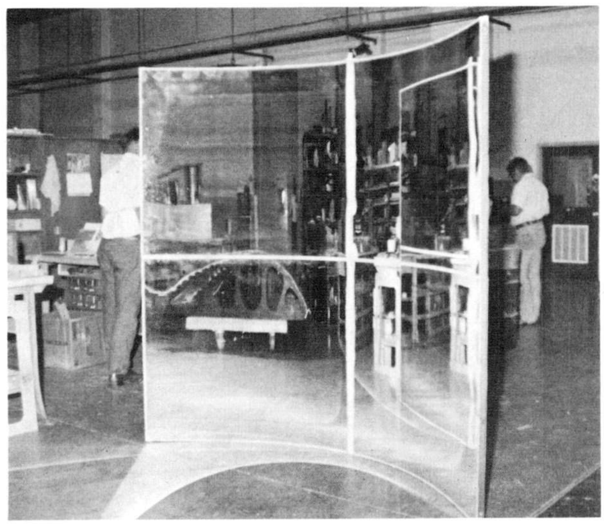

Figure 4-4. Sandwich Reflector Structure Prototype

e. <u>Wind Load Definitions.</u> Two new wind tunnel test series were conducted at LTV Co. and Colorado State University to confirm pitching moment characteristics for parabolic trough collectors (Figure 4-5). These data validate the influence of upstream

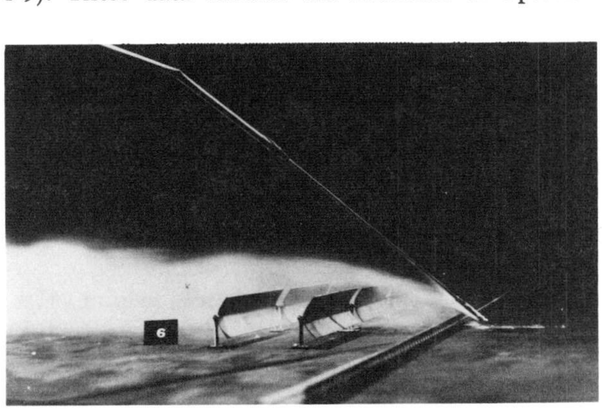

Figure 4-5. Scale-Model Parabolic Trough Array in the Wind Tunnel

interference from other collector rows and wind screen fences, and provide load definition for collector drive systems. An instrumented collector module was installed in the array at the Coolidge irrigation site to provide full-scale surface pressure distribution data. Data on drive string torque loads also are being acquired.

f. **Foundations.** Foundation designs for both drive and non-drive collector support pylons were prepared for the Performance Prototype Trough. These designs were based upon the poured-in-place reinforced concrete pier concept. Full-scale load tests (Figure 4-6) conducted by Applied Research Associates validated the theory used in preparing these designs.

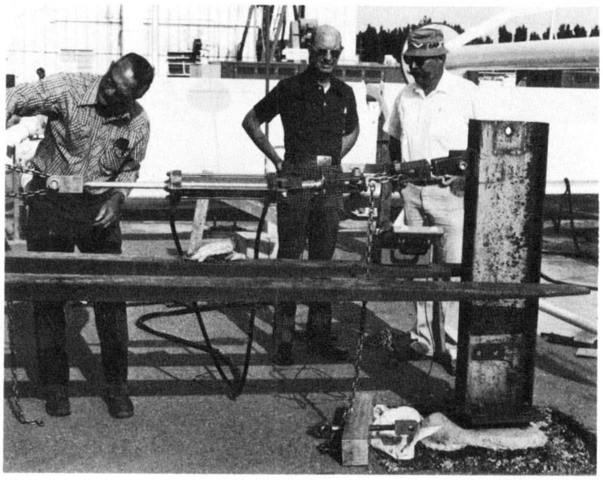

Figure 4-6. Parabolic Trough Foundations Undergoing Structural Load Tests

g. **Pylons.** The tracking support structure for multiple reflectors and their common drive requires foundations, pylons, and bearing support mechanisms. To reduce the cost of these components for mass production, design goals are to reduce the amount of materials used and devise lower-cost designs. The pylons (Figure 4-7) are being sized to match the structural load requirements of the particular string location. Reducing the along-the-row rigidity to minimal needs allows shorter trough gaps for reduced thermal loss and allows thermal expansion, away from the center drive, to be handled by pylon flexure. Pylons are being fabricated of high-strength, low-allow steels with weathering properties to eliminate the finishing for corrosion protection that low-carbon steels require. Hot-rolled beams of high-strength, low-alloy (HSLA) material are expected to be procurable in mill-run quantities for mass production of collectors. Bloomer-Fiske, Inc. of Chicago, has been the source of weldment prototypes in the HSLA material.

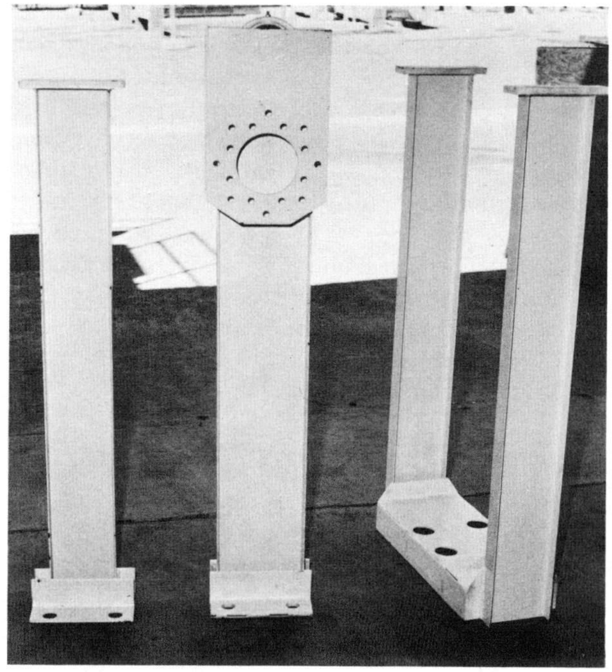

Figure 4-7. Collector Pylon Prototypes

h. **Receiver Development.** A 3-m (10-ft) modular receiver design (Figure 4-8) with a 3.17-cm (1.25-in.) outer diameter has been evaluated. This design will include press-fit dust shield collars and an anti-reflection surface glass jacket.

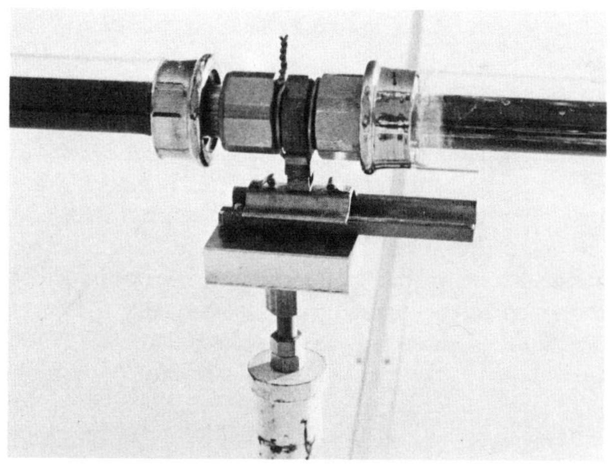

Figure 4-8. Receiver Prototype

A fluorocarbon elastometer (Viton, V-747) dust seal was exposed to an accelerated temperature and thermal expansion friction test to evaluate its survival potential. The conclusion is that the elastometer will survive at least 20 years of solar operation when properly isolated from concentrated sunlight. The expected thermooptical improvements should result in at least a 60% peak efficiency at 315°C (600°F) output.

i. Black Chrome Selective Coating Development. An understanding of how various plating parameters affect the thermal stability of electrodeposited black chrome coatings resulted from detailed laboratory experiments. This work has resulted in a Sandia Process Specification, "Electroplating Mild Steel Receivers for Concentrating Solar Collectors" (Ref. 4-1).

Highland Plating, a commercial plating facility, received a contract to demonstrate this process with full-scale parts. Three lots of 70 receiver tubes each were successfully plated by July 1981. The thermal stability of the tubes was comparable to that of the best coatings obtained in the laboratory.

An accelerated aging test was also developed. This test monitors the change in solar absorptance after heating at 450°C (840°F) in air for 8 hours. It is used to ensure that the black chrome coating will survive years of operation at the collector operating temperature of 300°C (570°F).

j. Anti-Reflection Surfaces. The receiver design includes a 3.05-m (10-ft) Pyrex glass jacket with anti-reflection surfaces and fusion joints only at the ends. The useful transmission of the glass, scattered within a 55-degree included angle, is 0.97 when properly treated. Because the collector efficiency increases directly with the transmission, a six-point efficiency enhancement is projected because of these surfaces.

The process requires the glass tubing to be phase-separated for 6 hours at 615 °C (1140 °F) while packed in alumina microspheres, pre-etched in dilute ammonium bifluoride for 15 min, and then etched in a mixture of hydrofluorosilicic and ammonium bifluoride acid for 8 min at 40 °C (140 °F).

k. Insulated Metal Hoses. Insulated metal hose assemblies were obtained from Anaconda Hose Co. and Hydroflex. Accelerated testing under actual use conditions (Figure 4-9) demonstrated an expected lifetime of over 20 years. The preferred, most cost-effective deployment, one which does not require the receiver to rotate about its own axis, was used. A superior insulation material for this use was identified from among several candidates. Tests also confirmed that the minimum bending radius of the assembly must be maintained at a margin considerably above the manufacturer's recommended minimum bend radius for the fluid-carrying inner hose. Assemblies with a bend radius only a slight margin above manufacturer's recommendations consistently failed to achieve the desired 20-yr life.

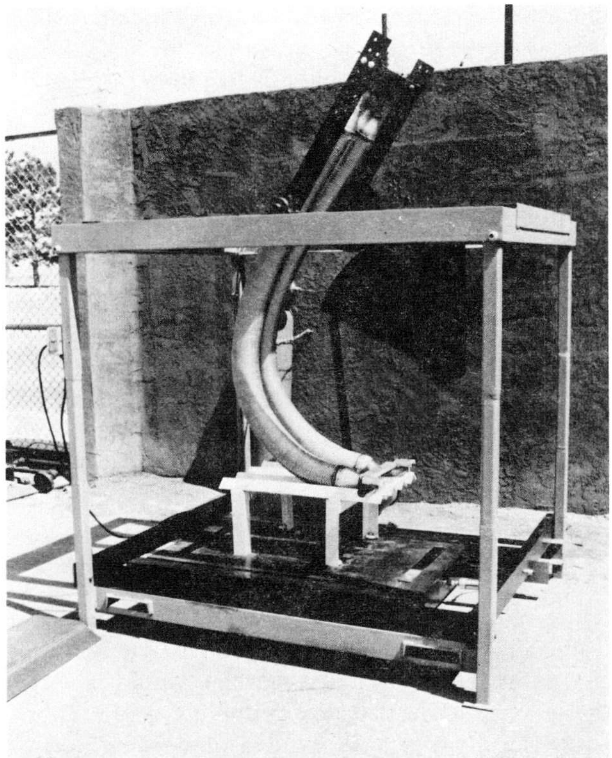

Figure 4-9. Insulated Metal Hoses on Test Stand

l. Drives. The driver for trough collectors (Figure 4-10) is the mechanism that rotates a string of collectors to track the sun, and stows the collectors in a particular orientation.

During FY 81, drive units furnished by various suppliers, including Cleveland Gear, Winsmith, Cone Drive, and Morse, were studied and the following findings noted: (1) Speed reducer units compact enough to fit in tight space restraints, yet strong enough to meet performance and environmental requirements, can be

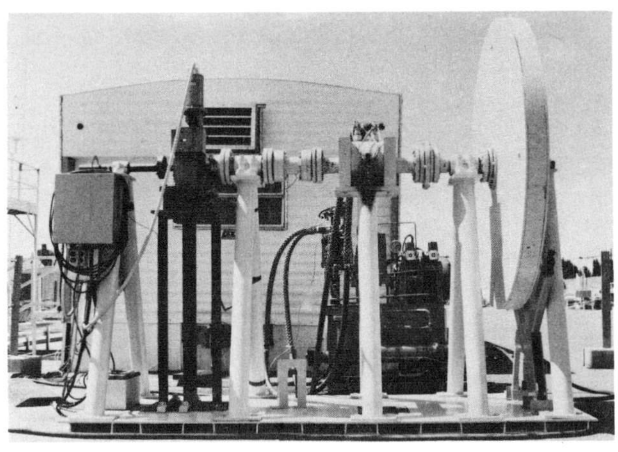

Figure 4-10. Drive String Test Stand

procured. (2) The worm gear design of the drive units self-locked the drive when it was not operating, assuring that the collectors would not drift from their last set position. (3) Efficiency for multiple-stage drive units with the desired speed ratios is low (around 16%), but this can be raised to about 24% by using improved lubrication and wear-in procedures.

m. Integrating Tracker. Two parallel, nickel, 5-mil-diameter wires installed along the axis of the receiver tube produce two analog signals from focused collector energy. The difference between the two signals is digitized by a microprocessor integrated into the Honeywell control system. Performance tests indicate that this integrating tracker has the sensitivity and reliability for accurate tracking.

n. Control System. A prototype version of an advanced solar field control system, developed by Honeywell, was delivered in FY 81 for installation and evaluation on the Performance Prototype Trough. This system integrates collector tracking, fluid control, safeties, status display, and communications into a microcomputer-based distributed processing system. Two-way serial communication between the master field controller and individual collector controllers permits near-real-time determination of individual collector status, and allows the collector tracking and control parameters to be set from the master controller. The master controller calculates sun position and provides it to the collector controllers for an ephemeris tracking capability. The system has the flexibility to accommodate various collector and field designs, and is expected to be available for industry use in FY 82.

o. Field Layout Studies. Jacobs Engineering Group completed tradeoff studies for the layout of a 4645-m^2 (50,000-ft^2) parabolic trough collector field. Results are published in a Jacobs report, Solar Collector Array Piping Design Optimization Studies (Ref. 4-2). A follow-on effort for the preliminary design of both east-west and north-south 4645-m^2 parabolic trough collector fields was placed with Jacobs Engineering Group. The preliminary designs will use the insulation thicknesses, collector spacings, and ΔT string lengths resulting from the recent studies. The designs will be executed to the point where a complete materials listing can be made for estimating the cost of constructing such a field.

p. Heat Loss in Collector Piping Manifolds. Heat loss in piping manifolds is a principal parasitic factor that decreases the overall thermal efficiency of parabolic trough collector fields. Computations of solar collector field performance typically underestimate the magnitude of thermal losses over the entire field, because the computations usually ignore the effects of piping components such as valves and pipe anchors. During FY 81, the heat loss from various piping components was measured (Figure 4-11). An uninsulated 5-cm (2-in.) control valve was found to lose 5,000 Btu/h at 315 °C (600 °F). Insulated, the heat loss was reduced to 1300 Btu/h at the same temperature. Similarly, an uninsulated pipe anchor lost about 1300 to 1400 Btu/h at 315 °C while insulation cut this heat loss to 900 Btu/h at 315 °C.

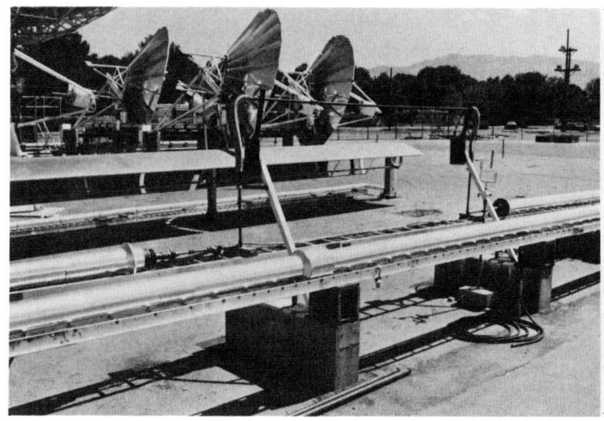

Figure 4-11. Manifold Pipe Heat Loss Test Loop

In addition, thermal siphoning from the receiver tube to an insulated piping manifold was identified as contributing to accelerated cooldown of the manifold. Thermal siphoning can be eliminated by placing either a dog-leg trap or a check valve in a 0.4-m (1-in.) line connecting the receiver to the manifold.

q. Collector Cleaning Study. The collector cleaning study (Ref. 4-3) investigated a matrix of cleaning parameters, such as cleaning materials, cleaning frequency, water pressure and water treatments, to identify good candidates for trough applications (Figure 4-12).

Only one detergent has been found that can restore glass or acrylic reflectors to 100% of their original specularity when applied at pressures between 2068 and 6895 kPa (300 to 1000 psi). This detergent contains approximately 3.5% hydrofluoric acid, and was used in a 3% solution with deionized water and a deionized water rinse. All other cleaning techniques (such as deionized water/mild detergent, soft water/mild detergent, deionized water only, soft water only, tap water/forced-air dry) result in a gradual, continuing loss of reflectance with time. Most of the surface contamination can be removed by applying a 2068- to

6895-kPa tap water spray, but the total dissolved solids in the local water supply determine to a large extent the accumulative soiling rate. In most cases, the actual cleaning techniques required will be site-dependent.

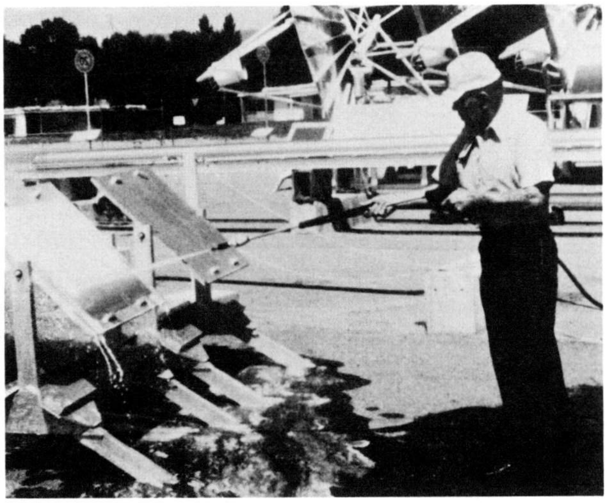

Figure 4-12. Collector Cleaning Test

3. Thermocline Storage Evaluation

Thermal energy storage can affect the performance of large solar thermal energy systems. Thermocline storage, a type of sensible heat storage, has the potential to meet the cost requirements for use in commercial systems. During FY 81, a 4.5-m^3 (1200-gal) engineering prototype thermocline subsystem (Figure 4-13) underwent heat loss testing, charge and discharge testing, and static testing. Thermosiphon loops and diffuser design were found to be weak points in the system and were corrected. Laboratory-scale studies were performed and led to a diffuser design incorporating a perforated plate and stacked screens. One-dimensional computer modeling of a thermocline in a static mode matched well with the large-scale experimental results.

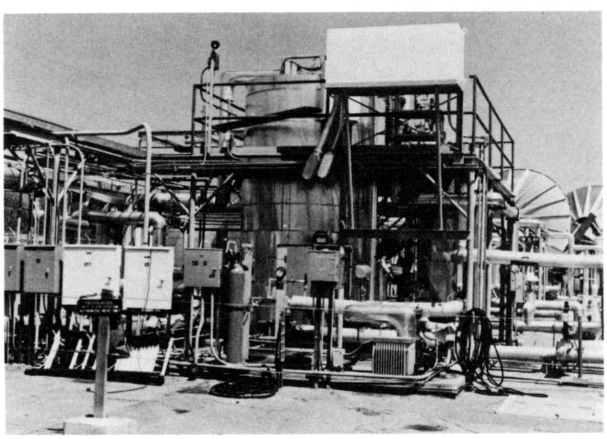

Figure 4-13. Prototype Thermocline Storage Subsystem

B. SYSTEMS EXPERIMENTS AND ANALYSES

1. Irrigation Projects

a. <u>150-kW Solar Irrigation, Coolidge, Arizona.</u> The Coolidge Solar Irrigation Project (Figure 4-14) is a line-focus installation that supplies electrical energy from a 150-kW turbine generator to the local electrical cooperative, Electrical District 2, at Coolidge, Arizona. The power is fed to the utility grid in exchange for power to run three 50-hp irrigation pumps located on the Dalton Cole Farm.

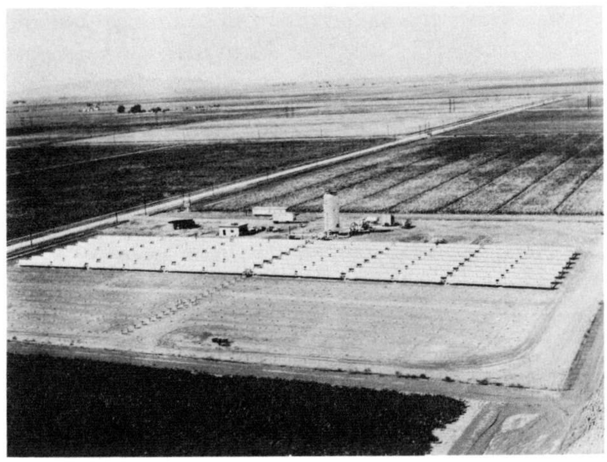

Figure 4-14. Deep-Well Irrigation Project, Coolidge, Arizona

At the time of the dedication, the facility was the world's largest operating solar thermal power plant. The site, south of Coolidge, was selected in February 1977 and a preliminary design study of the facility was undertaken shortly thereafter by three contractors and completed in August 1977. On the basis of the conceptual design competition, Acurex Corporation was selected as the prime contractor for the project and to supply the solar collectors. The major subcontractors are Sundstrand Corporation, the supplier of the organic Rankine-cycle power generation unit, and Sullivan and Masson Consulting Engineers, which developed the detailed design with Acurex.

<u>Description.</u> The collector field is made up of 2140.5 m^2 (23,040 ft^2) of Acurex line-focus parabolic trough collectors arranged in eight loops oriented north-south. Coilzak, an anodized polished aluminum with a reflectivity of 60%, was originally used for the reflective surface of the collectors. The average performance of this subsystem was increased to more than 70% by the use of FEK-244.

The system is designed around three heat transfer loops. One loop extracts warm heat-transfer oil from the bottom of a thermal storage tank, circulates the oil through the collector field, and returns it hot to the top of the thermal storage tank. The second loop extracts hot oil from the top of the storage tank, circulates the oil through a vaporizer heat exchanger, and returns it to the bottom of the storage tank or directly to the collector field inlet. The third loop circulates liquid toluene through the vaporizer heat exchanger and then expands the vapor through the turbine in the power conversion module to extract the energy for electrical power generation. The cycle is completed by condensing the expanded low-enthalpy vapor and pumping the condensate back to the vaporizer. The system flow diagram is shown in Figure 4-15.

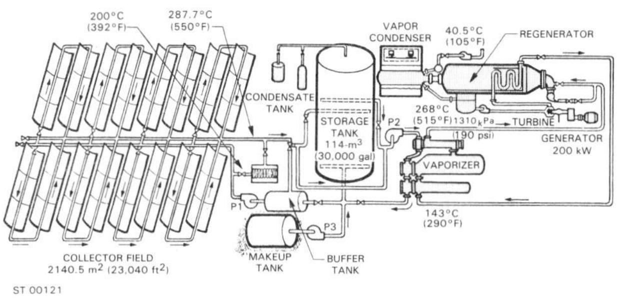

Figure 4-15. 150-kWe Solar-Powered Irrigation Facility Flow Diagram

Solar energy is converted to electrical energy by means of an organic Rankine-cycle power conversion module that uses toluene as the working fluid. The unit is complete with gear reduction and a 440-V, ac, 60-Hz, high-efficiency generator. Supporting equipment includes a vapor condenser for condensing the toluene, and a vaporizer assembly consisting of a preheater, an evaporator, and a superheater for vaporizing the toluene. Energy is stored in a 114-m^3 (30,000-gal) insulated tank 4 m (13.67 ft) in diameter and 15 m (49 ft) high. The control subsystem monitors and controls the collection and storage of solar energy and the generation and supply of electrical power. In addition, the subsystem protects against system-related anomalies such as high temperatures in the collector field and natural events such as gusty winds.

The control functions have built-in fail-safe action or direct limiting devices and are based primarily on closed-loop control and analog signal transmission. The data acquisition subsystem monitors the performance of the system and measures the auxiliary power consumed by the system.

Accomplishments, FY 81. The facility was operational throughout FY 81; performance data were collected through the winter and summer solstices and the spring and fall equinoxes; complete performance characteristics were determined for all elements of the system; and the system operated in excess of 90% of the good weather time, supplying 160,000 kWe of electricity to the utility grid.

A fire safety analysis of the facility was conducted using fault-tree analysis techniques. The results are summarized in SAND81-0781 (Ref. 4-4). A first-hand check of the analysis was obtained in September 1981, when a flex hose rupture occurred without producing a fire. The operator error which contributed to the flex hose being overstressed was corrected, the flex hose was replaced, and the facility was completely operational within 1 day.

Experience and Insights. Lessons learned from the construction and operation of the facility are summarized below.

(1) Construction:

(a) Piping joints tend to leak; threaded joints are the worst, followed by flanges, swagelock fittings, and welded joints.

(b) Conventional arc welding of plumbing joints is satisfactory in most cases. Tungsten inert gas welding is necessary for stainless steel attachments and swagelock thermocouple fittings.

(c) Thermocouples with swagelock fittings are best for measuring fluid temperatures.

(d) All valve bodies should be welded into their pipelines and valve stems should point downward to prevent leakage from getting into insulation.

(e) Insulation should be installed in multilayers with lapped joints.

(f) Manholes on the sides of a thermal storage tank are undesirable because they will leak fluid and are a source of heat loss.

(g) Leak tests should be performed on the pipelines with the lines filled with fluid and at temperature prior to insulating them.

(h) Operating personnel should be on-site during final construction and checkout.

(i) To prevent thermosiphoning, plumb downward away from heat sources.

(2) Operation:

(a) Decomposition of the Caloria HT-43 has been very slight so the automatic fill system for the storage tank has not been needed.

(b) Eighty percent of nonrecurring maintenance work has been done on the power generation subsystem.

(c) A rain switch was installed to allow the operators to point the collectors upward during a rainstorm.

(d) Provide an automatic closure valve in the pipeline to the base of the thermal storage tank to prevent a large oil spill.

(e) Provide easy, year-round access to all subsystems.

(f) Provide an evacuation route from potential oil spill areas and construct an earth berm around the thermal storage tank.

(g) Provide a well-marked, accessible "kill button" to deactivate valves, collectors, flow, etc., in the event of an emergency.

(h) Use water, not CO_2 or chemicals, on oil fires.

(i) Repair oil leaks on a priority basis, label all fluid containers carefully, and maintain tight control.

(j) Avoid overheating oil seals on pumps, etc.

(k) Provide a backup electrical power source to allow the collectors to be defocused in the event of a commercial power outage.

(l) Forbid the bypassing of safety devices.

(m) Set up extensive, periodic, preventive inspection and maintenance procedures, and maintain a good spare-parts inventory.

(n) Periodically tighten flanges, and clean receiver tubes weekly.

(o) A collector field temperature-control system that senses collector outlet oil temperature at only one point works well.

(p) Collector field start-up in cold weather using warm weather techniques has proven to be no problem.

Future Plans. The system is currently being run on a fully automatic basis. The collectors are positioned as the trackers acquire the sun in the morning. The fluid loop comes on automatically and as the operational temperature is achieved, the turbine is brought on line. Facility personnel are present only to perform routine tests and maintenance checks. They would detune the system if a failure occurred that the protection system did not detect, but such an event is quite unlikely.

b. **Shallow Well Irrigation, Willard, New Mexico.** At the Shallow Well Irrigation Project located near Willard, New Mexico (Figure 4-16), the energy collected from 1200 m^2 (13,000 ft^2) of line-focus parabolic troughs was used to drive a 25-hp irrigation pump and to generate 18 kW of electricity for a potato warehouse. The project was initiated in 1976 at the quest of New Mexico irrigation farmers. Sandia Laboratories and New Mexico State University (NMSU) were assigned to conduct the project: Sandia to design, construct, and operate an 18-kW solar thermal system to drive a deep-well turbine pump, and NMSU to conduct associated agricultural experiments.

Figure 4-16. Shallow-Well Irrigation, Willard, New Mexico

The system was dedicated on July 8, 1977. The system used line-focus solar collectors manufactured by Acurex Corporation, an organic Rankine-cycle turbine manufactured by Barber-Nichols Engineering Corporation, and a thermocline thermal storage system. Initially, 624 m^2 (6720 ft^2) of collectors and a 25-m^3 (6500-gal) thermal storage system were used to operate the heat engine continuously during the summer. The system pumped approximately 0.04 m^3/s (700 gal/min) of water into a ground level reservoir from a depth of 30 m (100 ft).

The experiment showed that solar energy could be successfully used to power irrigation pumps. However, there were some system design deficiencies in thermal heat transfer fluid control and heat engine operational stability. Design modifications were made, and the field was expanded by an additional 650 m^2 (7000 ft^2) of collectors manufactured by Solar Kinetics.

The thermocline storage system worked well and demonstrated that a two-tank system connected in series worked just as well as a one-tank system.

Much valuable experience was gained from this experiment. Because the objectives of the experiment had been achieved, DOE terminated its support of the system on July 31, 1980, and ownership of the system was transferred to NMSU. Before July 31, the collector field operated in more than 70% of the daylight hours and the turbine operated more than 400 hours. Spring equinox and summer solstice evaluation programs were successful.

In summer 1981, NMSU removed the experimental system from the site. A final experiment report has been prepared by SNLA and NMSU (Ref. 4-5).

2. Industrial Process Heat Field Tests

For the past 5 years, DOE has funded four cycles of solar energy field tests for producing industrial process heat (IPH) at various industrial plants around the country (see Table 4-1). Seven projects from Cycles 2 through 4, all but one using parabolic trough collectors, were under construction during FY 81. Four of these were completed, and the other three will be completed next year.

Table 4-1. Solar IPH Field Tests Funded for Construction

		CYCLE 1 HOT AIR-HOT WATER 60°-100°C (140-212°F)	CYCLE 2 LOW-TEMPERATURE STEAM 100°-176°C (212-350°F)	CYCLE 3 MID-TEMPERATURE STEAM 176°-288°C (350-550°F)	CYCLE 4 COST-SHARED STEAM AND HOT WATER	TOTAL
COLLECTOR TYPES	FLAT PLATES	4*	0	0	0	4
	EVACUATED TUBES	2	1	0	0	3
	PARABOLIC TROUGHS	0	3	4	2	9
	MULTIPLE REFLECTORS	1	0	0	0	1
	TOTAL SYSTEMS	7	4	4	2	17
STATUS	UNDER CONSTRUCTION	0	0	1	2	3
	CONSTRUCTION COMPLETED	7	4	3	0	14

*INCLUDES ONE COMBINATION FLAT PLATE/PARABOLIC TROUGH

Note: These tests were begun in another DOE organization and were incorporated into the program of the Solar Thermal Technology Division in 1980.

ST 00119

a. **Projects Completed.** Construction was completed on three Cycle 3 projects during the year. Each of the completed projects consists of a field of approximately 1,000 m^2 (10,760 ft^2) of parabolic trough collectors providing saturated steam to an industrial plant steam line.

At the Dow Chemical Plant, in Dalton, Georgia, steam at approximately 1034 kPa (150 psi) is used in the manufacture of latex foam. The system designer and integrator was Foster Wheeler Development Corporation, and the collectors are Suntec parabolic troughs. The plant and solar system are shown in Figure 4-17. The installation and operation of the system was satisfactory except for a number of improperly installed flexible hoses, which were susceptible to leakage. Consequently, Phase 3, Operation and Evaluation, was delayed until new hoses could be installed.

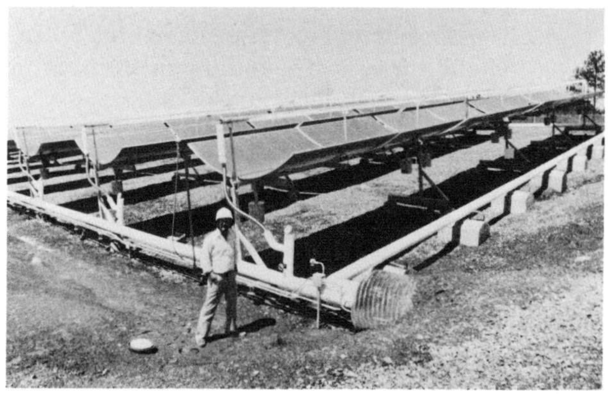

Figure 4-17. Collector Field at Dow Chemical Plant

The Lone Star Brewery project, in San Antonio, Texas, was entering the operational phase at the end of FY 81. The collectors are from Solar Kinetics, with an aperture area of 900 m^2 (9687 ft^2), and are mounted on the factory roof at the Lone Star plant. The system integrator was Southwest Research Institute of San Antonio. As in the Dow project, a hydrocarbon oil is the heat transfer fluid, and the output from the heat exchanger is saturated steam at about 860 kPa (125 psi). Figure 4-18 shows the roof-mounted system at Lone Star.

The last system that became operational this year is located at the Ore-Ida Foods Plant, in Ontario, Oregon, and was designed by TRW, Inc. (Figure 4-19). The collectors are Suntec troughs, ground-mounted,

Figure 4-18. Collectors in Operation at Lone Star Brewery

which supply steam to the main plant steam line at 212 °C (415 °F). The system differs from the other two in that the heat transfer fluid is pressurized water and an open-loop, flash boiler approach is used.

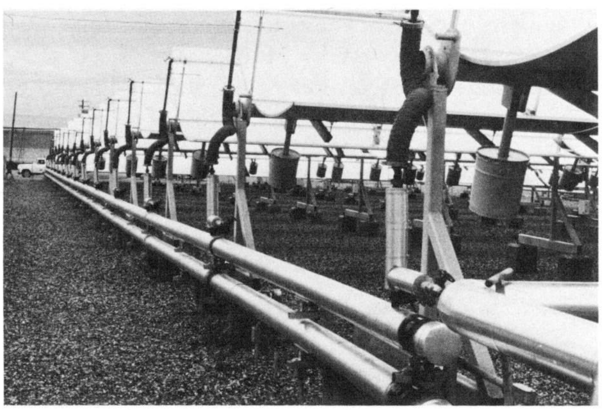
Figure 4-19. Collector Field at Ore-Ida Project

Construction of one of the Cycle 2 projects was also completed during the year. This was at the Tropicana plant in Bradenton, Florida. The collectors were General Electric TC-300 evacuated tube collectors with compound parabolic cusp (CPC) non-tracking reflectors. This project has been troubled by engineering, hardware, schedule and budget problems. The system was completed to the point that it could be operated in order to gain information on this type of collector system, but the acceptance test, held in November 1980, was not successful, and a Phase 3 contract has not been awarded. The principal problems are inadequate insulation and collector tube breakage from thermal shock. No further DOE funding of this project is anticipated.

b. Projects Under Construction. Construction proceeded at the two large (approximately 5,000 m^2/50,000 ft^2) cost-shared steam projects in Cycle 4 of the field test program. The field at the United States Steel Chemicals plant in Haverhill, Ohio, is nearly complete. The collectors are Solar Kinetics T-700, which are ground-mounted and use an oil heat transfer fluid. Steam at 1206 kPa (175 psi) is supplied to the plant steam line, where it is used in the manufacture of polystyrene and other plastics. The prime contractor is Columbia Gas System Service Corporation, a gas utility that contributed to the cost share with USS Chemicals. As of the end of FY 81, the system was scheduled to be operational within 3 months.

The other system is at Caterpillar Tractor Corporation in San Leandro, California, mounted on a factory roof. These collectors also are from Solar Kinetics; the system designer is Southwest Research Institute. Pressurized hot water is circulated through the field and used throughout the factory building as a heat source for vehicle parts washing. This system should be completed in early FY 82.

The last Cycle 3 project to be constructed is at the Southern Union Refinery in Lovington, New Mexico. Here, 900 m^2 (9687 ft^2) of Solar Kinetics collectors generate steam at 1344 kPa (195 psi) to be used in the refining process. Construction of this system was delayed last year to permit relocation of the solar collectors. The site initially selected entailed problems of reflector soiling because of a cooling tower adjacent to the proposed location. The contractor is Energetics, Inc.; the scheduled completion date is October 1981.

Finally, one of the Cycle 2 projects, at Home Laundry in Pasadena, California, has not yet been completed, and is scheduled for continued work in FY 82. A variety of engineering and budgetary problems have arisen at this project, but they are expected to be resolved with some additional DOE funding next year.

c. Other Projects. Four projects from Cycle 1 will be the focus of an upgrade program, managed by Energy Technology Engineering Center (ETEC). These systems, which are typically 4 years old, will be modified to bring them up to the current state of the art and to significantly improve performance. The systems are at Gilroy Foods, Campbell Soup, La Cour Kiln, and Riegel Textiles.

Design work was completed on two of the original Cycle 4 projects, at Bates Container Company in Ft. Worth, Texas, and Nestle-Libby in Santa Isabel, Puerto Rico. Budgetary limitations prevented proceeding into construction.

d. Support Activities. Studies of collector soiling and other types of optical degradation in the industrial environment support the IPH field test. An important source of this information has been an ongoing study by McDonnell Douglas Astronautics Corporation (MDAC), under contract to SNLA. Material-sample racks of the type shown in Figure 4-20 have been deployed at 10 industrial plant sites in the United States. Reflector and absorber samples are retrieved each month, and during the past 2 years more than 30,000 separate measurements of optical properties have been made. The result has been a significant improvement in the understanding of the environmental effects problem and an appreciation of the impact of industrial effluents on concentrator performance. The final report for this project will be available in early FY 82 (Ref. 4-6). A similar (although less extensive) program was conducted by DSET, Inc., in support of the large-scale, low-temperature IPH projects managed by the Solar Energy Research Institute (SERI) at five candidate sites.

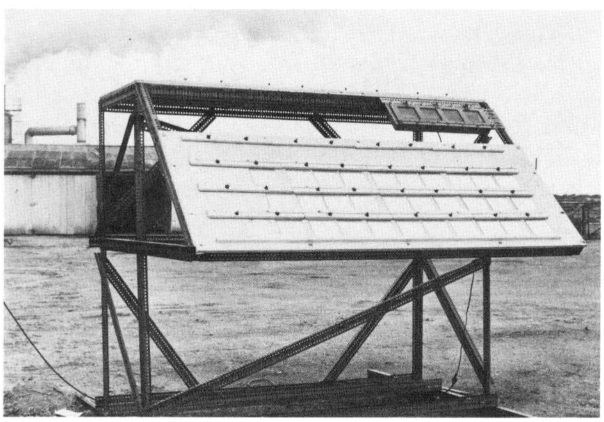

Figure 4-20. Materials Exposure Rack at Enhanced Oil Recovery Project near Bakersfield, California

In a related area, SNLA has prepared and published a report (Ref. 4-3) providing guidelines concerning collector cleaning to owners and operators of parabolic trough solar energy systems. The study was based on extensive laboratory and field experience in solar mirror cleaning, and on interviews with cleaning equipment vendors and representatives of other industries that have major cleaning requirements similar to those of solar concentrators (e.g., fleet car wash operations). Because the soiling problem is so site-specific, the prescriptions for cleaning must be also. Thus, the report offers guidelines for a series of decision points that allow the system owner to tailor the cleaning strategy to local conditions.

SERI published and distributed a report, Design Considerations for Solar IPH Systems (Ref. 4-7) culminating their efforts to aid IPH contractors in avoiding mistakes made in past field tests.

A more ambitious SERI activity is the report, Design Approaches for Solar IPH Systems (Ref. 4-8), that has been prepared in draft form. Unlike the design considerations report, which contained qualitative design recommendations, this report covers the quantitative details of designing a solar IPH system. Both documents rely heavily on lessons learned from IPH field tests, and cover flat plate, evacuated tube, and parabolic trough collectors. A final version is expected to be available in FY 82.

SERI continues to visit operating field tests once they have accrued sufficient operating hours to supply useful data. To check the data acquisition and instrumentation systems, a portable instrumentation package, which includes thermocouples, pyranometer, anemometer, power transducer and infrared thermometer, was assembled in October 1980.

Finally, a study of construction costs for solar IPH systems was carried out by Mueller Associates, Inc., under contract to SERI (Ref. 4-9). Standard industry methods for determining the actual cost of construction were used. The new information this has provided to the solar thermal program will be useful in identifying the most fruitful research areas for system improvement and cost reductions.

3. International Energy Agency/Small Solar Power Systems

The Small Solar Power Systems (SSPS) project to design and build a solar thermal power plant was begun in 1977 by members of the International Energy Agency (IEA). Nine IEA member countries are cooperating in the effort: Austria, Belgium, Germany, Greece, Italy, Spain, Sweden, Switzerland and the United States. Almeria, Spain, was the site chosen for the two side-by-side systems: a distributed collector system (DCS) and a central receiver system (CRS).* These systems are based on existing available technology, with a minimum of research and development effort. The SSPS plant was completed and in operation by the end of FY 81; the test and operations phase subsequently began and will proceed through the end of 1983 (Ref. 4-10).

The DCS, which is the largest operational solar thermal electric power plant using parabolic trough

*For a full discussion of the CRS, see Section II.B.2.

technology, will provide plant operational data on operations and maintenance to complement the U.S. Parabolic Trough Technology Program. Data from the solar-unique subsystems, such as collectors, storage, and their control systems, will provide valuable data for parabolic trough process heat applications. Figure 4-21 is a photo of the IEA/SSPS field, with the two DCS systems in the foreground.

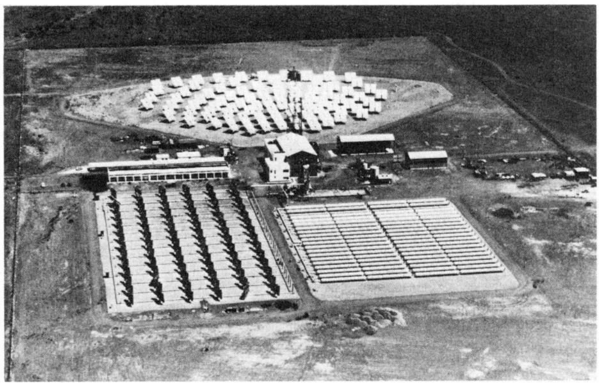

Figure 4-21. IEA SSPS Field, Late FY 81

The 500-kWe DCS comprises two types of line-focus parabolic trough collectors (a U.S. single-axis tracking system manufactured by Acurex, and a German two-axis tracking system produced by MAN*), a thermal storage system, and a power conversion system. The plant's total collector area is 5362 m^2 (57,716 ft^2), with the two collector fields approximately equal. Thermal energy collected by the heat transfer fluid, Monsanto Santotherm® 55 oil, is pumped at high temperature (295°C/563°F) to the top of a thermocline heat storage vessel. It then can be pumped to a steam generator to produce steam to run the steam turbine. Low-temperature (225°C/437°F) Santotherm® 55 is returned from the steam generator to the bottom of the thermocline storage vessel, then pumped back to the collector field.

a. Acurex Collector Field. The Acurex collector field has a total collector aperture area of 2674 m^2 (28,783 ft^2) and is made up of 10 collector loops of two rows each. (A loop represents the number of collectors required to raise the oil temperature from the field inlet temperature to the field outlet temperature; also known as a ΔT string.) The collector tracks the sun in a single-axis mode with the rotational axis oriented in an east-west direction. These collectors are similar to those employed at the solar thermal irrigation plant in Coolidge, Arizona, except for the reflecting surface. For the SSPS, back-surface mirrored thin glass (0.6 to 0.8 mm) with excellent optical properties is used as the reflector material for the first time in an experimental plant. The back-surface mirrored, tempered thin glass is bonded to a sheet steel (0.7 to 0.8 mm) to make up the collector reflecting surface.

b. MAN Collector Field. The MAN collector is two-axis tracking with a thick (4 to 5 mm), back-surface mirrored, hot-formed floatglass reflecting surface. The MAN field is made up of 14 loops, each loop consisting of a row of six two-axis tracking collectors, for a total collector aperture area of 2688 m^2 (28,933 ft^2).

c. DCS Thermal Storage. The single thermocline vessel of the DCS storage system is a vertical cylindrical shell with dished headers welded to both ends. The storage vessel is about 15 m (49 ft) high, and has an inside diameter of 4.2 m (13.78 ft) with a total volume of approximately 176 m^3 (46,500 gal). Because a nitrogen ullage, or blanket, is at the top of the vessel to prevent oxidation of the oil, control pressure, and accommodate changes in the fluid level, the actual working volume of hot oil for plant operation is about 115 m^3 (30,350 gal).

Two buffer storage tanks, one for each collector field, are used to prevent cold oil from the field from entering the thermocline storage vessel. Once the outlet temperature of oil from the fields reaches 295 °C (563 °F), the flow can be supplied to the storage vessel.

d. DCS Power Conversion System. A steam generator and a steam turbine/generator unit are the primary subsystems of the power conversion system. The generator consists of a separate economizer, evaporator (with a steam/water separation drum mounted above), and superheater.

The steam turbine is an eight-stage condensing turbine with one extraction for the deaerator. The turbine drives the air-cooled electric generator through a reduction gear of a single-reduction parallel-shaft type, having a calculated overall efficiency of 22.7%.

e. Test and Operations. The plant will be run under actual operating conditions to the maximum possible extent while test and operations personnel collect reliable data on the viability of the selected technical solutions, the behavior of the plant, and the economics of plant operation. To ensure that this data is available to U.S. industry and utilities, DOE has a representative on the Test and Operations Advisor Board, the group that provides recommendations on

*Maschinenfabrik Augsburg - Nürnberg, Federal Republic of Germany.

the planning and evaluation of operations. DOE is chairing the SSPS International Test and Evaluation Team that will conduct tests and experiments in parallel with routine operations and will report the results of all tests and operations.

4. Modular Industrial Solar Retrofit Program

The Modular Industrial Solar Retrofit (MISR) Program is a DOE project to develop modular trough systems for use in IPH applications and to terminate successfully the DOE trough development effort. The project will use collector technology suitable for retrofitting low- to mid-temperature steam applications currently burning premium fossil fuels such as oil and natural gas (Ref. 4-11).

a. Background. Much experience in the application of parabolic trough systems was gained from the shallow-well experiment at Willard, New Mexico, the deep-well experiment at Coolidge, Arizona (discussed earlier), and several solar IPH experiments. From these first-of-a-kind experiments, it became evident that installation costs were high and that operational reliability was lower than the state of technology would indicate. Because the experiments and related application analyses showed that retrofit of low- to medium-temperature IPH applications is a logical initial penetration for line-focus technology, the MISR project was developed. Industry will develop the designs, and privately funded experiments to obtain system cost and performance data are anticipated.

In the U.S., industry currently consumes about 25% of the total energy produced. Of this amount, 68% is used to generate heat for industrial processes. Approximately 30% of all process heat requires peak temperatures of 315°C (600°F) or less; if preheating applications are included, this percentage increases to 52%. Therefore, a significant amount of fossil fuel could be displaced by matching line-focus solar technology with industrial process heat applications.

b. Project Description. The MISR project is structured to select and qualify multiple designs of modular systems and to identify applications of several representative sites. Funding limitations have necessitated a reduced, single-cycle effort instead of the three cycles of experiments initially planned.

In the first phase of MISR, five detailed designs of modular systems will be developed by trough suppliers, and a qualification-test system for each will be evaluated for performance and reliability. The second phase will involve five conceptual designs for integrating the MISR candidate modules into a steam plant. Up to 10 industrial installations will be selected to serve as theoretical sites for such integrated systems.

Modular designs using standardized, proven components should reduce engineering costs and improve reliability for trough systems. Factory prefabrication of standardized components and subsystems will reduce custom engineering costs and on-site installation costs, thereby reducing costs further.

c. FY 81 Accomplishments. A MISR Project Technical Information Conference was held in February 1981. The MISR System Request for Proposal (RFP) was distributed in April 1981 to approximately 80 requesters, of which 12 submitted proposals. Five contracts for modular system designs were awarded in September 1981. Qualification will be conducted at SNLA and SERI to determine if the RFP specifications have been met.

In support of the RFP development, a packaged boiler usage survey was made in Texas, New Mexico, and Arizona. From the results of these surveys, the size of the MISR modules was set at 2500 m^2 (26,900 ft^2) of solar collector area, and the energy output was specified as steam up to 1725 kPa (250 psi). The RFP included both system specifications and design considerations, incorporating inputs from the four solar manufacturers under contract during FY 80, the expertise of the Stearns-Roger design team, and the experiences obtained from previous DOE solar experiments.

The PRDA for the MISR representative industrial site selection was released by DOE/ALO in September 1981. An information brochure on the potential MISR experiments was developed and distributed widely in May 1981.

d. Future Activities. The major effort in 1982 will be to complete industry designs, construct the qualification test sites, and begin qualification testing. Qualification tests will be completed in early FY 83. Industry interface design studies should be completed a few months after the system qualification tests are completed.

C. EXPERIMENTS AT TEST FACILITIES SUPPORTING PARABOLIC TROUGH PROGRAM, SANDIA NATIONAL LABORATORIES, ALBUQUERQUE

1. Flexible Hoses

A flexible hose test stand was used to simulate the environment that a flexible hose must survive in a collector field. The MOD-1 hose design survived 15,000 cycles at 315°C (600°F), equivalent to 42 years of use. The MOD-2 hose was then evaluated; however, the MOD-1 hose proved to be more durable and will be used on the Performance Prototype Trough.

2. Performance Prediction

A program to predict the performance of mid-temperature trough collectors was planned in FY 80 and implemented in FY 81. The objectives of this program were: to hand off to industry capabilities to test mid-temperature, parabolic trough collectors; to characterize a number of concentrating collectors; to predict thermal performance of these collectors in five U.S. cities; and to develop techniques to enable a comparison of the performance of parabolic trough solar collectors with that of compound parabolic concentrating (CPC) collectors. Three commercial facilities were judged to be technically qualified to test line-focusing, concentrating collectors: BDM, Albuquerque, New Mexico; DSET, Phoenix, Arizona; and Wyle Laboratories, Huntsville, Alabama. Fifteen line-focusing, concentrating collectors, loaned by manufacturers at no cost to Sandia, were characterized. Of these 15, the performance of one was so poor that no further effort was undertaken. The performance of two others was poor but improvements were feasible. Corrective action was taken by the manufacturers and the collectors were reevaluated.

The test results from the 12 remaining collectors were used in conjunction with Typical Meteorological Year (TMY) data to predict the performance in five cities. Document SAND80-1964 (Ref. 4-12) described the overall project and the techniques developed to predict thermal performance. Documents SAND80-1964/1-12 presented the results of the predictions for the following 12 collectors: Solar Kinetics T-700 with FEK 244 reflectors, Suntec with glass, Acurex with FEK 244 reflectors, Sun Heet, AAI, Acurex with glass reflectors, Solar Kinetics T-700 with glass reflectors, Alpha Solarco, Solar Kinetics T-600 with FEK 244 reflector, Custom Engineering with Sandia-designed receivers, Polisolar POL collector, and Toltec collector. Two CPC collectors were tested, the GE TC-300 at Sandia and the Sunmaster collector at Wyle.

Sandia has developed a technique to predict thermal performance of low-temperature trough collectors. The objectives of this program are (1) to characterize trough solar collectors capable of supplying energy for domestic water heating, operating absorption chillers, and other low-temperature applications; (2) to allow participating manufacturers to test modifications aimed at upgrading their collectors; (3) to predict thermal performance in eight cities where available sunshine is judged to create a potential market for those collectors.

Four manufacturers loaned the following basic and modified collectors at no cost to Sandia: 2 collectors each from Applied Solar Research (Phoenix, Arizona), E-Systems (Dallas, Texas), and Whiteline (Asheville, North Carolina); and 3 collectors from Sunpower Systems (Phoenix, Arizona). As of late summer 1981, testing had been completed on the two E-Systems collectors and two of the three Sunpower collectors. Documentation of results obtained is under way.

A Solar Kinetics T-2100 collector also was designed and fabricated, and a single module is scheduled to be assembled on the rotating platform at the Collector Module Test Facility (CMTF) in Albuquerque.

3. Glass-Reinforced Concrete

The Stanford Research Institute (SRI) was tasked by Sandia in May 1980 to characterize the properties of glass-reinforced concrete (GRC) used as a substrate material in parabolic troughs. SRI had claimed that glass fibers, used as a reinforcing agent instead of the conventional steel and mixed in with a sand-cement-water mixture, allowed the material to be used in sections as thin as 3/16-in. Also, SRI predicted possible cost reductions of 50% or more for heliostats and troughs using this material.

The study was completed in March 1981, and was documented (Ref. 4-13). Although many results were encouraging, the study raised more questions than it answered. The project was turned over to SERI for their consideration, as Sandia was developing other materials.

4. Driver and Control Systems Test Stand

The driver and control systems test stand was extensively tested before being put into use in September 1980. This test stand tests both mechanical drivers and electric motors and control systems, in both the steady state and transient conditions. Typical measurements include power, acceleration, velocity, torque, speed, current, voltage, power factor and systems response.

The following units were tested from January through July 1981: Cleveland Model 30-60 (3000-to-1 ratio); Winsmith Model 1DCTTM (3125-to-1 ratio); 1/2-hp Honeywell 24-Vdc motor with Sandia-engineered and EEG-fabricated controller; 1/2-hp Honeywell 180-Vdc motor with Dart standard configuration and factory-modified SCR controller; 3/4-hp Honeywell 180-Vdc motor with Hampton SCR controller; 1-hp Honeywell 180-Vdc motor with Dart SCR controller; 1-hp Dayton motor with Dayton SCR controller.

5. Performance Prototype Trough Test Site Construction

The Performance Prototype Trough System, currently under development by Sandia, consists of 97.5 m (320 ft) of 2-m-aperture solar collector parabolic trough. Site work is complete on the test site and collector foundations were poured in August 1981. The trough system arrived in September and should be installed in early FY 82.

6. Central Receiver Test Facility Cost History

At Sandia Livermore's request, the costs (including out-of-pocket expenditures) associated with building the Central Receiver Test Facility (CRTF) were documented in a Sandia Report (Ref. 4-14).

7. Mass Production PRDA Testing

Solar Kinetics, Acurex, and Suntec are developing improved collectors. Sandia will test the results of these efforts at each manufacturer's plant. Fluid loops have been secured and Sandia is setting up control and data acquisition systems for these tests.

8. Black Chrome Test

The black chrome testing continues, using the Solar Kinetics collector for a test stand for various types of black chrome. The system operated for 989 hours from January through July 1981. The results of black chrome degradation were analyzed, but documentation has not yet been completed.

9. Receiver Seal and Support Test Stand

The tester was modified to accommodate two receiver tubes and their glass envelopes for O-ring testing. Silicon and Viton O-ring testing started February 13, 1981, outdoors with minimal thermocouple instrumentation and manual control of the heater temperature. 10,000 cycles (simulated 20-yr frictional life) were completed on March 25, with no visible deterioration of the O-rings. Data gathered manually two to five times a day indicated a wide variation of receiver tube temperatures because of wind conditions and heater power variations.

The tester was moved inside to eliminate the environmental effects, a temperature controller was installed to maintain a constant temperature on the O-ring collars, and load cells were installed to monitor the O-ring frictional forces.

Two sets of Viton O-rings were tested beginning May 4. After 21 days of continuous static testing, 25 days of dynamic testing was conducted to evaluate varying frictional forces. Frictional forces of 50 and 55 lb were used, then gradually decreased to 40 lb. Documentation is in progress.

10. Receiver Tube Evaluation

Tests of the Viton and silicon O-ring seals on the Custom Engineering troughs showed that the seals must be protected from the high intensity of the concentrated light, which caused temperatures up to 232 °C (450 °F) on the rings. After several shield designs were tested, a preliminary design that should reduce deterioration and increase seal life resulted. Such shielding techniques reduced temperatures to just over 176 °C (350 °F), within the design specifications of the seal.

11. Motor Control

The Hampton and two versions of the Dart SCR motor controllers were tested over a 2-month period. The start and stop delay times, on-signal pulse times, and motor-coast after turn-off were evaluated with 4- and 2-ohm resistors switched across the motor leads after the off-signal to provide dynamic braking. Little difference was noted between the effects of the 2- and the 4-ohm resistors. At full load, dynamic braking was not very effective; at reduced loads, motor coasting was reduced significantly.

12. Pipe Loss Experiments

Pipe loss test results were obtained for straight insulated pipe, pipe with an air-driven control valve in line, pipe with two hand-controlled valves in line, and pipe with pipe stands welded to them. Test results are being analyzed and a report is in progress. The pipe loss test system has since been removed and the parts distributed to other users.

SECTION V
HEMISPHERICAL BOWL TECHNOLOGY

A. FIXED-MIRROR DISTRIBUTED-FOCUS

The fixed-mirror, distributed-focus (FMDF) solar energy concept uses large, bowl-shaped, fixed-aperture collectors to concentrate solar energy on tracking linear receivers. FMDF systems operate at temperatures up to 750 °C (1380 °F) and thus have a broad range of applications. However, because of their fixed apertures, they produce less energy annually per unit of reflective area than do tracking systems. For FMDF systems to gain acceptance, therefore, their production costs must be low enough that performance-cost ratios are competitive with other solar concepts.

During FY 81, FMDF technology development, rather than following a broad plan of design, fabrication of prototypes, testing, and experimental projects as was proposed earlier, focused on two specific problems of a support nature: to understand better the nature of stresses in spherically curved glass mirrors, and to gain a better understanding of FMDF system performance.

1. Stress Analysis of Glass Mirrors

To reduce the cost of FMDF systems, elastically formed, commercial-grade, float glass is used as the reflective material for the mirrors. Although mirrors made from this glass have shown good resistance to impact in hail tests and to thermal cycling in development tests, they have cracked under exposure to localized low-level radiation caused by multiple-bounce reflections on the surface of FMDF collectors. To better understand this problem, two contracts were placed to analyze stresses in spherically curved glass mirrors. One, with Shelltech Associates, was for an analytical determination of stresses; the other, with the Naval Research Laboratory (NRL), was to determine stresses experimentally.

The Shelltech analysis was completed early in FY 81, and a final report was issued (Ref. 5-1). In this analysis, membrane and bending stresses were predicted to reach a maximum of 3000 psi at the center of the mirror for a collector radius of 11-1/2 m (37-1/2 ft) (similar to the Crosbyton Analog Design Verification System). Adding a short-term thermal stress of 1000 psi brings the total to 4000 psi. Stresses in mirrors with larger radii of curvature will be less. Allowable stress of soda-lime glass is 1000 psi. A life-time analysis by SNLA personnel indicates that soda-lime glass mirrors subjected to constantly applied tensile stress of 1500 psi have a 30% probability of cracking within 10 years.

NRL used grid photography and moire analysis to measure bending stress in sample mirrors from the Crosbyton ADVS and photoelastic methods to measure membrane stresses. Bending stress ranged between 1000 and 2500 psi and maximum membrane stresses were 1500 psi. These measurements essentially confirmed the Shelltech analysis.

2. Computer Simulation Model of 5-MW FMDF Power Plant

A computer simulation model of a 5-MW FMDF steam electric power plant was completed during FY 81. The model uses SOLTES, a general purpose code for evaluating performance of solar energy systems. The 5-MW electric power plant incorporates a variable, small-community electrical load (2.5 MW_p) and Typical Meteorological Year (TMY) weather data. The model includes the major components of a steam power plant such as collectors, turbines, etc., and in addition, a complete two-phase piping network and thermocline storage (Figure 5-1).

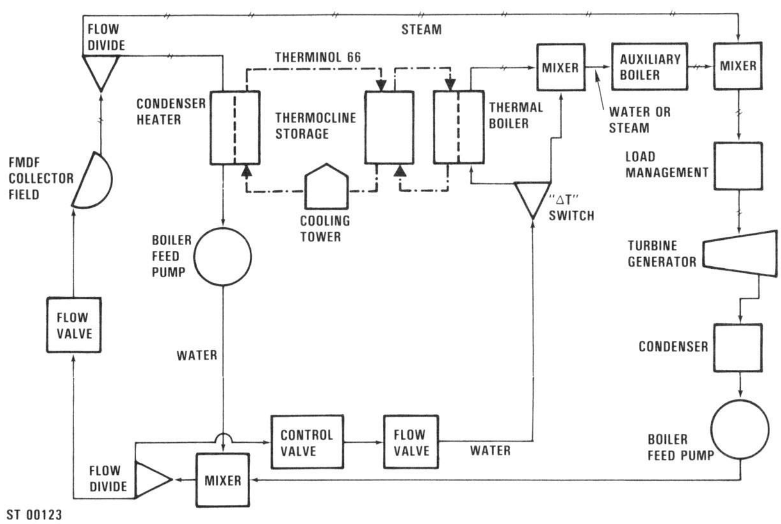

Figure 5-1. Schematic of FMDF Steam Power Plant

The SOLTES model was run against full-year weather data in three configurations: (1) no thermal storage, excess energy collected supplied to grid, (2) thermocline storage, and (3) no storage, collector field sized to minimize collection of excess energy. For the hybrid plant using ten 60-m (200-ft) diameter collectors with a peak efficiency of 0.67, the fuel displacement fraction is 0.49 and 0.37, respectively, for the first two configurations. For the third, it is 0.15 with five 60-m collectors.

B. CROSBYTON SOLAR POWER PROJECT

The Crosbyton Solar Power Project began in 1976 with an effort to develop a conceptual design for a 5-MWe solar hybrid electric power plant to serve the city of Crosbyton, Texas. That conceptual design was the basis for the Analog Design Verification System (ADVS), construction of which was completed in FY 80.

Figure 5-2. Analog Design Verification System Operating in Crosbyton, Texas

The ADVS (Figure 5-2) is a 20-m-diameter version of one of the ten 60-m collectors planned for the Crosbyton Solar Power Plant (Figure 5-3). It consists of 438 spherically curved glass mirror panels, each about 1 m square, which focus incoming sunlight onto a 5.5-m-long receiver made up of two helically wound tubes. These tubes are the same inside diameter (65 mm) and length (112 m) as projected for the full-scale system. By virtue of the bowl concept, the mirror panels are fixed, offering the potential of low-cost, rugged mirror structures. The sun is tracked by moving the receiver, which operates as a boiler and provides steam at nominal conditions of 538 °C (1000 °F) and 1000 psi.

In FY 81, the ADVS completed 20 months of operation, and first generated electricity for the local grid.

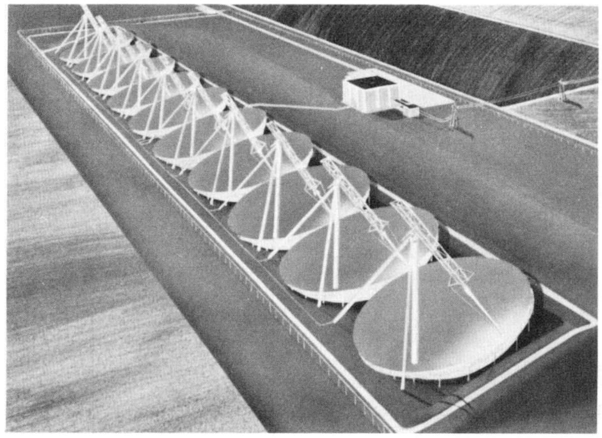

Figure 5-3. Conceptual Design of the Proposed Crosbyton Solar Power Plant

The experimental data verified that the ADVS can produce usable energy as efficiently as design studies had indicated, with peak measured efficiency 63% at nominal steam conditions. The analysis techniques and computer codes used in the project to date have been shown to be highly accurate at off-peak, as well as peak, conditions. This enabled reliable performance and design analyses in support of the development of a preliminary system design for the full-scale power plant during FY 81. Also, virtually daily operation of the ADVS has provided many practical insights that are being factored into the design as the project proceeds toward final design and construction. Future operation of the ADVS will emphasize the experimental evaluation of design features for the proposed full-scale plant.

During FY 81, a turbine/generator was installed to produce electricity using steam from the ADVS. This turbine was not designed for the ADVS application so its performance is not indicative of the potential of the bowl collector. However, this exercise provided valuable experience in using the energy collected in a representative application. The generated electricity was fed to the local utility grid.

Technical questions related to bowl solar collector technology still remain, but the largest uncertainty in the concept's commercial future is the cost. One of the objectives of the preliminary system design developed in FY 81 was to identify all significant elements of fabrication and construction costs. Immediate plans are to submit the preliminary design to a cost analysis by an independent, outside organization. The results of that analysis will play an important role in the formulation of recommendations for continued development of the bowl concept in general and the Crosbyton Solar Power Plant in particular.

SECTION VI

SALT-GRADIENT SOLAR PONDS

A salt-gradient solar pond is a body of still water that collects solar energy and stores it as thermal energy. This thermal energy can then be used for such purposes as electric power generation, industrial and agricultural process heat, space heating and cooling, and desalination.

A salt-gradient solar pond uses salt to control the density of the water, with a high salt concentration maintained near the surface. Even though it is warm, high-salinity water near the bottom of the pond is denser than the cool, low-salinity water near the surface, which prevents convection, thus reducing thermal losses. The gradual upward diffusion of salt creates an intermediate region which insulates the bottom layer. The required level of salinity is maintained through periodic injection of higher concentrations of salt at the storage layer and by flushing the pond surface with low-salinity or fresh water.

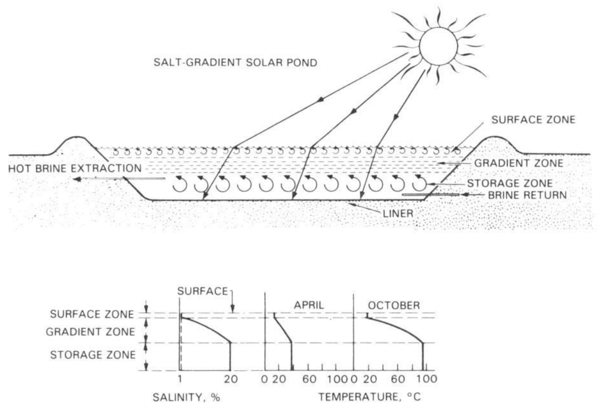

Figure 6-1. Schematic of a Typical Salt-Gradient Solar Pond

Figure 6-1 shows a schematic of a typical salt-gradient solar pond. Sunlight entering the pond is partially absorbed in the top two layers, with the storage layer absorbing the remainder. Since the non-convecting layer suppresses convection, the thermal energy in the storage layer can only be lost by conduction through the top two layers and through the bottom of the pond. Heat is extracted from the pond by withdrawing hot brine from the top of the storage layer, extracting the heat in an external heat exchanger, and then returning the somewhat cooler water to the bottom of the storage layer.

Used in an electrical generating system, the salt-gradient pond itself performs three critical functions: collection, storage, and waste heat rejection. In the lower layer of the pond, temperatures approach 90°C (194°F) or more. The lower layer operates as a thermal energy reservoir that can supply energy at a nearly constant rate day and night, summer and winter; several weeks of storage capacity is quite practical. Evaporation cools the upper layer of the pond. This layer can be used to reject waste heat from the power plant and eliminate the need for cooling towers. Thermal energy from a solar pond is used to drive a Rankine cycle heat engine (Figure 6-2). Hot water from the bottom layer of the pond is pumped to the evaporator where the organic working fluid is vaporized. The vapor flows under high pressure to the turbine wheel and the electric generator linked to it. The vapor then travels to the condenser where cold water from the surface of the solar pond condenses the vapor back into a liquid. The liquid is pumped back to the evaporator where the cycle is repeated.

Solar pond work in FY 81 concentrated on an extensive study of the regional applicability of solar ponds, research on the extraction of heat and mass from solar ponds, design of a test tank that models a solar pond, and a feasibility study of the Salton Sea Project.

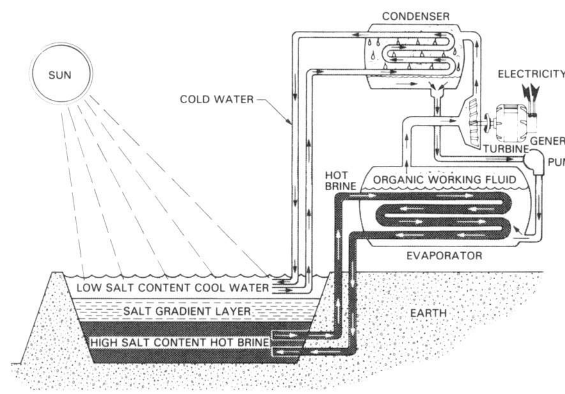

Figure 6-2. Salt-Gradient Solar Pond for Electrical Generation

A. ANALYSIS AND SUPPORTING RESEARCH

1. Regional Applicability Study

A study (Ref. 6-1) to assess solar pond resources, applicability, and potential was conducted by a JPL team with support from two subcontractors: The Benham Group, which surveyed and analyzed land availability and values, and Ormat Turbines, Ltd., which performed case studies to determine design and performance parameters for specified applications. The study focused on the general characteristics of 12 defined geographic regions, omitting site-specific details, and included:

(1) A survey of natural resources essential to solar ponds.
(2) An examination of meteorological and hydrogeological conditions affecting pond performance.
(3) The identification of potentially favorable pond sites.
(4) Calculation of potential thermal and electrical energy output from solar ponds.
(5) A study of selected pond design cases.
(6) An evaluation of five major potential market sectors in terms of technical and energy-consumption characteristics and solar pond applicability and potential.
(7) A detailed economic analysis considering relevant pond system data and financial factors.
(8) A comparison of solar pond energy costs with conventional energy costs.

The United States was divided into 12 geographic regions. Criteria for defining regions included a moderate number of regions, coincidence of region boundaries with state boundaries, and a proper reflection of similar pond-related characteristics within each region. The primary determining factors were insolation level and the availability of water and salts. The five major applications addressed were space heating for residential, commercial and institutional buildings; industrial process heat; agricultural process heat; electric power; and desalination.

In the residential, commercial and institutional buildings sector, solar ponds can provide thermal energy at sufficiently high temperatures for building space heating and domestic water heating in all regions, except Alaska. The need for thermal energy in space heating and domestic water heating exists in every state and region. The availability of low-cost land in proximity to end-use buildings is a limiting factor, as vacant land is scarce and costly in most developed areas.

In the industrial process heat sector, the need for thermal energy below 93°C within the manufacturing sector is concentrated in California, Texas, and the Great Lakes region. Food, furniture, paper, chemicals, leather, stone/clay/glass and primary-metals processing are among the major industries to which solar ponds can be suitable energy suppliers. Many of the more than 176,000 existing industrial impoundments may be suitable for conversion into solar ponds.

In the agricultural process heat sector, solar ponds can supply thermal energy to a number of agricultural processes: crop drying, livestock brooding, livestock waste disposal, space and water heating for livestock shelters, greenhouse conditioning, farmhouse space and water heating, and irrigation pumping. The high-yield period of a pond (i.e., fall) coincides with the high energy demand period of most farms as crop processing activities occur most frequently around this time.

Solar pond application in the electric power sector is perceived to be limited by resources rather than need. Most of the United States is or can become connected to utility grids, and the grids presumably can absorb any amount of power that is generated by solar ponds. Electric power ponds will be constructed mostly on a large scale (hundreds or thousands of acres in area), and on sites where the essential natural resources are available at low or no cost.

The current desalination market for solar ponds is small, but the need for desalination is projected to increase substantially during the next two decades, i.e., from 273 million gallons per day (mgd) of desalted water in 1981 to 2500 mgd in the year 2000. Solar ponds are perceived to be capable of providing thermal energy to the distillation desalination process and electric or mechanical power to the reverse osmosis and electrodialysis processes.

The study concluded that ponds are applicable in all regions except Alaska. Compared with conventional energy sources, solar ponds have the best chance for near-term viability in several southern, high-insolation regions for large-scale electric power and municipally financed thermal applications.

2. Heat Extraction Study and One-Dimensional Boundary-Layer Migration Model

In a salt-gradient solar pond, hot brine from the storage layer is continuously or intermittently circulated through an external heat exchanger from an initially convective layer. This layer is bounded at the top by a stratified region (gradient), although there is no physical partition separating these two regions, and it is bounded below by a horizontal plane (bottom of the pond) which is heated daily by the sunlight penetrating to this depth and being absorbed on the bottom. Additionally, volumetric heating occurs in the bulk of the pond as a result of radiation absorption.

The extraction of heat and mass from solar ponds was investigated at SERI, with the objective of identifying the governing mechanisms and relevant parameters that influence the response of the pond to fluid circulation and limit the rate at which heat may be extracted from the storage layer by currently proposed extraction methods. The experiments should identify the optimal locations for withdrawal and injection ports and the maximum rate at which energy can be withdrawn while ensuring gradient stability. Results obtained from the laboratory investigation will be extrapolated to large solar ponds and, if necessary, will be used to provide specific guidelines for additional tests that may need to be conducted in a large research pond.

Accomplishments for FY 81 include: a review of the research on heat and mass extraction from salt-gradient solar ponds and related topics to identify the relevant parameters that limit the extraction rate on the basis of gradient stability; a detailed analysis of the extraction problem, based on existing analytical, numerical, and experimental work; a definition of experimental goals for a heat and mass extraction test program, including specific measurements to be performed and accuracy required; and the design of a test tank that adequately models a section of the solar pond. The test tank consists of a sealed rectangular cell 1 m wide by 2 m high by 10 m long; the top surface is open to ambient and a removable internal partition allows testing in a 5-m-long section. The tank is electrically heated from the bottom. The perimeter of the tank is heavily insulated and guard heaters will null heat losses through the side walls. Removable injection and withdrawal manifolds consist of adjustable slots which cover the width of the tank. Seven windows provide visual access to the entire length of the tank, supplementing the data collected by sensors immersed in the tank. Details of the FY 81 accomplishments have been published in two SERI reports (Ref. 6-2 and 6-3).

The FY 82 objectives of this research effort are to build and instrument the laboratory facility, to perform shakedown and calibration tests, and to initiate the laboratory tests on heat and mass extraction under simulated pond conditions.

The FY 83 objectives are to complete all laboratory tests on different extraction methods in order to determine the physical factors which limit the rate at which heat and mass may be withdrawn from the storage layer; to determine the most efficient extraction method; and to scale the results to large solar pond conditions.

B. SYSTEM EXPERIMENT (SALTON SEA PROJECT)

During FY 81, a feasibility study for a salt-gradient solar pond power plant in or near the Salton Sea of California was completed (Ref. 6-4). The study team was composed of Southern California Edison Co. (SCE), which provided overall project management; Jet Propulsion Laboratory (JPL) as technical manager; Ormat Turbines, Ltd. of Israel, which conducted site and system analyses; and WESTEC Services, Ltd., which evaluated environmental issues. The Departments of Energy and Defense (DOE and DOD) and the California Energy Commission are also project sponsors, but did not participate in this study. The conclusions of the study supported the continuation of plans for design and construction of a proof-of-concept 5-MWe solar pond experiment, as the preliminary phase in a 600-MWe power plant consisting of about a dozen ponds.

Two sites were studied: a "wet" site on the western shore of the Salton Sea; and the "dry" site at Bristol Lake, a dry inland desert lake. Estimated performance is similar for both sites: a 250-acre solar pond will support year-round baseload operation and achieve a 66% load factor and a power profile that lies within ± 15% of 5 MWe. Although constructing a solar pond at a "wet" site will be more difficult and costly, its abundant water supply offers more commercial potential, making it the candidate for the pond experiment.

The study recommended continuing the project into the conceptual design phase. This would include developing a system concept design for the "wet" site; conducting a comprehensive geotechnical investigation; studying dike design options to determine the lowest cost configuration; and continued experiments to resolve questions related to brine compatibility, pond bioactivity and soil/brine chemical reactions. After these tasks are completed, reliable cost estimates and construction schedules can be made. These estimates are needed for the decision to proceed with final design and construction of the proof-of-concept experiment.

SECTION VII
RESEARCH AND ADVANCED DEVELOPMENT

A. MATERIALS RESEARCH

1. Mirror Testing

Reflectors for solar thermal concentrators continue to present an area of serious concern for solar researchers. The endurance of mirrors in a solar application may be disappointingly small and, when mirrors are more durable, it is difficult to determine just what processes led to that particular quality of mirror. To formalize and better organize mirror testing, a matrix approach to testing mirrors (MATM) experimental plan was developed with the cooperation of SERI, SNLA, SNLL and Battelle Pacific Northwest Laboratory (BPNL). These laboratories, all active in solar materials research, agreed that the MATM would yield the most significant results within the time and resource constraints of the program.

The matrix incorporates most of the static and dynamic environmental conditions to which mirrors are exposed in normal service. The six conditions that are considered to contribute most to the degradation process are humidity, temperature, thermocycling, ultraviolet (UV) radiation, environmental pollution, and mechanical force. The levels arbitrarily chosen for the matrix tests were the maximum and minimum values likely to be found, and a median value lying between them. The parameters are listed along with the magnitudes to be used in the test matrix in Table 7-1.

To test seven mirror types using three duplicates of each data point for all the combinations presented by the matrix would require over 75,000 test samples, which is not practical in current programs. A committee consisting of representatives from the four cooperating laboratories named above decided to restrict the number of variables in the matrix and to initially accept a certain level of risk by ignoring the possible interactions between those variables. There are also practical constraints on the parameter levels available with current testing equipment. Within this framework, it was agreed that the higher levels of temperature and humidity would be used, that thermocycling would, for the first attempts, not include freeze/thaw cycles, and that only one nominal pollution concentration would be used. After samples were exposed to various environments, the effects were measured by a number of techniques listed in Table 7-2.

The tests were grouped into three phases, with Phase I tests conducted at SERI and BPNL. At SERI, humidity, temperature, high temperature cycling, and time were tested. The goal of Phase I was to confirm the general validity of the approach and to reduce the size of the matrix to a magnitude that would allow reasonably speedy evaluation of the approach. The SERI Phase I tests are now complete and the following conclusions can be drawn from them:

(1) Levels of 78% relative humidity at 80°C

Table 7-1. Materials Testing

Environmental Parameter	Parameter Magnitude	Combinations
Humidity, relative %	0, 50, 90	3
Temperature, °C	20, 40, 60, 80	4
Thermal cycling, °C	High temperature (+20 to maximum); freeze/thaw (−20 to +20)	2
Ultraviolet radiation	0, 10x normal maximum	2
Pollutant mix	0, 10x, 100x nominal EPA maximum	3
Mechanical stress	0, ±0.2x, ±0.5x nominal maximum to substrate failure	5
Time, wk	0, 1, 2, 4, 8	5

Table 7-2. Reflecting Materials Evaluation Techniques

Technique	Principal of Operation	Comments
Hemispherical reflectance	300- to 800-nm spectral scans to look for surface plasmon in roughened silver films	Time-consuming
Solar reflectance	300- to 2500-nm spectral scans to look for Bruggeman and Garnett roughening effects	Time-consuming
Gier Dunkel portable	Spectrally averaged hemispherical reflectance	Fast, but not as accurate
Photography (1x)	May be quantifiable using Quantimet	Fast, permanent record
Darkfield photography (100x)	Measures scattering centers only	Fast, permanent record
Photography (UV)	May be able to monitor local regions of surface plasmon enhancement	Hard to do with conventional light sources
Differential laser scans	Monitors two laser frequencies for reflectance differences	Time-consuming
Specular reflectance	Sandia portable specularity instrument	Difficult to use consistently
Diffuse reflectance	Spectral information sensitive to scattering centers	Time-consuming
Acoustic characterization	Sensitive to debonding	Not readily available
Surface analysis	Auger electron spectroscopy, scanning electron microscopy, secondary ion mass spectroscopy, electron spectroscopy for chemical analysis, etc.	Expensive
Surface-enhanced Raman (SER)	Very sensitive to small chemical changes on the silver	Difficult to use

(176 °F) and 78% relative humidity with 20 ° to 80 °C (68 ° to 176 °F) temperature cycling are sufficient to cause measurable reductions (4 to 15%) in reflectance in typical silver-glass mirrors over a 4-wk period.

(2) Mirror degradation appears as light-scattering centers, reduced hemispherical reflectance, and edge corrosion.

(3) Thermocycling, even with high humidity, causes less mirror degradation than high humidity soaking; therefore, it was eliminated from the Phase II plans.

(4) There is some subjective evidence that edge corrosion on the specimens is encouraged by thermocycling.

(5) There is some evidence that high temperatures, regardless of the humidity present, lead to defects that seem to be caused by either agglomeration or delamination of the silver.

At BPNL, eight different types of mirror coupons were subjected to accelerated environmental stresses and studied as a function of time. Phase I demonstrated that under the heat and moisture stresses, the eight mirror types could be reliably ranked in order of their expected outdoor performance. Even mirrors of the same construction supplied by two different commercial manufacturers could be rated for their relative performance in as little as 2 weeks. Mirror samples to be used in the Phase II testing are described in Paragraph 3, below.

There is very little information of a planned statistical technical nature regarding the lifetimes and degradation rates for mirrors in real-time exposure. Despite the lack of scientifically planned real-time exposure tests in the past, there is much information among scientists and researchers in the solar energy field concerning the general pattern of degradation and the possible mechanisms of the degradation of mirrors. The stability of the silver layer is known to affect the durability of mirrors, both mechanically through agglomeration and chemically by oxidation or sulfidation of the silver film. Backing paints, sensitizer layers to promote adhesion, and the encroachment of corrosive effects through the edge seals of laminated mirrors are also recognized as affecting durability. Until further data is available from planned tests, this available information may serve as the data base for correlation between laboratory testing and the performance meaurement of mirrors in field installations.

2. Mirror Performance

Controlled information on mirrors and real-time exposure is also being obtained through the Solar Thermal Material Handbook Data Acquisition Program, sponsored by SERI at the DSET Laboratories near Phoenix, Arizona. For 6 years, this program has accumulated information on environmental exposure of mirror samples in low and high desert climates, marine climates, and industrial climates. Recent refinements in the methods of measuring the effects of degradation under such real-time exposures and of correlating those measurements with mildly accelerated exposures (approximately eight-fold acceleration) mean that real-time information with which to correlate the effects observed in the matrix approach should be available during the next year.

3. Advanced Mirror Development

Numerous experiments to develop alternate approaches to the manufacture of mirrors have been carried out. The conventional wet chemical process, the standard method of mirror production for many years, uses a thin salt film as a sensitizer to promote adhesion of the silver to the glass and subsequently covers the exposed surface of the silver with a thin film of copper to promote paint adhesion. Attempts to replace that method have included vacuum, radio frequency sputtering, and thermal reduction of organometallic films to produce the silver layer; investigation of other metals and metal salts as the adhesion promoter or sensitizer layer; and investigation of other materials to provide the protective film on the back of the silver. From these efforts, the following have been selected as candidates for Phase II of the matrix test plan described above:

(1) Float glass/organometallic Ag.

(2) 0317 glass/organometallic Ag/CeO.

(3) Float glass/sputtered or e-beam Ag with adhesion promoter/Inconel.

(4) Float glass/wet chemistry silver/electroless nickel.

(5) Polycarbonate/silver - Sheldal.

(6) Acrylic/A1-FEK (control sample).

These mirrors were selected on the basis of various short-term and simpler exposure tests including salt spray cabinets and weatherometer tests.

4. Intermediate Temperature Absorbers

Work to develop selective absorber coatings that would maintain stable performance above the normal limits of black chrome (300° to 350°C/572° to 662°F) was conducted. Research in this area in FY 81 included studies of cermet coatings of platinum and aluminum oxide, cobalt oxide films, and other more conventional absorbers such as black chrome and pyromark paint.

Cermets of platinum and alumina that show great promise were made for SERI by Telic Corporation. Two types of cermet coating are used, one in which the platinum content is graded in concentration and one in which a thin layer of the cermet near the center of the sheet contains a small amount of platinum with more or less pure alumina lying on either side of that thin layer. The latter requires far less platinum and so is the most economical. This coating technique offers significant advantages over other processes being considered, because it will allow uniform coating of inside curves, hemispheres and domes.

5. Low-Cost Concentrators

The materials work on low-cost concentrators has emphasized weight reduction and reduction in the cost of the optical elements. Two approaches were studied in FY 81: one uses low-cost materials in the form of paper honeycomb and melamine sheet plastic to form petals or troughs in appropriate optical shapes; the other uses thin polymer membranes stretched over a metal frame to produce the flat surface to which reflecting materials may be attached. The former method was used to manufacture three parabolic troughs with FEK 244 sheet as the reflective material. These troughs have successfully completed mechanical tests, and will be installed at the SERI test site for performance analysis.

To study the second method, a membrane heliostat was constructed in FY 81. It consists of a polypropylene membrane stretched on a circular frame 284.5 cm (112 in.) in diameter with springs around the parameter giving it a surface tension of 137.9 kPa (20 lb/in.^{2}). Its weight is approximately 0.167 kPa (3.5 lb/ft^2). Individual, 1-ft-square, 0.23-cm- (0.09-in) thick mirror tiles provide the reflecting surface on this experimental model. Initial tests using several different methods were conducted, and quantitative results will be obtained when the photographs taken of the tests have been measured on densitometers and the data tabulated.

Mechanical creep in the polypropylene membrane material has reduced the tension in the membrane, leading to the conclusion that another type of film may be more appropriate for this application. This is not a critical matter, because many other available polymer films do not have the obvious mechanical creep characteristics of polypropylene.

6. Metallic Coatings for Protection of Silver-Glass Solar Mirrors

Seven industrial concerns working with BPNL examined the problem of metallic coatings for protection of conventional wet process silver-glass mirrors. Two processes that are potentially adaptable to the present mirror line technology are being considered. Ion-plated mirrors with overcoatings of A1, A1/Cu alloy, 301 stainless steel, Cr, and Ni were fabricated on soda-lime silicate and alumino-borosilicate glass substrates. Accelerated tests (heat and heat plus moisture) from the stress matrix showed these mirrors offer no significant advantages over the conventional paint-backed mirrors. Mirrors protected by a tough thin coating of electroless nickel were successfully fabricated by one company. The process used to coat these mirrors should be readily adaptable to conventional mirror lines. These mirror coupons will be subjected to environmental matrix testing.

7. Dust Accumulation Studies

BPNL, working in cooperation with Black and Veatch and the JPL Low-Cost Solar Array Project, began characterizing the effects of environmental contamination on solar thermal concentrator systems. Preliminary results obtained during FY 81 indicate that if field sites are carefully chosen, total specular losses from dust can average less than 10% after 1 year or more without washing. Scattering losses exceed absorptive losses by factors of two to seven.

8. Solar Thermal Materials Characterization

BPNL performed over 3000 characterizations of transparent and reflective materials samples for industry and DOE contractors in FY 81. Measurements included spectral and solar transmittance and reflectance, specularity, and figure. The results provided engineering assessments and scientific feasibility data.

9. Thermal Containment Materials

The compatibility of containment materials with high-temperature working fluids and thermal storage media is a major concern for many solar applications. Information derived from the literature and industrial operation experience exists for most proposed thermal fluids, but the available information rarely covers all important aspects of the solar thermal operating environment, such as the effects of thermal cycling and sustained or cyclic stresses. Repeated thermal cycling of containment materials constitutes a major distinction between the operating conditions of solar thermal systems and the current industrial data base. Molten nitrate salts are one of the most promising thermal transport/storage fluids, but until recently there was minimal information on whether potential containment alloys are resistant to stress-induced cracking in that environment at the temperatures of interest.

SNLL has been conducting studies to determine whether environmental cracking of containment alloys will occur in molten nitrate salts under either sustained or cyclic stresses. To simulate various aspects of the receiver operating environment, experiments were conducted under isothermal conditions using constant strain rate, constant load, and reversed strain fatigue techniques. To date, the results do not indicate that environmental cracking will pose a problem for solar applications involving molten nitrate salts. At least one alloy, Incoloy 800, exhibits better mechanical properties in a nitrate salt environment than in air.

Although these isothermal experiments have provided useful data, a closer simulation of solar receiver operation requires that thermal cycling effects be modeled. Because of the experimental complexity of such simulations in comparison to isothermal tests, an analysis was performed to see whether thermal cycling corrosion fatigue experiments and thermal cycling pumped test loops were feasible. As the analysis shows no serious obstacles, conceptual design of these experiments has begun, with final design and fabrication scheduled for completion in FY 82.

10. Polymer Development and Evaluation

With the introduction of selected synthetic UV stabilizers into candidate polymers for mirrors and mirror enclosures, service lifetimes have been extended. Preliminary evaluation of the chemical stability of the modified polymers indicates that the techniques developed are very promising.

An evaluation of the long-term optical clarity of two candidate polymeric film materials (Kynar®, a fluorocarbon, and Acrylar®, a polymethyl methacrylate film) for concentrator mirror and dome enclosure applications was completed (Ref. 7-1). The study evaluated the effects of thermal annealing on the morphological and chemical changes in these materials that affect their optical transmittance. Kynar® was found to undergo a thermally activated chain and crystal reorientation process that leads to a gradual loss in optical transmission. Acrylar®, which contains a bound UV absorber, showed no degradation to 85 °C (185 °F).

11. Ceramics

An assessment was conducted that defines the need for ceramic materials in currently conceived solar thermal energy systems, determines the related ceramic technology readiness, and defines the effort required to have adequate, enabling ceramic technology for solar thermal uses (Ref 7-2).

12. Cellular Glass

Because of its low weight and cost, cellular glass is a prime candidate for mirror substrates. A study evaluating the effects of a freeze/thaw environment on cellular glass found no physical or mechanical degradation occurring during 53 freeze/thaw cycles; the mechanism and degree of degradation is highly dependent on several design and environmental variables (Ref. 7-3). The strength, fracture mechanics, and slow crack growth behavior of cellular glass were also studied. Several important mechanical phenomena were successfully modeled, and critical engineering design data were developed.

B. FUELS AND CHEMICALS

1. Introduction

The solar thermal Research and Advanced Development (R&AD) program is aimed at developing a technology base that will expand the use of solar thermal technology in both the depth and the breadth of applications. The SunFuels program element addresses the energy-intensive liquid and gaseous fuels and chemicals industry markets. It is designed to offer the nation new alternatives to produce solar fuels and chemicals from renewable resources (e.g., H_2 from H_2O using solar energy).

Exploratory studies and feasibility experiments have been conducted on various solar fuels and chemical processes as a part of the SunFuels Program. These include coal gasification, oil-shale retorting, biomass pyrolysis experiments, and investigations of the production of fuels from water-splitting cycles. Initial results of these investigations show significant potential for solar thermal energy use in the production of liquid and gaseous fuels and chemicals.

2. Program Objectives and Goals

The objectives and goals of the SunFuels Program are to:

(1) Establish by 1989-1992 the technical and economic feasibility of producing storable/transportable fuels from renewable resources using solar thermal energy, thereby providing the transportation and chemical industries with new long-term options.

(2) Develop large-scale water-splitting capability to produce hydrogen and fuels.

(3) Initiate a subsystem research experiment (SRE) at the solar tower for a selected process in FY 85-86.

(4) Define advanced processes to produce fuels and chemicals from renewable feedstocks.

3. FY 81 Program Accomplishments

During FY 81, a number of potential SunFuels processes were investigated, and market assessment studies were done to provide program focus and establish program priorities. The FY 81 accomplishments of the SunFuels Program include:

(1) An overall SunFuels Program strategy and plan was defined (Ref. 7-4).

(2) Candidate SunFuels systems were identified based on market and other selection criteria.

(3) Critical reviews of the status of research and development of two potential water-splitting cycles developed by Westinghouse and General Atomic Co. were completed.

(4) Initial review of 26 candidate processes was completed and workshops to identify candidate processes for SRE-1 were conducted.

(5) Oil-shale retorting experiments (Figure 7-1) conducted at White Sands, New Mexico, showed the technical feasibility and advantages of the controlled pyrolysis of oil shale using direct solar heat (Ref. 7-5).

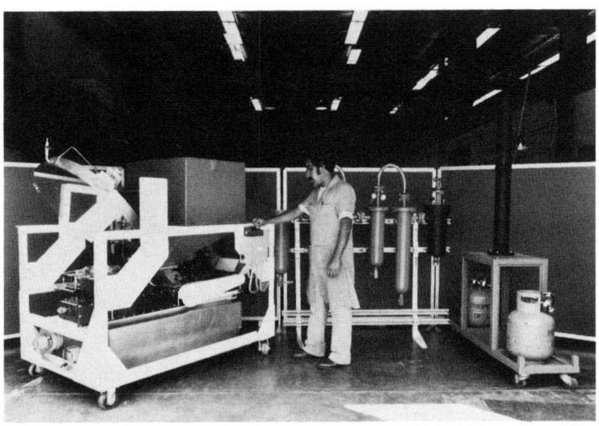

Figure 7-1. Oil Shale Solar Reactor

(6) Much of the technology for flash pyrolysis of biomass, particularly cellulosic material (Figure 7-2) has been established. FY 81 research emphasized the relationship of the radiant flux to the composition of the pyrolysis products.

(7) The gasification of coal by indirect use of solar heat in a continuous process was investigated (Ref. 7-6). The major technical question that remains regards the construction and durability of the very high-temperature (1038°C, 1900°F) heat exchanger.

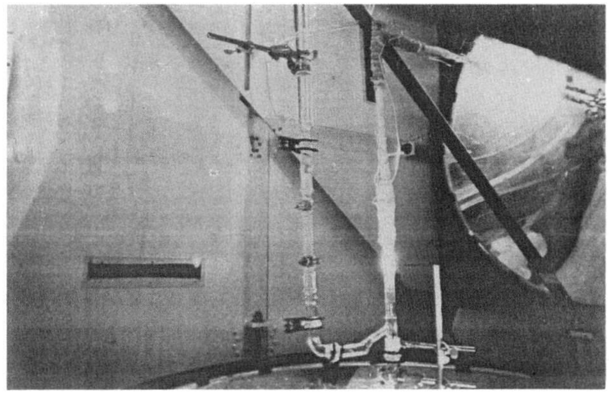

Figure 7-2. Bench Reactor for Biomass Pyrolysis

(8) Studies of the design and fabrication of high-temperature solar reactors centered on both catalytic and non-catalytic reactors operating at 870°C (1600°F) (Ref. 7-7). Preliminary results indicate that a non-catalytic endothermic reaction at 870°C can be interfaced successfully with a central receiver.

C. APPLIED THERMAL RESEARCH

1. Receiver Convective Heat Losses

The thermal performance of solar central receivers is governed by energy loss processes in which receiver-captured solar energy is lost to the atmosphere rather than transferred to the receiver working fluid. Convective losses, in particular, are very difficult to predict because the combination of high operating temperatures and large receiver dimensions are parameters that have never been examined by heat transfer scientists. A research program was established to investigate heat transfer under these conditions with the ultimate objective of predicting and perhaps controlling the convective losses. This applied research program includes a balance of experimental and analytical work for both external and cavity configurations. The principal emphasis during FY 81 was the construction and operation of experimental facilities designed to measure convective heat transfer at the high surface temperatures and large dimensions characteristic of solar receivers. A workshop was held at which the research results were discussed and reviewed. The research programs and the workshop are discussed below.

a. External Receiver Research. An experimental and analytical research project directed at understanding convective losses from external receivers was carried out under the direction of Stanford University and Nielsen Engineering and Research (NEAR), Inc. of

Mountain View, California. The objectives of the project are: (1) to conduct a set of experiments which will provide data to support development of a predictive model for heat transfer through a turbulent external boundary layer subject to orthogonal buoyancy forces; and (2) to incorporate these results into a computer code which will accommodate additional fluid mechanical conditions that exist in an external receiver configuration. A large heated flat-plate experiment has been performed at NEAR, and a numerical, Navier-Stokes code is being developed at Stanford. To accurately characterize external solar receiver flows, a 3-m by 3-m flat plate, electrically heated to 500 °C (932 °F), and a mixed convection test facility were constructed and used for detailed heat transfer measurements. The mixed convection test facility (Figure 7-3) is designed to provide known and controlled external winds; the flat plate is inside the tunnel and is roughly the size of the dark area on the side of the tunnel. Flow quality in the tunnel was outstanding with good velocity uniformity and very low turbulence levels. During FY 81, the test facility and flat plate were constructed, checked out, and used to measure heat transfer. Data were obtained for free, forced, and mixed convection. The surface heat transfer data indicate mixed orthogonal convection, which is an important and complex energy transfer process. Detailed boundary layer measurements have also been made and are being incorporated into the Stanford code. Future experiments may involve a large heated cylinder in the NASA-Ames wind tunnel that will link the two-dimensional flat plate results to the three-dimensional reality and additional complexity of central receivers.

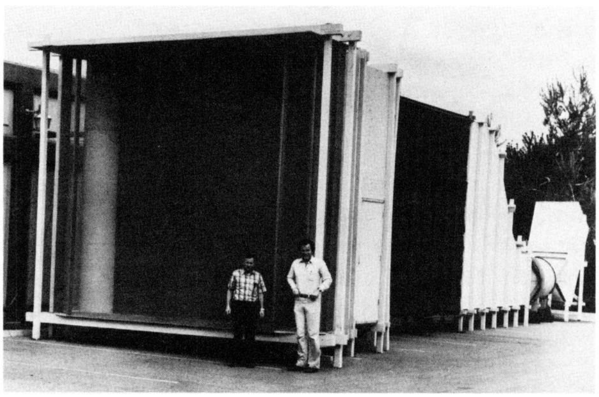

Figure 7-3. Mixed Convection Test Facility

b. Cavity Receiver Research. Experimental and analytical research directed at understanding heat transfer processes in cavity receivers has been carried out at the University of California, Berkeley, and at Sandia National Laboratories, Livermore (SNLL). A simplified model of cavity flow based on the fire sciences approach to modeling complex three-dimensional flows was developed. Although this model makes a number of simplifying assumptions and requires specification of some model parameters, its results can be and have been compared with experimental data. A more complex model employing a numerical solution of the Navier-Stokes equations is under development at Berkeley. A small cavity experiment has been constructed at Berkeley to provide data for model development. Flow visualization has been used to understand the flow processes inside the cavity and the effect of external winds on the cavity flow. The small size and relative low temperatures of the cavity, however, result in dimensionless quantities that are not representative of actual receivers. For that reason, a large electrically heated cavity whose Grashof numbers and surface temperatures are more characteristic of actual receivers was constructed at SNLL. The cavity (Figure 7-4) is a cube, 2.15 m (7 ft) on a side, with one side open. It is lined with Inconel strips that are electrically heated to temperatures of up to 750 °C (1382 °F). During FY 81, construction and checkout of the large cavity experiment was completed and initial data on energy losses were obtained. The convective losses from the cavity were measured in two ways: by a calculation of the enthalpy flux and by an energy balance. To obtain the

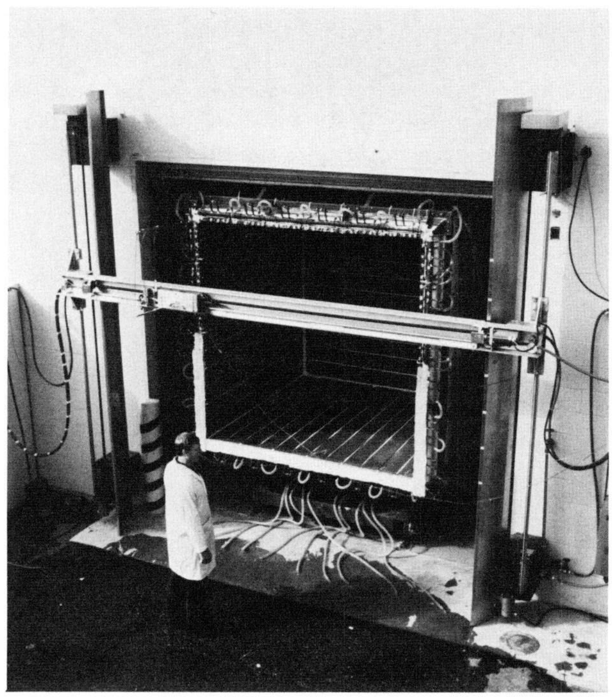

Figure 7-4. Receiver Test Facility

enthalpy flux, temperature and velocity profiles in the aperture plane were measured with thermocouple and pitot-static probes. An energy balance of measured input power and radiative and conductive losses also predicted the convective loss. The convective energy losses measured by two approaches were in good agreement, but larger than predicted. The flow observed in this more realistic experiment was very complex, highly three-dimensional and turbulent. Future work involving more detailed measurements will aid development of a three-dimensional turbulent version of the Berkeley numerical model.

c. Workshop. A DOE/SERI/SNLL "Workshop on Convective Losses from Solar Central Receivers" was held at Sandia National Laboratories in Livermore in March 1981. Seventy persons attended to hear and discuss reports of research and progress in this area since the previous workshop, in April 1979. Results of analytical and experimental investigations of convective heat transfer for both cavity and external receiver configurations were presented by U.S. and European researchers. The work presented and directions for future research were discussed and commented upon by a panel of university professors expert in heat transfer and fluid mechanics (Ref. 7-8). Although important progress had been made since the first workshop, continuing research is necessary to understand the loss mechanisms at receiver conditions in order to implement effective control strategies.

2. High-Temperature Ceramic Receiver

Under contract from JPL, Sanders Associates, Inc. has developed a high-temperature ceramic solar receiver for use with parabolic dish concentrators (see Section III.A.3). This receiver utilizes state-of-the-art ceramics in the form of silicon carbide solar-receiving honeycomb matrix elements and mullite storage elements. Rigidized insulation holds these elements in place and is encapsulated by a carbon steel exterior pressure vessel. Solar energy entering the receiver through a quartz window 20 cm (8 in.) in diameter heats the ceramic honeycomb. Gas passing through the honeycomb then extracts the energy and exits the receiver.

During FY 81, a Sanders receiver was manufactured and delivered to the PDTS where it underwent an extensive series of tests. The receiver reached its highest steady-state operation at 1204°C (2200°F) exit temperature and during transient runs (2-hour duration), it achieved up to 1427°C (2600°F). In addition to this successful high-temperature test, preliminary estimates of efficiency for this receiver are 60% at 1204°C and up to 90% at 871°C (1600°F) when aperture spillage losses are accounted for separately.

The Sanders receiver testing has shown the high-temperature receiver concept could be used in systems with temperatures exceeding the existing state of the art of metal designs. The experiment shows that ceramic elements can be used in high-temperature, high-flux environments if proper designs are used. Transmission of high solar fluxes through quartz windows was demonstrated for cavity-type receivers. The regimen of testing has approximately simulated the operation required to power the advanced gas turbine (AGT) engine currently being developed for automotive applications.

SECTION VIII
SUPPORTING PROGRAMS

A. SOLAR THERMAL TEST FACILITY USERS ASSOCIATION

1. Introduction

The Solar Thermal Test Facilities (STTF) Users Association (UA) was organized in 1977 at the request of DOE to inform competent researchers, particularly those in universities and industrial R&D laboratories, of the availability of federally funded solar test facilities, and to interest them in helping advance solar thermal technology.

The UA uses workshops, technical publications and support of innovative experiments to inform creative people of solar thermal possibilities and to secure for the government their professional advice and support. DOE now benefits from the free assistance of nongovernment engineers and scientists who participate actively in UA programs.

The UA has operating agreements with four major U.S. solar test facilities and two in Odeillo, France. It seeks early identification of promising solar thermal applications by supporting a variety of high-temperature solar experiments. These include investigations of the use of solar energy to produce hydrogen, gasify coal, pyrolyze biomass, and produce calcium carbide and elemental phosphorus. The UA also supports experimental work to learn more about the design of thermal receivers for effectively capturing high-intensity solar radiation and using it to drive chemical reactions or other large-energy-consuming high-temperature processes. This experimental work, although preliminary, has identified several possible applications for solar thermal energy and led to the establishment of a DOE solar fuels and chemicals program in 1981.

The UA was incorporated in 1977 in the state of Texas; it is a not-for-profit organization with membership available to individuals and institutions who have a serious interest in advancing solar thermal technology. At present there are about 85 individual and 12 institutional members. The UA is managed by an executive director who reports to a seven-person executive committee (EC), elected by the membership. The EC is comprised of three members from industry and three from universities; the seventh member is not as yet designated but the position is presently filled by a representative from a DOE National Laboratory. Operators of the participating solar thermal test facilities are ex officio members of the EC and are active in UA affairs. The University of Houston operates the UA under a yearly contract awarded by DOE.

2. Objectives

The objectives of the UA program are to foster the development of solar thermal technology through cooperative university, industry and government research, and to provide the government with access to creative ideas and professional viewpoints of nongovernment scientists and engineers. To implement this objective, the UA performs the following functions:

(1) Uses workshops, newsletters, announcements, technical papers and presentations to facilitate exchange of solar thermal information among members of the solar community, both national and international.

(2) Stimulates participation of creative scientists and engineers in solar thermal programs, encouraging them to contribute their best ideas to the advancement of process heat, solar electric, and solar fuels and chemical applications.

(3) Encourages more rapid advancement of solar thermal technology by soliciting, reviewing, and funding proposals from universities, industries, and government laboratories.

(4) Encourages increased use of private sector resources in development of cost-effective solar thermal applications.

(5) Evaluates capabilities of solar thermal test facilities, and helps assure their productive use.

(6) Acts as the point of contact for nonprogrammatic users of the STTFs and as the primary access link between users and STTFs.

3. Summary of Activities

In January 1981, a workshop on "Testing for Long-Term Performance" was held in Albuquerque. Approximately 70 representatives from industry, universities and government attended, including one each from Italy and France. The annual Business Meeting and Technical Sessions were held in April in Pasadena, California, and attended by 55 persons, including representatives from France, Canada, and the Federal Republic of Germany. Proceedings from both meetings are available from the UA office in Albuquerque.

By November 1980, 36 proposals had been received in response to the "High-Temperature Solar Research Program" announcement published in June 1980. Eleven proposals were recommended as Priority 1, and the following eight experiments were funded in FY 81 (names of the principal investigator & the sponsoring research institute are in parentheses):

(1) Contract for the use of solar energy to decompose zinc sulfate as a key step in the solar production of hydrogen (Shell, Lawrence Livermore National Laboratory).

(2) Small-particle heat exchanger experiment (Hunt, Lawrence Berkeley Laboratory).

(3) Exploration of the use of solar thermal energy to produce elemental phosphorus from phosphate rock (Whaley, Institute of Gas Technology).

(4) Project to investigate a solar-driven coal pyrolysis and gasification reaction on the vertical solar furnace in Odeillo, France (Beattie, Los Alamos National Laboratory).

(5) Lab test of a vortex-flow solar chemical reactor (Bomar, Georgia Institute of Technology).

(6) Experiment to study the reactions of black chrome to intense solar radiation over extended periods (Ignatiev, University of Houston).

(7) Study to determine whether high temperatures produced by solar energy can be used to cure and glaze ceramic tile (Harris and McNamara, Georgia Technical Research Institute).

(8) Design and test of an advanced temperature instrumentation system capable of measuring solar reactor temperatures to approximately 2200 °C (Negas, National Bureau of Standards).

B. ENVIRONMENTAL CONTROL STUDIES

Environmental studies of solar thermal technology were concluded and documented through reports in FY 81 for the following activities: (1) environmental monitoring at the 10-MWe Barstow site and surroundings; (2) vegetation management and recovery at desert sites disturbed for STT development; (3) ecological and environmental effects of accidental or mismanaged releases of STT fluids; and (4) programmatic environmental assessment of the U.S. DOE/STT program. These activities are summarized below.

The environmental monitoring of the 10-MWe Barstow site has so far documented the following environmental effects: (1) the complete destruction of the ecosystem within the power plant site; (2) the displacement of an estimated 160 metric tons of windblown sand from the heliostat field into adjacent downwind areas; and (3) reductions in numbers of some annual plants in areas of maximal sand deposition. No effects on vertebrate populations or on shrubs occupying downwind areas have been observed.

Field experiments relating to the vegetation of the area show that grazing damage from small animals is one of the most limiting factors in restoring vegetation onto disturbed desert lands. Some form of protective fencing is needed for at least 2 years after transplanting in order to assure survival of the plants. Cost analyses show that restoration of vegetation at a density of 675 shrubs an acre would cost a minimum of $3,000 per acre for the first year of transplanting, plus an on-going annual maintenance cost of $500 per acre for at least a 3-year period.

Regarding possible deleterious effects of STT fluids, field and laboratory experiments have confirmed that for a broad spectrum of solar thermal technology, the toxicity of heat transfer and storage materials to plants varies as a function of soil type. Additionally, there is a potential long-term persistence of these materials (such as Therminol 66, Caloria HT 43, and DOW 200) in natural environments.

Finally, technical content from sections of the two original environmental assessments have been updated and earlier non-compliance issues have been resolved in the draft Programmatic Environmental Assessment of the STT Program which has been circulated for review.

C. SOLAR THERMAL INSOLATION ASSESSMENT

The optimum design of any solar thermal system depends on the accuracy and availability of meteorological data relevant to the siting (environment) of the system. A common misconception among designers is that relevant information is available from the archives of the National Weather Service or other parts of the National Oceanic and Atmospheric Administration (NOAA). In fact, the data available are seldom adequate for one or more of the following reasons:

(1) Measurements are not available for the intended site of the system installation.

(2) Measurements available are not those required, as in the need for direct normal (beam) radiation data.

(3) Resolution or time scale of the data is not adequate.

(4) The period of record is insufficient to indicate long-term means or extremes.

Efforts during FY 81 have been directed towards two tasks that focus on these and other problems of adequate resource assessment: the development of Insolation Historical Data Bases and improved insolation measurements.

1. Historical Data Bases

Pertinent data from the archives of the National Climatic Center have been transferred to the SERI Computer Center to establish a resource data base containing the best available information accessible to the research staff. The historical data base consists of the full complement of SOLMET data (measurements from 26 stations in the continental United States), ERSATZ data (derived insolation data for 222 sites in the United States), and TMY data for both data sets. Additional sources of resource data have been found, such as the WEST Associates Monitoring Program (managed by Southern California Edison), and are under analysis for acceptability.

User-oriented products have been prepared to make these data available to a wider audience. Demand for the Insolation Data Manual, prepared under this task, has been very high because of the large number of stations (248) and corresponding resource/load information available in printed form. Computer media products have also been developed to provide more detailed summaries, i.e., hourly to daily time scales, of the insolation resource data base. A comparison of results obtained from integrating the hourly data from those ERSATZ stations that also reported measurements of daily total global horizontal radiation as part of the SOLDAY data set is in progress. The results of this study will be used to evaluate the regression techniques developed for the ERSATZ data. Similarly, an evaluation of the SOLMET rehabilitation techniques has produced a generalized direct normal from global horizontal radiation model. Other conversion schemes, such as the insolation available on tilted surfaces, will result from this work. A significant product of perhaps the widest interest will be the forthcoming Solar Energy Resource Atlas for the United States. Comprehensive summaries of revised insolation data will be found in large-format maps, tables, microfiche, and narrative of the atlas.

2. Insolation Measurements

As part of the insolation measurements efforts, data from the new NOAA/DOE Solar Monitoring Network is being compiled. New instrumentation and data acquisition systems have been in place at 38 stations in the United States and territories since 1976. Most importantly, the deployment of normal incidence pyrheliometers has allowed a wider monitoring coverage of the direct normal (beam) radiation component than has been available historically. Work has begun to evaluate the rehabilitation techniques used by NOAA to generate the 26-station SOLMET and 222-station ERSATZ data sets using the measurements from this network are being evaluated.

Eight universities, under contract to the DOE as Solar Energy and Meteorological Research Training Sites, have created a specialized data set spanning July 1, 1980, to July 1, 1981. These research-quality measurements will form a unique 1-min meteorological data base which includes all of the insolation parameters, including energy on tilted surfaces. Coordination of this effort includes the development of measurement quality control procedures.

The Insolation Research Laboratory operating at the SERI Interim Field Test Site provides the insolation and surface meteorological measurements to support outdoor tests. Calibration facilities were completed to ensure the necessary traceability to the World Radiation Reference scale of radiometry. The laboratory complements the monitoring station on top of South Table Mountain, some 100 m above and 1 km to the north of the Interim Field Test Site.

During FY 81, a study of mesoscale insolation variability was initiated. The principal goals of this study are: (1) to determine, for various climates, the characteristics of insolation variation on a 10- to 300-km scale; (2) to develop techniques to predict the variability for a given region; (3) to develop techniques to estimate insolation between measurement sites; (4) to establish insolation data sets on a mesoscale; and (5) to compare ground-based measurements of insolation with satellite-based estimates.

This year the SERI Insolation Research Laboratory began receiving insolation data from three mesoscale networks. Two of the networks, one near Denver, Colorado, the other near Miles City, Montana, received SERI support for measuring insolation. To ensure high quality data from the two SERI-supported networks, 75 pyranometers were simultaneously calibrated. The third network, run by WEST Associates, is located in the southwest and has accumulated 5 years of insolation data at several sites. Initially, the research effort has focused on analyzing the WEST Associates network data because it has the longest period of record. The techniques used here will then be applied to the other two networks. Variation maps are being produced and interpolation techniques tested.

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2-2 *Final Report, Second-Generation Heliostat Development for Solar Central Receivers*, Boeing Engineering and Construction, SAND81-8175, March 1981.

2-3 *Second-Generation Heliostat Development, Vol. I, Final Report*, and *Vol. II, Appendices*, Martin Marietta Corp., SAND81-8176, April 1981.

2-4 *Final Report, Second-Generation Heliostat with High-Volume Manufacturing Facility Defined by General Motors*, McDonnell Douglas Astronautics Co., SAND81-8177, April 1981.

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2-7 Baker, A.F., *International Energy Agency Small Solar Power Systems (SSPS) Project Review (January 1981)*, SAND81-8216, May 1981.

3-1 *Parabolic Dish Concentrator Designs and Concepts*, Compiled by B. Beveridge, JPL Document 400-98, January 1981.

3-2 *Test Report, Receiver Qualification Tests*, Ford Aerospace & Communications Corp., August 1981.

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3-4 *Small Community Solar Power Experiment*, JPL Document 400-82/3, November 1980.

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4-13 Ploeger, D., and R. Lundgren, *Conceptual Design of a Glass-Reinforced Concrete Solar Collector*, SAND81-7011, July 1981.

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5-1 *Stress Analysis for Spherically Curved Glass Reflectors*, Shelltech Associates Contract Report, SAND81-7015, June 1981.

6-1 Lin, E.I.H., et al, *Regional Applicability and Potential of Salt-Gradient Solar Ponds in the United States*, JPL Publication 82-10, November 1981.

6-2 Zangrando, F., *Laboratory Experiments on Heat and Mass Extraction from Solar Ponds: 1st Quarterly Report, 1 April 1981 - 30 June 1981*, PR-252-1394, November 1981.

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Appendix A
Bibliography

SOLAR THERMAL ENERGY SYSTEMS BIBLIOGRAPHY

The following is a comprehensive listing of available publications covering the field of solar thermal technology. This bibliography was compiled in part by the Meridian Corp., under contract to JPL. To obtain publications of interest, contact the source listed at the end of each entry. The addresses and phone numbers of these sources are as follows:

1. National Technical Information Service (NTIS)
   U.S. Department of Commerce
   5285 Port Royal Road — Phone: (703) 487-4600
   Springfield, VA 22161 — (FTS) 937-6011

2. Solar Energy Research Institute (SERI)
   Document Distribution Service
   1617 Cole Boulevard
   Golden, CO 80401 — (303) 231-1158

3. JPL Document Review Group (JPL)
   Jet Propulsion Laboratory
   4800 Oak Grove Drive
   Pasadena, CA 91109 — (213) 354-5090
   Mail Stop 111-116-B
   (Ask for "JPL Pub. Number"; copies free, if available)

   Re The Solar Thermal Report, contact
   Peggy Panda
   Jet Propulsion Laboratory
   4800 Oak Grove Drive
   Pasadena, CA 91109
   Mail Stop 502-208 — (213) 577-9319

4. Solar Thermal Technology Division (DOE/STT)
   U.S. Department of Energy
   600 E. Street, N.W.
   Washington, D.C. 20585 — (202) 252-5558

5. Robert S. Riordan (Riordan/CRI)
   Director of Applied Energy Research and Public Service
   Center for Research, Inc.
   2291 Irving Hill Road
   Lawrence, KN 66045 — (913) 864-4078

6. American Society of Agricultural Engineers (ASAE)
   2950 Niles Road, P.O. Box 410
   St. Joseph, MI 49085 — (616) 429-0300

A. OVERALL PROGRAM DESCRIPTION AND/OR TECHNICAL CONCEPTS

1. *A Guide to the Solar Thermal Energy Systems Program - Fiscal Year 1981*

   By: Meridian Corporation and PRC Energy Analysis Company

   This document acquaints interested parties with the Solar Thermal Energy Systems Program at the U.S. Department of Energy. The guide provides information on the various technical concepts which are being developed within the program; some of the major projects and field experiments which utilize solar thermal technologies; the structure of the program; how it is managed; and a summary of all major solicitations planned for Fiscal Year 1981. The appendices provide further information on conferences, meetings, exhibits, and other sources of information about the program.

Pages	Date	Contract No.
152	January 1981	DE-AC01-80ET-20647

Source: DOE/STT

2. *Solar Thermal Report*

By: Jet Propulsion Laboratory

As a monthly report, this document provides current information on state-of-the-art advancements, current and upcoming events, legal and regulatory issues, and the latest contract awards.

Pages	Date	Report No.
12	Monthly Report	JPL 5106-10

Source: JPL

3. *A Description and Assessment of Large Solar Power Systems Technology*

By: Sandia National Laboratories

The systems being sponsored by the Department of Energy's Large Solar Thermal Central Power System Program are summarized. Included are the technical concepts upon which the systems are based and, to the extent possible, estimated cost, performance, and assessment of typical systems. The document provides potential users with an overview of present technologies and those technologies that will be available within the next several years. Assessments of the strengths and weaknesses of each technology are included in the hope that developers of the technology will be able to improve component and system designs.

Pages	Date	Report No.	Contract No.
158	April 1980	SERI/SAND 79-8015	EG-77-C-01-4042

Source: NTIS

4. *Solar Thermal Energy Systems Research and Advanced Development Program Review*

By: Solar Energy Research Institute

The presentation summaries submitted by the speakers at the Solar Thermal Energy Systems Research and Advanced Development Program Review conference held in Oakland on April 8 & 9, 1981 are provided. The proceedings have been prepared by printing the papers made available by the individual authors. The document benefits technical individuals interested in the results of solar thermal activities and major accomplishments over the past year.

Pages	Date	Report No.
152	April 8 & 9, 1981	SERI/CP-633-1145

Source: NTIS, SERI

5. *Annual Technical Report, Solar Thermal Point-Focusing Thermal and Electrical Applications Project: Volume I: Executive Summary; Volume II: Detailed Report; Fiscal Year 1979.*

By: Jet Propulsion Laboratory

This report is a detailed compilation of key FY 79 activities and results for the Point-Focusing Thermal and Electric Applications (PFTEA) Project. This project, previously called the Small Power Systems Applications Project, was renamed to denote a realignment of the project's charter and reflect significant program changes. The Small Community Solar Thermal Power Experiment (SCSE), Isolated Application Experiment and Industrial Application Experiment were discussed, as were developments in system engineering implementation of the experiment, and testing and analysis of technology applications.

Pages	Date	Report No.
Vol. I - 39	April 1, 1980	DOE/JPL-1060-30, Vol. 1
Vol. II - 150		DOE/JPL-1060-30, Vol. 2

Source: JPL

B. APPLICATIONS POTENTIAL

Enhanced Oil Recovery

6. *Solar Thermal Enhanced Oil Recovery (STEOR)*
   Vol. I - Executive Summary
   Vol. II - Statement of Work
   Vol. III - Summary of Additional Work

By: Advanced Energy Systems Laboratory, Exxon Research and Engineering Company; Foster Wheeler Development Company; and Honeywell, Inc.

Steam injection, either to stimulate individual wells or to drive oil to the producing wells, is by far the major thermal process used today, and has been in use for over 20 years. Since steam generation at the necessary pressures (generally below 4000 kPa (580 psia)) is within the capabilities of present day solar technology, it is logical to consider the possibilities of solar thermal enhanced oil recovery (STEOR).

This project consisted of an evaluation of STEOR by a team from various Exxon affiliates, Foster Wheeler Development Corp. and Honeywell Inc.

The results of the study are presented in three volumes. Volume I contains the executive summary. Volume II contains Sections 2 through 8, together with Appendices A through K, in response to the original contract statement of work. Volume III summarizes the additional work performed to evaluate STEOR as a privately financed commercial venture at Exxon's Edison Field near Bakersfield, California.

Pages	Date	Report No.	Contract No.
Vol. I - 25	November 1980	SAN/0307-1	DE-AC 03-79C830307
Vol. II - 280			

Source: NTIS

7. *Solar Enhanced Oil Recovery; An Assessment of Economic Feasibility*

By: Sandia National Laboratories

This document provides qualitative reasons why steam Enhanced Oil Recovery (EOR) appears to be well suited to solar energy. These include favorable characteristics regarding energy use, land availability, energy form, and geographical location. A cost model based on a number of working assumptions is also provided to indicate the competitiveness of solar thermal systems versus conventional fuel-burning EOR systems using crude oil prices and solar system costs.

Pages	Date	Report No.	Contract No.
52	May 1979	SAND-79-9787	DE-AC04-76DP00789

Source: NTIS

8. *Solar Repowering/Industrial Retrofit Systems*
Category B: Solar Thermal Enhanced Oil Recovery System
Executive Summary

By: Martin Marietta; Exxon Corporation; Foster Wheeler Corporation; and Black & Veatch Consulting Engineers

A conceptual design for a central receiver solar thermal system for a thermal-enhanced oil recovery (TEOR) process in Exxon's Edison oil field near Bakersfield, California, is discussed. The solar power system would produce 29.3 MWe in the form of steam, using 818 heliostats with an area of 49 m^2 (528 ft^2) each, and displacing 43,000 barrels of oil per year. The central receiver STEOR system was found to compete favorably with the present crude oil combustion process even in the near term.

Pages	Date	Report No.	Contract No.
18	July 1979	MCR-80-1352	DE-AC03-79SF10737

Source: NTIS

Industrial Applications

9. *Application of Solar Energy for the Generation and Supply of Industrial Process Low- to Intermediate-Pressure Steam Ranging from 300°F to 550°F (High Temperature Steam)*

By: Acurex Corporation

This report highlights the study on Acurex's design for a solar industrial process heat system to be installed at the ERGON, Inc. Bulk Oil Storage Terminal in Mobile, Alabama. The 1874 m^2 (20,160 ft^2) solar energy collector field will generate industrial process heat at temperatures ranging from 150 to 290°C (300 to 550°F). The solar energy system will provide approximately 44% of the process heat required.

Pages	Date	Report No.	Contract No.
276	December 1980	SAN/2196-1	ET-78-C-03-2196

Source: NTIS

10. *Design Costs and Performance Comparisons of Several Solar Thermal Systems for Process Heat*

By: Sandia National Laboratories

Conceptual designs of central receiver, parabolic dish, and parabolic trough systems are obtained for several process heat applications. Cost and performance estimates are made for each of these designs and these are used to calculate levelized delivered process heat costs. The results indicate that central receiver systems will provide energy costs competitive with those of parabolic trough and parabolic dish systems over the range of demand sizes and temperatures studied, above 3 MWt and above 93°C (200°F).

Pages		Date	Report No.	Contract No.
Vol. I - Executive Summary	28	March 1981	SAND 79-8279	DE-AC04-76DP00789
Vol. II - Concentrators	74			
Vol. III - Receivers	114			
Vol. IV - Energy Centralization	94			
Vol. V - Systems	78			

Source: NTIS

11. *Solar Production of Industrial Process Steam (Phases II and III)*

By: Acurex Corporation

These documents concern a solar facility supplying 172°C (345°F) process steam to the Johnson and Johnson manufacturing plant in Sherman, Texas. The facility consists of 1070 m^2 (11, 520 ft^2) of parabolic trough concentrating collectors, a 18,921-ℓ (500-gal) flash boiler, and a circulating pump. Phase II summarizes the construction, startup/checkout, costs, and performance of the facility from July 1, 1978, through January 31, 1980. Phase III summarizes costs and performance from January 1, 1980, through March 31, 1981.

Phase II - Fabrication and Installation, Final Report for the Period July 1, 1978, Through January 31, 1980.

Pages	Date	Report No.	Contract No.
136	February 1981	SAN/1713-3	DE-AC-3-77C531713

Phase III - Operation and Evaluation of the Johnson & Johnson Solar Facility, Final Report for the Period January 1, 1980, Through March 31, 1981.

Pages	Date	Report No.	Contract No.
123	March 1981	SAN/1713-3	DE-AC-3-77C531713

Source: NTIS

12. *Solar Industrial Process Heat Markets for Central Receiver Technology*

By: Sandia National Laboratories

This document examines the potential market for solar industrial process heat produced by central receivers. Based on a synthesis of the available information, it is concluded that only two types of central receiver systems need be developed to have a significant impact on industry: (1) systems producing saturated steam up to 287°C (550°F), and (2) systems delivering air up to 650° to 815°C (1200° to 1500°F).

Pages	Date	Report No.
17	April 1980	SAND 80-8214

Source: NTIS

13. *Analysis of Collectors for Process Heat Applications*

By: Sandia National Laboratories

This document estimates the cost effectiveness of a variety of solar collector designs for process heat applications by considering optical efficiency, receiver efficiency, pumping losses, pipe thermal losses, tracking power requirements, and total cost estimates. Evaluated are parabolic dishes, hemispherical collectors, parabolic troughs, tilted reflectors with fixed receivers, semi-cylindrical fixed receivers with fixed reflectors and movable receivers, and linear fresnel lens. Locations considered are Albuquerque, New Mexico, Charleston, South Carolina, and Boston, Massachusetts. Parabolic dishes, parabolic troughs and fresnel lenses were the most cost-effective; hemispherical collectors were not cost-competitive.

Pages	Date	Report No.	Contract No.
26	February 1979	SAND 78-1977	AT (29-1)-789

Source: NTIS

14. *Survey of U.S. Industrial Process Heat Usage Distributions*

By: Sandia National Laboratories

The survey uses 1972 data on United States industrial classifications to estimate the quantity and power range of industrial process heat usage. In terms of number of facilities, small, lower temperature users dominate. In terms of total energy consumed, the larger ones (10 MW thermal and above) dominate.

Pages	Date	Report No.
29	Fall 1980	SAND 80-8234

Source: NTIS

15. *Comparison of Solar Thermal and Fossil Total Energy Systems for Selected Industrial Applications*

By: Oak Ridge National Laboratory

Economic analyses of a conventional system (grid-electric, package-boiler) and total energy systems based on phosphoric acid fuel cells, diesel-piston engines, and central receiver solar thermal systems were performed for each of four industrial applications: a concrete block plant in Arizona, a fluid milk processing plant in California, a sugar beet processing plant in Colorado, and a meat-packing plant in Texas.

A series of sensitivity analyses was performed to show the effects of variations in fuel price, system size, cost of capital, and system initial cost. The effects of changing the allowed business investment tax credit and of eliminating the allowance of fuel cost as an operating expense for tax purposes were also examined.

Pages	Date	Report No.	Contract No.
75	June 1980	ORNL/TM-7022	W-7405-eng-26

Source: NTIS

16. *Solar Industrial Process Heat Conference Proceedings - December 16 - 19, 1980, Houston, Texas.*

By: Solar Energy Research Institute (editors)

This collection of 46 papers presented at the Sixth Annual Solar Industrial Process Heat Conference presents the latest views of the solar industry concerning industrial use of solar. Topics covered include the hardware and performance of past solar industrial demonstration projects, market assessment and survey, commercialization, and the economics of solar for industry. Short papers from contractors' poster sessions include discussions of solar for hot water, hot air, low- and intermediate-temperature steam and high-temperature applications. Summaries of three panel discussions, by solar users, by solar manufacturers and on financing, end the volume.

Pages	Date	Report No.
316	December 1980	SERI/CP-632-952

Source: NTIS, SERI

Electricity Applications

17. *Utility Views on Solar Thermal Central Receivers*

By: Sandia National Laboratories

The content of recent meetings with southwestern U.S. utilities concerning solar thermal central receivers is documented in this report. These meetings focused on identifying technical demonstrations and government incentives.

Pages	Date	Report No.	Contract No.
45	April 1980	SAND-80-8203	DE-AC04-76DP00789

Source: NTIS

18. *Proceedings of the National Conference "The Integration of Solar Energy into Utility System Planning and Strategies: 1980-2000"*

By: The Kansas Power and Light Company and The University of Kansas

Views and information presented at the conference are discussed regarding the following questions: (1) How do utilities develop plans for solar energy in demand forecasting, plant expansion, capital requirements, load management, and customer relations? (2) Which solar technologies will emerge as dominant in the future? (3) What rate of growth in the use of solar energy can be expected by utility managers? (4) How can utilities use information on developments in solar technology in their operations, planning, and management? (5) What part can utilities expect to play in the financing and control of major solar energy technologies?

Pages	Date	Report No.	Contract No.
278	May 1980	None	None

Source: Riordan, CRI

19. *Siting Issues for Solar Thermal Power Plants with Small Community Applications*

By: Jet Propulsion Laboratory

The siting issues associated with small, dispersed solar thermal power plants for utility/small community applications of less than 10 MWe are considered. The siting issues discussed include system resource requirements, environmental effects of the system, and the potential impact of the plant on the environment. The first two sections of the report provide background for the subsequent issue discussions. The introductory section describes the SPSA Project and the requirements for the first engineering experiment and gives the objectives and scope for the report as a whole. A brief overview of solar thermal technologies is followed by a discussion of some technology options.

Pages	Date	Report No.
36	February 1, 1979	DOE/JPL-1060-78/2

Source: NTIS, JPL

20. *A Comparative Ranking of 0.1- to 10-MWe Solar Thermal Electric Power Systems: Volumes 1 & II Final Report*

By: Solar Energy Research Institute

These documents report a comparative analysis of the major generic Solar Thermal Electric Power Systems in the 0.1 to 1 MWe and 1 MWe to 10 MWe ranges. The 0.1 to 1 MWe range was considered primarily for industrial, nonutility applications. Volume I summarizes the results for both 0.1 to 1 MWe and 1 to 10 MWe capacity studies. Volume II contains tabularized system performance summaries, ranking methodology data, and a complete set of key references.

Pages	Date	Report No.	Contract No.
Vol. I - Summary of Results - 157	August 1980	SERI/TR-351-461	3456.10
Vol. II - Supporting Data - 155	July 1980	SERI/TR-351-461	3456.10

Source: NTIS, SERI

21. *Analysis of Public Sector Incentives for the Construction and Operation of Solar Field Experiments: The Case of Solar Thermal Repowering/Retrofit Plants*

By: PRC Energy Analysis Company

Existing energy supply investment incentive options at the federal, regional, and state levels of government were identified and analyzed. Since the thrust was to identify programs of immediate consequence, a requirement existed for a distilling mechanism to sort through the various incentive options available to the public. Private-sector experience in selecting projects was studied, and a scoring model with Delphi inputs from a workshop was used as the distilling mechanism.

Pages	Date
75	July 1980

Source: DOE/STT

22. *Saguaro Power Plant Solar Repowering Project Final Technical Report - Executive Summary*

By: Arizona Public Service Company; Martin Marietta; Badger, Gibbs & Hill, Inc.

This final technical report summarizes the work performed between September 1979 and July 1980 on the conceptual design, cost and performance of the Saguaro Power Plant Solar Repowering Project. This project involved a gas/oil-fired steam-Rankine electric power generation plant, 41 miles north of Tucson, Arizona, to be repowered by a solar thermal central receiver. The report is published in four volumes: Executive Summary; Volume I - Conceptual Design; Volume II - System Requirements Specification; and Volume III - Appendices.

Pages	Date	Report No.	Contract No.
32	July 1980	DOE/SF 10739-1	DE-AC-3-79SF10739

Source: NTIS

23. *Newman Unit 1 Solar Repowering - Final Report - Vol. IA - Executive Summary*

By: El Paso Electric Company

The report describes the conceptual design and cost estimates of the Newman Unit 1 Repowering Project, using central receiver technology. The Newman Unit 1, located near El Paso, Texas, would receive 41 MWe from the solar system as designed.

Pages	Date	Report No.	Contract No.
35	July 1980	DOE/SF-10740-1/1A	DE-AC03-79SF10740

Source: NTIS

24. *Southwestern Public Service Company Solar Repowering Program Final Technical Report - Executive Summary*

By: General Electric Company

General Electric and Southwestern Public Service Company consider solar energy to be a viable alternative to conventional energy sources. After an extensive 9-month study, the companies consider the sodium central receiver to be technically feasible for repowering fossil fuel installations. Additional engineering required to integrate the solar power source with the existing Plant X Unit 3 presents no major technical problem.

The Plant X repowering conceptual design study provides the foundation for construction and operation of a solar demonstration facility. The companies involved conclude that a repowering demonstration facility is needed to develop acceptable experience for the commercial use of solar technology in the nation's utility industry.

Pages	Date	Report No.
28	July 1980	DOE/SF-10740-1

Source: NTIS

25. *Conceptual Design of the Solar Repowering System for West Texas Utilities Company Paint Creek Power Station Unit No. 4 - Executive Summary*

By: Rockwell International; West Texas Utilities Company; Boeing Engineering & Construction; and Sargent & Lundry Engineers

A conceptual design of a 60-MWe, sodium-cooled, solar central receiver repowering system for West Texas Utilities Paint Creek Unit 4 (a 110-MWe gas-fired, baseload unit) is provided. A large number of trade studies and optimizations were carried out to find the most cost-effective design with the greatest potential for widespread application and commercialization. The optimum size for the solar repowering plant was determined to be 60 MWe, with enough thermal storage to provide 4 hours of 60 MWe output, on March 21. The tower is 154 m (505 ft) high, surrounded by 7882 heliostats (each 49 m^2/ 528 ft^2) on 430 acres.

Pages	Date	Report No.
45	July 15, 1980	ESG-80-18

Source: NTIS

26. *Solar Repowering System for Texas Electric Service Company Permian Basin Steam Electric Station Unit No. 5 Final Report - Executive Summary*

By: Rockwell International and Texas Electric Service Company

This report discusses the conceptual receiver repowering system for Texas Electric Service Company's Permian Basin Steam Electric Plant No. 5. The economic assessment shows the specific concept is not now cost-competitive with burning natural gas alone at the existing plant, but the report stresses the need to go ahead with on-line development, since delay may keep solar from developing into a viable option. The solar central receiver system will use 4742 heliostats (each with a mirror area of 564 m^2/607 ft^2), a 10.6 m (34.8 ft) external receiver on top of a 110 m (360.9 ft) tower and provide 1 hour of storage using liquid sodium as the storage medium.

Pages	Date	Report No.	Contract No.
30	July 15, 1980	ESG-80-22	DOE/SF/10607-1/1

Source: NTIS

Agricultural Applications

27. *Agricultural Energy*
Vol. 1: Solar Energy: Livestock Production
Vol. 2: Biomass Energy: Crop Production
Vol. 3: Food Processing

By: American Society of Agricultural Engineers

This three-volume document contains selected papers and abstracts from the 1980 American Society of Agricultural Engineers (ASAE) National Energy Symposium. Over 170 papers discuss such topics as energy losses to the soil surrounding a below-grade solar energy storage pond, solar grain drying, active and passive space and water heating systems, synfuel production, wind power, and process heat applications.

Pages	Date	Report No.
Vol. I - 1-272	March 1981	ASAE Publication
Vol. II - 273-580	April 1981	
Vol. III - 581-671	May 1981	

Source: ASAE

Cogeneration

These final reports provide information on the seven solar cogeneration projects completed in FY 81. They are the result of a DOE Request for Proposal (No. DE-RP03-08SF10768) for "Conceptual Design of a Solar Central Receiver System Integrated with a Cogeneration Facility." They cover a wide range of industrial applications (sugar cane processing, natural gas processing, enhanced oil recovery, sulfur mining and copper smelting) as well as space conditioning and domestic hot water for military bases. All are specific site applications. Some were already cogenerating, while others would add cogenerating capability along with the solar central receiver. Each report contains an executive summary, a main body, and appendices in one or more volumes. They also include facility descriptions, conceptual design details, system performance, economic findings, development plan, and site owner's assessment.

28. *Conceptual Design of a Solar Cogeneration Facility at Pioneer Mill Co., Ltd, Final Report, August 1981, DOE/SF/11431-1.*

29. *Solar Cogeneration Facility, Cimarron River Station, Central Telephone and Utilities - Western Power, Final Report, August 1981, DOE/SF/11439 - 1/1, 1/2, 1/3.*

30. *Conceptual Design of a Solar Cogeneration Facility, Industrial Process Heat (Category A), Final Report, July 1981, DE-AC0380SF11438, Vol. I, Vol. II.*

31. *Texasgulf Solar Cogeneration Program, Final Report, June 1981, DOE/SF/11437-1, 2.*

32. *Solar Central Receiver System Integrated With a Cogeneration Facility for Copper Smelting, Final Report, August 1981, DE-AC03-81SF-11533, Appendix A through I.*

33. *Fort Hood Solar Cogeneration Facility Conceptual Design Study, Final Report, August 1981, MDC G9716 Vol. I, Vol. II (DE-AC03-81SF11495).*

34. *Robins Air Force Base Solar Cogeneration Facility, Final Report, August 1981, AESD-TME-3114 Vol. I, Vol. II (DE-AC03-81SF11494).*

Source: NTIS

Repowering

The following reports describe the technical and economic aspects of 14 conceptual central receiver designs submitted to DOE. Of these, 13 are the result of a DOE Request for Proposal (No. DE-AC03-79SF10506) for "Solar Repowering/Industrial Retrofit Systems." All are conceptual design studies for adding solar central receiver technology to existing plants for utility electrical power generation or industrial process heat applications. Each report contains an executive summary, a main body, and appendices in one or more volumes. They also include facility descriptions, conceptual design details, system performance, economic findings, development plan, and site owner's assessment.

35. *Technical and Economic Assessment of Solar Hybrid Repowering, Public Service of New Mexico/Westinghouse, December 1978, SAN-1608-1, 2.*

36. *Saguaro Power Plant Solar Repowering Project, Arizona Public Service/Martin Marietta, July 1980, DOE/SF/10739-1, 2, 3, 4.*

37. *Newman Unit 1 Solar Repowering, El Paso Electric Company/Westinghouse, July 1980, DOE/SF-10740-1/A, 1.*

38. *Solar Repowering for Electric Generation Northeastern Station Unit 1, Public Service Oklahoma, Black & Veatch/Public Service Company of Oklahoma, July 1980, DOE/SF-10738-1/1, 2, 3.*

39. *Sierra Pacific Utility Repowering, McDonnell Douglas/Sierra Pacific Power Company, July 1980, SAN/0609-1.*

40. *Southwestern Public Service Company Solar Repowering Program, General Electric/Southwestern Public Service, July 1980, DOE/SF-10741-1.*

41. *Conceptual Design of the Solar Repowering System for West Texas Utilities Company, Paint Creek Power Station No. 4, Rockwell International, ESG/West Texas Utilities, July 1980, DOE/SF/11065-1/1, 2.*

42. *Solar Repowering for Texas Electric Service Company Permian Basin Steam Electric Station Unit No. 5, Rockwell International, ESG/Texas Electric Services Company, July 1980, DOE/SF-10607-1/1, 2.*

43. *Solar Industrial Retrofit System North Coles Levee National Gas Processing Plant, Northrup, Inc./Arco Oil and Gas Company, July 1980, DOE/SF/10736-1/1, 2, 3.*

44. *Solar Repowering Industrial Retrofit Systems Category B Solar Thermal -- Enhanced Oil Recovery Systems, Martin Marietta/Exxon Corporation, July 1980, DOE/SF/10737-1/1, 2.*

45. *Gulf Mt. Taylor Uranium Mill Solar Retrofit Solar Repowering Industrial Retrofit Systems Study, McDonnell Douglas/Gulf Research, July 1980, DOE/SF/10608-1/1, 2.*

46. *Solar Industrial Retrofit System for the Provident Energy Company Refinery, Foster Wheeler/Provident Oil Company, July 1980, DOE/SF/10606-1.*

47. *Solar Energy Systems United States Gypsum Plant Solar Retrofit, Boeing Engineering & Construction/U.S. Gypsum Company, DOE/SF-10742-ES, 1, 2.*

48. *Solar Central Receiver Reformer System for Ammonia Plants, PFR Engineering Systems, Inc./Valley Nitrogen Producers, July 1980, DOE/SF/10735-1/1, 2.*

Source: NTIS

C. SAFETY AND ENVIRONMENT

49. *Environmental Readiness Document, Solar Thermal Power Systems*

By: Department of Energy, Asst. Sec. for Environment

The Office of Environment within DOE periodically prepares Environmental Readiness Documents to review and evaluate the environmental status of developing technologies. The document is intended to identify potential environmental problems associated with solar thermal power systems. Included are analysis of ecological effects, health and safety concerns, land use and institutional issues.

Pages	Date	Report No.
30	August 1979	DOE/ERD-0019

Source: NTIS

50. *Worker Health and Safety in Solar Thermal Power Systems Vol. I - Overview of Safety Assessments*

By: University of California, Los Angeles

Some aspects of safety in solar thermal power systems (STPS) have been studied to ascertain ways in which worker health and safety may be protected. Unique STPS hazards are also examined. A data base and methodology for quantitative predictions of injury rate is proposed. The methodology utilizes ordered comparisons of worker activities in STPS and in current industrial practice. Generic and design-specific hazards of thermal energy storage are examined by an event and fault tree methodology. In Volumes II-VI, the effects of the diffuse nature of solar energy on routine hazards are assessed by establishing strawman designs for alternative STPS. Failure rates are estimated from extant data, and preferential rankings of the alternative STPS are made. Hazards of off-normal events in which thermal mismatches exist in receiver and generating subsystems, and the characteristic hazards of solar ponds, are also addressed.

Pages	Date	Report No.
39	October 1979	UCLA 12/1211

Source: NTIS

51. *Worker Health and Safety in Solar Thermal Power Systems*
Vol. VII - The Toxicological and Health Implications of Solar Process Fluids

By: University of California, Los Angeles

The report examines the toxicological and health implications of high-temperature solar thermal process fluids. Fluids are first identified and characterized according to their physical and chemical characteristics, then screened for toxicological effects. A literature search was conducted on the most toxic compounds drawing largely on information from electric utility, petroleum refining, and chemical process industries.

Pages	Date	Report No.
277	October 1980	UCLA 12/1265

Source: NTIS

D. COST AND VALUE DATA AND FINANCING

52. *The Effect of Operating Temperature on the Cost of Energy from Solar Thermal Electric Power Plants*

By: Sandia National Laboratories

The operating temperature of a solar thermal electric power plant controls the efficiency of the collector field, the efficiency of the power generation system and the cost of the thermal energy storage system. This report evaluates the effect of these three items, as temperature is varied, on the annualized cost of energy produced by both stand-alone solar and solar/diesel hybrid power plants. The type of solar power plant considered uses a line-focus distribution collector field and a Rankine cycle power generation system. Systems using different collector performance models, Rankine-cycle working fluids, and thermal energy storage concepts are included in the evaluation.

Pages	Date	Report No.	Contract No.
90	July 1979	SAND 79-0801	DG-AC04-76DP00789

Source: NTIS

53. *Cost/Performance of Solar Reflective Surfaces for Parabolic Dish Concentrators*

By: Jet Propulsion Laboratory

The report discusses materials under consideration for the reflective surfaces of parabolic dish solar concentrators. Some important performance factors for the mirrors are summarized and typical costs are treated briefly. Although much of the data considered are general and applicable to flat or curved solar reflectors, capital investment cost/performance ratios are computed specifically for the parabolic dish concentrators using a mathematical model. The results are given in terms of initial investment cost for reflective surfaces per thermal kilowatt delivered to the receiver cavity for various operating temperatures from 400 to 1400°C (750 to 2550°F). Conventional glass mirrors have the lowest cost/performance ratios, followed closely by aluminum reflectors.

Pages	Date	Report No.
60	July 15, 1979	DOE/JPL-1060-40 JPL Publication 81-2

Source: NTIS, JPL

54. *Municipal Bond Financing of Solar Energy Facilities*

By: Solar Energy Research Institute

The report examines the application of the laws of municipal bond financing to solar facilities, taken broadly to include biomass conversion systems, wind-power installations, ocean thermal systems, solar heating and cooling systems, process heat systems, solar thermal systems, photovoltaic systems, and solar-powered satellites. It discusses the different types of municipal bonds, the legal principles behind them, and laws regarding tax exemptions. The report concludes that legal obstacles to the use of municipal financing can be substantially overcome, but that use will ultimately depend on the technical and economic feasibility of the systems involved.

Pages	Date	Report No.	Task No.
70	December 1979	SERI/TR-434-191	6721.40

Source: NTIS, SERI

55. *The Coupling Between Recurrent and Capital Costs in a Solar Thermal Process Heat System*

By: Sandia National Laboratories

The report models the costs associated with cleaning line-focus solar collectors. The goal is to improve overall understanding of operation and maintenance costs on energy produced from solar collector systems.

Pages	Date
16	January 1979

Source: DOE/STT

E. OPERATION, MAINTENANCE AND TEST RESULTS

56. *1980 Annual Report of the Coolidge Solar Irrigation Project*

By: Sandia National Laboratories

The Coolidge Solar Irrigation Facility at Coolidge, Arizona, consists of a 2136.8-m^2 (23,000-ft^2) line-focus collector subsystem, a 113.55-m^3 (30,000-gallon) thermal storage subsystem, and a 150-kWe (142.2-Btu/s) power generation unit. This document reports the performance of the facility and its operational and maintenance requirements from the facility's initial operation in October 1979 to August 31, 1980.

Pages	Date	Report No.	Contract No.
160	February 1981	SAND 80-2378	DE-AC04-76DP00789

Source: NTIS

57. *Operation and Evaluation of the Willard Solar Power System: Final Report*

By: New Mexico State University; Sandia National Laboratories

The operation of the Willard solar thermal power system is analyzed and evaluated. The 19 kW (25 hp) power system was coupled to a shallow well and sprinkler system near Willard, New Mexico, irrigating approximately 32 hectares. Data on the performance of the major subsystems (collector array, thermal storage, and the organic working fluid Rankine cycle heat engine) is provided.

Pages	Date	Report No.
270	November 1980	13-5004

Source: NTIS

58. *Mid-Temperature Solar Systems Test Facility Predictions for Thermal Performance Based on Test Data*

By: Sandia National Laboratories

Thermal performance predictions based on test data are presented for various solar collectors with glass reflector surfaces, for three different collector output temperatures at five cities in the United States: Fresno, California; Albuquerque, New Mexico; Fort Worth, Texas; Charleston, South Carolina; and Boston, Massachusetts.

Suntec Solar Collector with Heat-Formed Glass Reflector Surface

Pages	Date	Report No.	Contract No.
26	November 1980	SAND 80-1964/2	DE-AC04-76DP00789

Acurex Solar Collector with Glass Reflector Surface (Based on Test Data)

Pages	Date	Report No.	Contract No.
26	April 1981	SAND 80-1964/6	DE-AC04-76DP00789

Solar Kinetics T-600 Solar Collector with FEK 244 Reflector Surface

Pages	Date	Report No.	Contract No.
26	April 1981	SAND 80-1964/9	DE-AC04-76DP00789

Custom Engineering Trough with Glass Reflector Surface and Sandia-Designed Receivers

Pages	Date	Report No.	Contract No.
26	May 1981	SAND 80-1964/10	DE-AC04-76DP00789

Polisolar Model POL Solar Collector with Glass Reflector Surface

Pages	Date	Report No.	Contract No.
26	May 1981	SAND 80-1964/11	DE-AC04-76DP00789

Source: NTIS

59. *Solar Production of Industrial Process Heat Hot Water: Operation and Evaluation of the Campbell Soup Hot Water Solar Facility*

By: Acurex Corporation

The report summarizes the operation and evaluation of a solar hot water facility designed by Acurex Corporation and installed in November 1977 at the Campbell Soup Company canning plant in Sacramento, California. The period of evaluation was from October 1979 through September 1980. Hot water for washing empty soup cans before they are filled is provided by 413.8 m^2 (4455 ft^2) of flat plate collectors and 267.5 m^2 (2880 ft^2) of parabolic trough concentrators (east/west orientation) with 65 m^3 (17,150 gal) of storage.

Pages	Date	Report No.	Contract No.
157	December 1980	SAN/1218-4	DE-AC03-76CS31218

Source: NTIS

60. *Heliostat Operation at the Central Receiver Test Facility, 1978-1980*

By: Sandia National Laboratories

The data and conclusions presented in this report are for the operation of the Central Receiver Test Facility (CRTF) using 222 CRTF heliostats from 1978 through 1980. The CRTF beam produces a total power of 5.5 MWth and a peak intensity of 2250 kW/m^2 near solar noon. A new safe operating strategy has recently been implemented, as well as improvements in the targeting accuracy. The mirror reflectivity is maintained near 80% by cleaning with natural rains or snow. The CRTF had logged almost 300,000 operating hours by the end of 1980.

Pages	Date	Report No.	Contract No.
27	May 1981	SAND 81-0275	DE-AC04-76DP00789

Source: NTIS

61. *Systematic Rotation and Receiver Location Error Effects on Parabolic Trough Annual Performance*

By: Sandia National Laboratories

The effects of certain systematic errors on performance and their influence on the design of parabolic troughs are covered. Systematic rotation error is the angle between the reflector vertex-focus axis and the vertex-sun axis; systematic receiver location error is the vertical deviation of a receiver from focus. Systematic rotation errors of 0.016 radions result in annual performance degradation of greater than 30%. Systematic receiver location errors can have a similar effect depending upon magnitude. Techniques for calculating the influence of systematic errors on performance are given and methods for identifying and minimizing these errors are suggested.

Pages	Date	Report No.	Contract No.
21	April 1981	SAND 81-0159	DE-AC04-76DP00789

Source: NTIS

F. TECHNOLOGIES

Parabolic Troughs

62. *Proceedings of the Line-Focus Solar Thermal Energy Technology Development: A Seminar for Industry (Albuquerque, NM, September 9, 10, 11, 1980)*

By: Sandia National Laboratories

This document contains the proceedings of the titled line-focus seminar. Approximately 50 authors contributed to the document, which contains 49 papers in the following areas: overview; line-focus system development, subsystem development, and component development; material development; and instrumentation development.

Pages	Date	Report No.	Contract No.
354	February 1981	SAND 80-1666	DE-AC04-76DP00789

Source: NTIS

63. *Design Considerations for Solar Industrial Process Heat Systems - Nontracking and Line-Focus Collector Techniques*

By: Solar Energy Research Institute

This document lists items that should be considered in each aspect of designing a solar industrial process heat system using flat-plate, evacuated tube, and line-focus collectors. Qualitative design considerations are stressed, providing the experienced designer with both a checklist and valuable information for designing new systems. A glossary of technical terms and an appendix listing further sources of information is included.

Pages	Date	Report No.	Task No.
55	March 1981	SERI/TR-632-783	1011.00

Source: NTIS, SERI

64. *Thermally Formed Half-Parabola Glass Panels: Final Report*

By: Ford Aerospace and Communications Corporation; Western Development Laboratories Division; and Sandia National Laboratories

This final report presents the results of a contract between Ford Aerospace and Communications Corporation and Sandia National Laboratories covering the manufacturing of prototype solar panels and a related manufacturing analysis. The contract involved using windshield-forming technology to form flat glass into the curves needed for solar trough concentrators. The report concludes that a griddled fixture design concept is viable for short-term prototype production, but recommends exploring air float gas hearth processes for long-range, high-volume production.

Pages	Date	Report No.	Contract No.
64	January 1981	SAND 80-7158	DE-AC04-76DP00789

Source: NTIS

65. *Solar Thermal Energy: Abstracts of a Special Seminar for Industry*

By: Sandia National Laboratories

This document is a compilation of abstracts from eleven papers presented at the Modular Industrial Solar Retrofit (MISR) Conference, held in Albuquerque, NM, February 3 and 4, 1981, under the sponsorship of the Department of Energy and Sandia National Laboratories. The papers were presented in four sessions: technology status and the MISR Project, MISR System Design Request for Proposal, MISR field experiments, and seminar attendees' participation.

Pages	Date	Report No.	Contract No.
32	February 3-4, 1981	SAND 81-0373	DE-AC04-76DP00789

Source: NTIS

66. *Fluid Temperature Control for Parabolic Trough Solar Collectors*

By: Sandia National Laboratories

Computer simulation studies of temperature control techniques for heat transfer fluid in parabolic trough solar collector fields are discussed. Of particular interest is whether these fields can meet the temperature generation requirements for cogeneration systems. The results indicate that the temperature control requirements can be satisfied using readily available components.

Pages	Date	Report No.	Contract No.
34	June 1980	SAND 80-7158	DE-AC04-76DP00789

Source: NTIS

67. *Evaluation of Line Focus Solar Central Power Systems, Vol. I & II*

By: Energy Resources Division
The Aerospace Corporation

The report describes Aerospace Corporation's analysis and evaluation of three designs based on line-focus technology, and compares their potential with that of the central receiver point-focus concept. The three designs are a BDM Corporation parabolic trough collector system with a conventional low-pressure non-reheat steam cycle; a General Atomic solar collector with fixed mirror/tracking receiver design and a draw-salt working fluid; and an SRI International system with heliostats and a tower-mounted line receiver using a high-pressure reheat system cycle. Volume I is the Executive Summary; Volume II contains the System Evaluation and Appendices.

Pages	Date	Report No.	Contract No.
Vol. I - 24	March 1980	ATR-80 (77773-03)	EY-76-C-03-1101 (PA#14)
Vol. II - 130	March 1980		

Source: NTIS

68. *Line-Focus Solar Central Power System, Phase I, Vol. II, Final Report*

By: SRI International

This is the final document for the Phase I study of the Line-Focus Central Power System. It contains a summary of the system analysis, parametric analysis, selection and conceptual design of the optimized system, and the determination of markets for solar line-focus central power plants.

Pages	Date	Report No.	Contract No.
419	April 1980	DOE/ET/20550	AT03-76ET20550

Source: NTIS

Central Receivers

69. *Solar Power Tower Design Guide*

By: Sandia National Laboratories

This document is intended to aid an energy user to make a preliminary evaluation of whether a solar central receiver plant is technically and economically feasible and desirable for the user's application. The main text provides information to assist private sector planners, engineers, and operators by describing and explaining the cost elements, performance, and operation of solar central receiver systems. It includes 37 illustrations, 12 tables, a glossary of terms, and a summary of heliostat specifications.

Pages	Date	Report No.
130	April 1981	SAND 81-8005

Source: NTIS

70. *1980 Solar Central Receiver Technology Evaluation*

By: Sandia National Laboratories

A task force of Sandia National Laboratories, Livermore, personnel reviewed and evaluated the status of solar central receiver technology as of early 1980. The methodology and results of the evaluation are described. The evaluation concentrated on the detailed component and system designs developed by industrial firms; the conclusions are based on these designs, and recommendations for the allocation of DOE R&D resources within the solar central receiver program are given. Application of central receiver technology to industrial process heat is also briefly discussed.

Pages	Date	Report No.	Contract No.
50	October 1980	SAND 80-8235	DE-AC04-76DP00789

Source: NTIS

71. *Solar Central Receiver Fuels and Chemicals Project Status Report - October, 1980 to June, 1981*

By: Sandia National Laboratories

This report describes solar central receiver fuels and chemicals project activities at Sandia National Laboratories, Livermore, in the period October 1980 to June 1981. During this time several fuels and chemicals processes were studied and ranked according to four comparative criteria: process maturity, solar integration, market potential and competitive economics. Two processes, ethane pyrolysis and steam reforming of methane, were selected for further study. The report describes the study criteria, status of ongoing work, and future activities.

Pages	Date	Report No.
25	August 1981	SAND 81-8232

Source: NTIS

Parabolic Dishes (Point-Focusing Distributed Receiver Systems)

72. *Parabolic Dish Solar Thermal Power Annual Program Review Proceedings*

By: Jet Propulsion Laboratory

These proceedings present the papers and panel discussions given at the Parabolic Dish Solar Thermal Power Annual Program Review held in Pasadena, California on January 13-15, 1981. It was sponsored by the U.S. DOE and conducted by Jet Propulsion Laboratory.

The objective of the review was to present the results of activities of the Parabolic Dish Technology and Applications Development portion of DOE's Solar Thermal Energy Systems Program. Thirty-four papers were presented on the subjects of development and testing of concentrators, receivers, and power conversion units; system design and development for engineering experiments; economic analysis and market assessment; and advanced development activities. Two panel discussions were held regarding technology development issues and application/user needs.

Pages	Date	Report No.
206	May 1, 1981	DOE/JPL 1060-46

Source: JPL

73. *Annual Technical Report for the Point-Focusing Distributed Receiver Technology Project: Volume I: Executive Summary; Volume II: Detailed Report; Fiscal Year 1979.*

By: Jet Propulsion Laboratory

This report details accomplishments of the Point-Focusing Distributed Receiver (PFDR) Technology Project to produce thermal and electrical power using parabolic dish technology. It covers developments in dish components (concentrators, receiver and heat transport networks, power conversion equipment), manufacturing techniques, system engineering, and system testing.

A focus of this program is to develop industrial capability and system designs which will enable power produced by PFDR technology to be economically competitive with other energy sources. Studies included designs of modular units utilizing various engine designs. The Brayton-cycle engine is regarded as the most promising electrical energy convertor to meet the program's near-future needs.

Pages	Date	Report No.
Vol. I - 37	April 1, 1980	DOE/JPL-1060-30, Vol. 1
Vol. II - 140		DOE/JPL-1060-30, Vol. 2

Source: JPL

74. *Proceedings of the First Semi-Annual Distributed Receiver Systems Program January 22 - 24, 1980, Lubbock, Texas*

By: Jet Propulsion Laboratory

These proceedings present the 38 papers given at the First Semi-Annual Distributed Receiver Systems Program Review held in Lubbock, Texas, January 22 - 24, 1980. It was sponsored by the U.S. DOE, Jet Propulsion Laboratory, Sandia Laboratories, Albuquerque, and Texas Tech University. Papers cover the developments in parabolic dish concentrator design, production of parabolic dish concentrators, receivers, power conversion equipment, hardware tests and evaluation, mass production costing, and applications of distributed receiver systems including parabolic dishes, hemispherical bowls and parabolic troughs.

Pages	Date	Report No.
262	April 15, 1980	DOE/JPL-1060-33

Source: JPL

75. *Chemical Energy Storage Systems Screening and Preliminary Selection*

By: Jet Propulsion Laboratory

This report (one of two) describes the first part of a two-part study on chemical storage and transport of solar-derived thermal energy. Both topical reports were prepared in support of an overall study that is assessing the use of paraboloidal dish solar thermal systems for high temperature industrial applications. This effort is being conducted by the Advanced Systems Definition task of the Research and Advanced Development element of the Solar Thermal Power Systems Project at Jet Propulsion Laboratory (JPL).

The first part of the study focuses on (1) identifying and collecting a comprehensive list of candidate reversible chemical reaction cycles; (2) screening these cycles to a (mainly qualitative) set of criteria (stressing exothermic temperatures of 426°C [800°F] or higher, and eliminating those creating operational problems involving transport of solid chemical components); and (3) selecting a list of the ten best candidates, on the basis of reaction characteristics, for further evaluation. This further evaluation concentrates on the chemical engineering and cost analyses of the selected ten candidates, and is discussed in the second part of this study, "A Chemical Engineering and Cost Study of Energy Transport and Storage Systems Using Reversible Chemical Reactions".

Pages	Date	Report No.
81	August 1980	JPL 5105-40

Source: JPL

76. *Secondary and Compound Concentrators for Parabolic Dish Solar Thermal Power Systems*

By: Jet Propulsion Laboratory

This report discusses the addition of secondary optical elements, such as a Fresnel lens or a mirror, to a parabolic dish solar concentrator to increase the geometric concentration ratio attainable at the given intercept factor. At a fixed intercept factor, higher overall geometric concentration may be obtainable with a long focal length primary and a suitable secondary to increase the geometric ratio if the receiver temperature is high and errors in the primary are large. Using secondaries may reduce cost by allowing the receiver and power conversion equipment to be located closer to the ground, and by eliminating the heavy structure needed to support the equipment at the primary focus. This report discusses which folded-path configurations are the most promising and identifies areas that need further research in the use of secondary and compound concentrators.

Pages	Date	Report No.
39	April 15, 1981	DOE/JPL-1060-43

Source: JPL

77. *The Small Community Solar Thermal Power Experiment*

By: Jet Propulsion Laboratory

This report describes the Small Community Solar Thermal Power Experiment (SCSE), a JPL-managed project to build a pilot 500 kW parabolic dish electric plant in a small community chosen through a competitive process. The report gives the project's objectives and management; describes system component hardware, plant design, and construction schedule; identifies the six semi-finalist communities for the sites; and discusses parabolic dish applicability to small community electrical generation needs in general.

Pages	Date	Report No.
47	January, 1981	5105-52, Rev. A

Source: JPL

Hemispherical Bowls

78. *Crosbyton Solar Power Project: Volume VII: Performance and Cost of Solar Gridiron Electric Power Plants*

By: Texas Tech University

This lengthy report describes the Crosbyton Solar Thermal Hemispherical Bowl Project in Lubbock, Texas. It includes a description and operating results of the existing 10-kWe experimental bowl; and discusses the proposed 5-MWe, 10-bowl solar gridiron pilot electric facility's performance prediction, analysis and costs. Chapter 1, "Introduction to the Project," may be made available as a separate Executive Summary. This volume follows six past project reports describing preliminary analysis and design of the project.

Pages	Date	Report No.
Executive Summary - 30	December 1979	Not yet assigned
Vol. VII - 300 (approx.)		

Source: Jan. 1982 - July, 1982: George Pappas, Department of Energy, Albuquerque Operations Office, (505) 846-5205; after July, 1982: NTIS

Solar Ponds

79. *Solar Ponds*

By: Solar Energy Research Institute

A compendium of analyses on solar ponds was performed at SERI in 1979 to investigate the performance, economics, applications and total quad potential of the primary types of non-convecting salt-gradient ponds, and the two types of convecting ponds, shallow solar and deep saltless; and to determine the relative advantages and disadvantages of various types of solar ponds. The report concludes that solar ponds have potential for displacing very significant quantities of conventional energy, and notes that further development and demonstration work is needed to research basic unresolved issues of identifying least-cost salt sources of salt-gradient ponds, and surface glazings and night insulation for saltless ponds.

Pages	Date	Report No.
43	April 1980	SERI/TR-351-587

Source: SERI

80. *Comparison of Solar Pond Concepts for Electrical Power Generation*

By: Battelle Pacific Northwest Laboratories

A detailed report which identifies the major types of solar pond designs for electric power generation, including the salt-gradient solar pond, convective ponds with membranes or gels, and shallow convecting ponds; analyzes and compares their performance; and estimates ponds and power plant system costs.

Overall conclusions were that electricity production was not cost-competitive based on then-current central station power production technology; cost might be warranted for specific circumstances such as isolated costs; if technical practicability is established, solar ponds could be competitive with other energy sources in some circumstances; and there are a number of problems which could prevent ponds from being widely used.

Pages	Date	Report No.
117	October 1975	BNWL-1951

Source: NTIS

81. *Miamisburg Salt-Gradient Solar Ponds: Mid-1980 Status Report*

By: Monsanto Research Company Mound Facility

A brief report which reviews the design, two-year performance and overall costs of the City of Miamisburg, Ohio's solar pond built to provide thermal energy to an outdoor swimming pool in summer and to a recreational building in winter. Two main operational concerns, corrosion of the metallic heat exchanger and the failure of selected seams in the plastic pond liner, are discussed. Suggestions are made to prevent or minimize problems with future ponds.

Pages	Date	Report No.
22	Spring 1981	CONF-800737-1

Source: NTIS

82. *Status Report - Salton Sea Solar Pond Power Plant*

By: Jet Propulsion Laboratory

This report describes the feasibility study results and concept for a prototype 5-MWe solar salt pond electricity generation plant at the Salton Sea in Southern California. This project, funded jointly by the U.S. DOE, the California Energy Commission and Southern California Edison, is managed by Jet Propulsion Laboratory and subcontracted to Ormat Turbines, Ltd. (designers of the Israeli solar salt pond installations,) and WESTEC Services. The report describes the prototype concept, discusses problems of water clarity and other environmental considerations and long-range plans for a potential commercial-scale plant of 12 50-MWe modules in 1990. This paper was presented at the International Solar Energy Society's American Section conference in Philadelphia, May, 1981.

Pages	Date	Report No.
4	May 1981	None-unpublished by govt.

Source: Write Bob French, Jet Propulsion Laboratory, Mail Stop 507-228,
4800 Oak Grove Drive, Pasadena, CA 91109.

83. *Salton Sea Project Phase 1, Final Report*

By: Jet Propulsion Laboratory

This report presents the final results of the feasibility study made for a salt-gradient solar pond power plant in or near the Salton Sea of California. The report covers systems design, environmental considerations, water and soil chemistry, dike construction, computer modeling, tradeoff studies, the potential of solar ponds for generating electric power, and cost considerations. The report recommends that the project should continue into Phase 1a, Conceptual Design.

Pages	Date	Report No.
121	January 1982	JPL 5107-2

Source: JPL

84. *Conference on Solar Ponds: The Salt-Gradient Concept for Thermal and Electrical Energy*

By: Jet Propulsion Laboratory

This report contains viewgraphs from the 11 talks given at a one-and-a-half day conference conducted by JPL for the Industrial Associates Office of the California Institute of Technology. Topics covered include a general presentation of solar salt pond design; discussion of the Salton Sea project; specific discussion of various applications of solar ponds such as for small stand-alone systems, desalination, and the mining industry; and issues related to use of solar ponds including chemistry of a pond and environmental impacts of ponds. While the viewgraphs are limited in use without texts of the oral presentations, they are useful for a knowledgeable reader wanting more specific up-to-date facts about solar pond research.

Pages	Date	Report No.
171	May 15, 1981	JPL 5105-85

Source: JPL

Supporting Systems

85. *Design Study of a Kinematic Stirling Engine for Dispersed Solar Electric Power Systems, Final Report*

By: United Stirling (Sweden)

This study describes the processes and results which have led to the detail design of an efficient Stirling engine generator with concentrated solar radiation heat input. Various conceptual designs were evaluated and developed for both a free-piston and kinematic Stirling engine for small dispersed solar-powered applications in identical parallel path programs.

The study performed configuration definition studies, including a detailed parametric evaluation of the selected concepts, with a final ranking of all attractive configurations; these included single and multiple cylinder engines with rhombic and crank shaft drive, different seal systems and heat exchanger arrangements. For the conceptual design, a 4-cylinder double crank shaft engine with annular regenerators was selected; with the power level increased to 20 kWe output from the alternator.

Pages	Date	Report No.	Contract No.
103	1980	NASA CR-159588 or DOE/NASA/005679/2	DEN 3-56

Source: NTIS

86. *Electrochemical Energy Storage Systems for Solar Thermal Applications*

By: Jet Propulsion Laboratory

This report evaluates existing and advanced electrochemical storage and inversion conversion systems that may be used with terrestial solar-thermal power systems. It assesses the status, cost and performance of existing storage systems, and projects the cost, performance and availability of advanced systems. A prime consideration is the cost of delivered energy from plants utilizing electrochemical storage.

The report addresses three broad areas: (1) the electrochemical, or battery, component of the storage system; (2) the balance of the system, or all components other than the battery; and (3) the overall solar-thermal plant with electrochemical storage. Included in the latter area is a tabulation of the levelized costs of delivered energy from complete plants with 16 different, advanced electrochemical systems. This tabulation ranks the systems in order of economic attractiveness.

The results of the study indicate that the five most attractive electrochemical storage systems are the iron-chromium redox (NASA LeRC), zinc-bromine (Exxon), sodium-sulfur (Ford), sodium-sulfur (Dow), and zinc-chlorine (EDA).

Pages	Date	Report No.
120	March 1, 1980	DOE/JPL-1060-30, Rev. 1

Source: JPL

Insolation Resource Assessment

87. *Insolation Resource Assessment Program Contractors Annual FY 80 Review and Report*

By: Solar Energy Research Institute

This document contains papers on the Insolation Resource Assessment Program in three sessions: solar energy meteorological research and training sites (university grants); NOAA, SERI, and Canadian insolation assessment and research projects; and national labs and contractor insolation assessment and research projects.

Pages	Date	Report No.	Contract No.
151	August 19-21, 1980	SERI/CP-642-977	EG-77-C-01-4042

Source: NTIS, SERI

G. INFORMATION USER STUDIES

88. *Solar Thermal Electric Power Information User Study*

By: Solar Energy Research Institute

This report describes the results of a series of telephone studies of potential users of information on solar thermal electric power (STEP) conducted as part of a larger study concerning information of all solar electric technologies. The report identifies specific solar thermal information user group needs, the priority of those needs, and methods of disseminating information to each group. The report includes discussion of sample size, sample characteristics and survey design.

Pages	Date	Report No.	Contract No.
172	February 1981	SERI/TR-751-750	EG-77-C-01-4042

Source: NTIS, SERI

89. *Solar Information User Priority Study*

By: Solar Energy Research Institute

This report identifies, for each solar technology, those members or potential members of the solar community who, either currently or in the future, will require solar information. In addition, it rates each user's relative need for information within the subsequent three years. The information was intended to serve as a basis for information product and data base development for the Solar Energy Information Data Bank (SEIDB).

Pages	Date	Report No.	Contract No.
74	May 1980	SERI/TR-751-472	EG-77-C-01-4042

Source: NTIS, SERI

H. COMPONENT MANUFACTURING TECHNIQUES

90. *Heliostat Production Evaluation and Cost Analysis*

By: General Motors Corporation

This report is an extensive analysis of how the costs of heliostats are related to the quantity produced. The objective is to evaluate whether mass production will significantly reduce costs. The report focuses on the factory production costs of the McDonnell Douglas Astronautics Company Solar Central Receiver prototype heliostat. Factory cost is the sum of all costs necessary to place a finished product on the dock ready to ship. The report is printed in two volumes, an Executive Summary and the report itself. At an annual heliostat production rate of 25,000, factory cost/m^2 = \$95.80, installed cost/m^2 = \$122.12. For a production rate of 250,000, factory cost/m^2 = \$67.31, installed cost/m^2 = \$89.48.

Pages	Date	Report No.	Contract No.
Executive Summary - 24	December 1979	SERI/TR-8052-2	EG-77-C-01-4042
Full Report - 338	December 1979	SERI/TR-8052-1	EG-77-C-01-4042

Source: NTIS, SERI

Appendix B
List of Acronyms and Abbreviations

LIST OF ACRONYMS AND ABBREVIATIONS

ADVS	analog design verification system
AGT	advanced gas turbine
BPNL	Battelle Pacific Northwest Laboratory
CMTF	Collector Module Test Facility
CPC	compound parabolic cusp, compound parabolic concentrating
CRS	central receiver system
CRTF	Central Receiver Test Facility
CTU-WP	Central Telephone and Utilities-Western Power
CY	calendar year
DCS	distributed collector system
DOD	Department of Defense
DOE	Department of Energy
EC	executive committee
EPA	Environmental Protection Agency
ESG	Energy Systems Group (Rockwell)
ETEC	Energy Technology Engineering Center
FACC	Ford Aerospace Communications Corporation
FMDF	fixed-mirror, distributed-focus
FY	fiscal year
GE	General Electric
GRC	glass-reinforced concrete
HSLA	high-strength, low-alloy
IEA	International Energy Agency
IPH	industrial process heat
JPL	Jet Propulsion Laboratory
kWe	kilowatts electric
kWt	kilowatts thermal
MAN	Maschinenfabrik Augsburg - Nurnberg
MATM	matrix approach to testing mirrors
MDAC	McDonnel/Douglas Astronautics Corporation
MISR	Modular Industrial Solar Retrofit
MWe	megawatts electric
MWt	megawatts thermal
NASA	National Aeronautics and Space Administration
NEAR	Nielsen Engineering and Research
NMSU	New Mexico State University
NOAA	National Oceanic and Atmospheric Administration
NRL	Naval Research Laboratory
ORC	organic Rankine cycle
PCA	power conversion assembly
PDTS	Parabolic Dish Test Site
PG&E	Pacific Gas and Electric
PKI	Power Kinetics, Inc.
PRDA	Program Research and Development Annoucement
R&AD	research and advanced development
RF	radio frequency
RFP	Request for Proposal
SAGT	solarized advanced gas turbine
SAI	Science Applications, Inc.
SAN	DOE San Francisco Operations Office
SCR	surface-enhanced Raman
SER	silicon-controlled rectifier
SERI	Solar Energy Research Institute
SNLA	Sandia National Laboratories, Albuquerque
SNLL	Sandia National Laboratories, Livermore
SRE	subsystem research experiment
SRI	Stanford Research Institute
SSPS	Small Solar Power Systems
STAR	solar tracking angle reference
STEP	Solar Total Energy Project
STI	Solar Turbines International
STMPO	Solar Ten-Megawatt Project Office
STTF	Solar Thermal Test Facilities
TBC	Test Bed Concentrator
TMY	Typical Meteorological Year
UA	Users' Association
UV	ultraviolet

Appendix C
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