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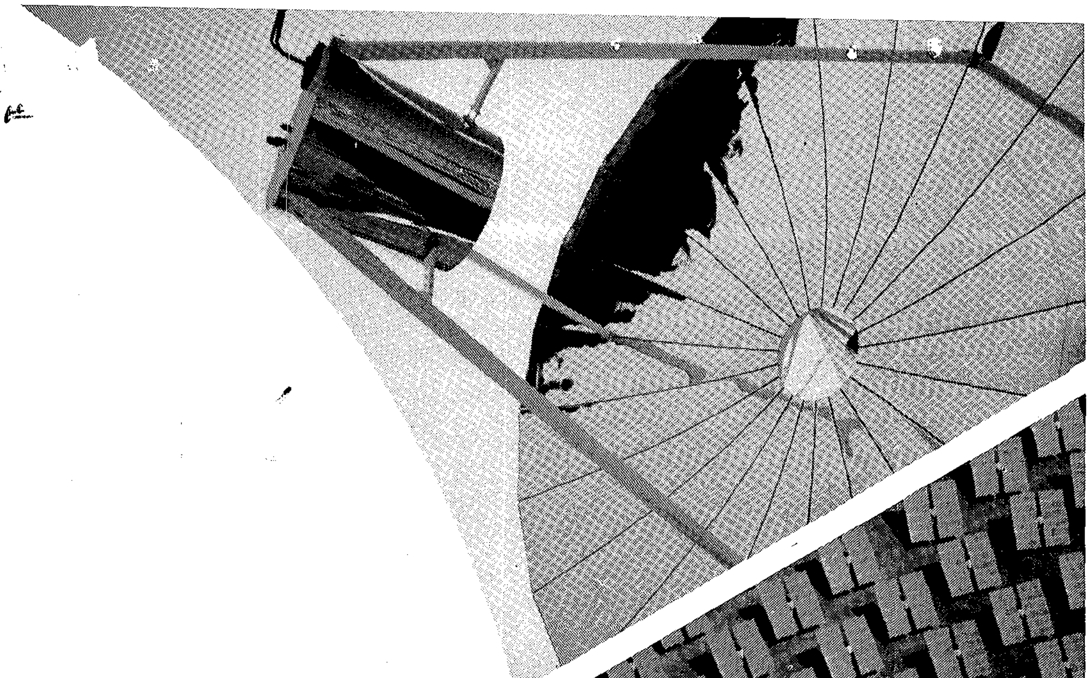

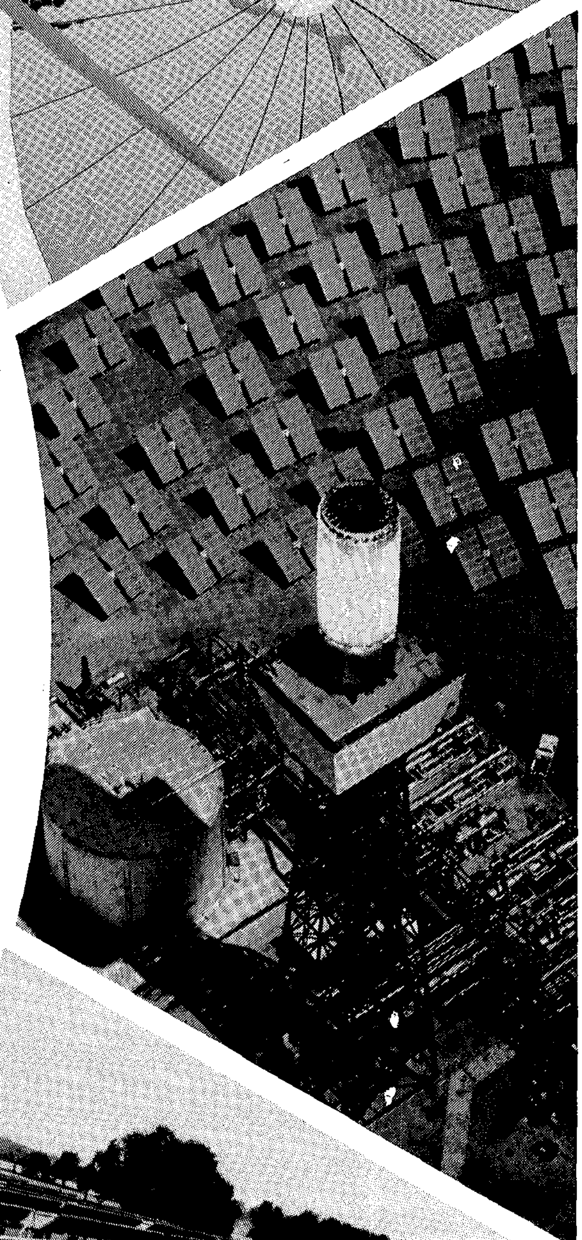

Solar Thermal Technology

Annual Evaluation Report Fiscal Year 1982

Volume I: Executive Summary

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July 1983

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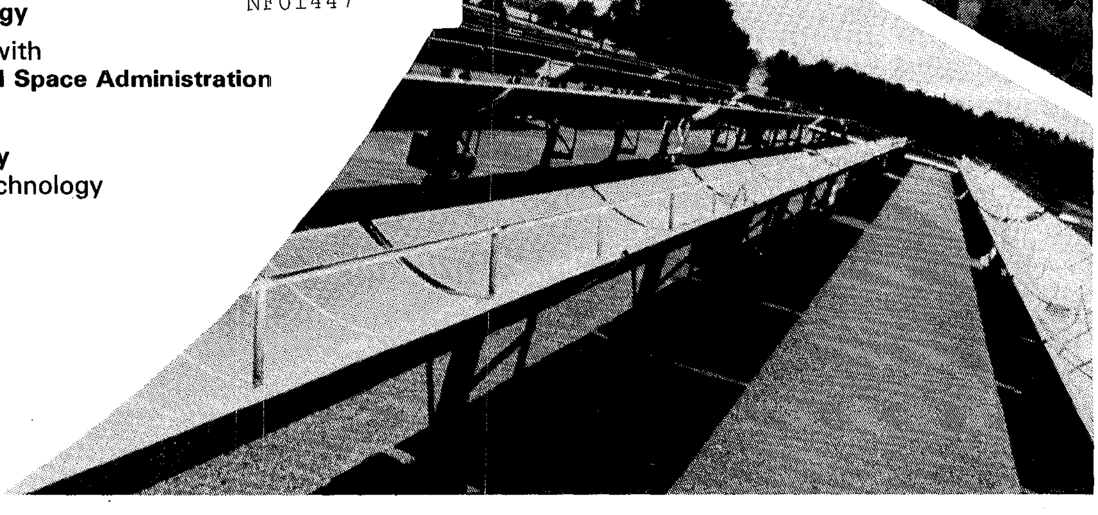
Prepared for
U.S. Department of Energy
Through an Agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California



JPL Publication 83-60

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ABSTRACT

This report, which is divided into two volumes, documents the accomplishments and progress of the U.S. Department of Energy Solar Thermal Technology (STT) Program during FY 1982, covering the period from October 1, 1981 to September 30, 1982. The focus of the STT Program is research and development leading to the commercial readiness of three primary solar thermal concepts: the central receiver, parabolic dish, and parabolic trough. To a lesser extent, the hemispherical bowl and salt-gradient solar pond are also being studied. This development effort is complemented by numerous research and planning activities.

Volume I, the Executive Summary, contains a brief description of each technology and highlights of the fiscal year's technical activities. Volume II details FY 1982 accomplishments and includes a bibliography, list of contacts, acronyms, and definition of terms relevant to solar thermal technology and the STT Program.

ACKNOWLEDGMENTS

The work described herein was carried out by various research organizations and government laboratories, including the Jet Propulsion Laboratory, Sandia National Laboratories, and the Solar Energy Research Institute, their contractors, and supporting universities for the U.S. Department of Energy directly and through its field operation offices in Albuquerque, New Mexico, and San Francisco, California. This report was coordinated by the STT Program's Technical Program Integrator at Sandia National Laboratories in Livermore, California; it was published by the Jet Propulsion Laboratory, California Institute of Technology, for the U.S. Department of Energy through an agreement with the National Aeronautics and Space Administration (NASA Task RE-152, Amendment 342; DOE-Sandia/NASA Interagency Agreement No. 92-9458).

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SECTION I

INTRODUCTION AND SYSTEMS DESCRIPTION

Solar thermal systems offer a significant potential energy source for a wide range of applications, including industrial process heat, electrical generation, cogeneration (total energy), and fuels and chemicals production. Through the research and development efforts described in this evaluation report, the Solar Thermal Technology Program of the U.S. Department of Energy (DOE) is establishing a firm base upon which the private sector can build a viable, self-supporting industry. Fiscal year 1982 activities have brought solar thermal technology closer to being reliable, mass-producible, and cost-competitive for widespread production and use.

Solar thermal technologies use the sun's energy to produce heat, which can be used directly as process heat in industrial and agricultural applications, be converted to mechanical or electrical power, or used in endothermic chemical reactions for producing fuels and chemicals. The focus of the DOE Solar Thermal Technology Program is the development of three primary solar thermal concepts: the central receiver, parabolic dish, and parabolic trough. To a lesser extent, two other concepts, the hemispherical bowl and salt-gradient solar pond, are also being studied.

In a central receiver system, a field of computer-guided heliostats (mirrors) focuses sunlight onto a large tower-mounted receiver. The concentrated heat energy absorbed by the receiver can be transferred to a circulating working fluid to power an electric generator or provide heat for industrial or chemical processes. Part of the heated working fluid may be diverted to an energy storage subsystem that allows the power plant or factory to operate during non-solar hours.

Parabolic dish systems use point-focusing collectors that track the sun in two axes and focus radiant energy onto a receiver at the focal point of the paraboloidal concentrator. Each dish module can be used alone or in multi-module systems. Energy from a heat transfer fluid circulating through the receiver can be converted directly into electrical energy by using a heat engine/generator coupled to the receiver, or the heat can be used in endothermic processses for production of fuels or chemicals. Alternatively, the total thermal output from a field of collectors can be transported to a central heat exchanger for direct use or conversion to mechanical and/or electrical energy.

Parabolic troughs are U-shaped collectors lined with a highly reflective material that concentrate sunlight onto a linear receiver tube positioned along the focal line of the trough. A fluid in the receiver is heated by the radiant energy and then transported to the point of use by means of a piping network designed to minimize heat loss. As with central receivers and parabolic dishes, the hot fluid can be used directly or converted to mechanical or electrical power. Troughs are principally used for process heat applications because they operate at lower temperatures (up to 400°C) than central receivers or dishes, which operate up to 1000 and 1500°C, respectively.

Energy conversion using a stationary hemispherical bowl is accomplished as sunlight, reflected off the surface of the bowl, heats a linear receiver suspended above the bowl cavity. The receiver, a hollow tube surrounded by a spiraling coil, is moved to maintain a position at the focal line of the bowl's reflecting surface. Water is piped along one of the receiver supports, is fed into the tube, and flows to the lower end of the receiver. The heat absorbed by the receiver converts the water to steam, which rises up through the spiral coil. The steam can be drawn off to power a turbine and produce electricity, or it can be used directly as process heat. The system operates with steam at temperatures and pressures of around 550°C and 7 MPa.

Salt-gradient solar ponds are bodies of still, salt (saline) water that collect solar energy and store it as thermal energy. Natural convection (the rising to the surface of warm water as its density decreases) is suppressed by maintaining a stable density gradient of dissolved salts. A high salt concentration is maintained by pumping in concentrated brine near the pond's floor. At the same time, low salt concentration is maintained near the surface by feeding low-density water into the top layer. To generate electricity, hot brine is drawn from the bottom layer of the pond and pumped to an evaporator where a liquid with a low boiling point is vaporized. The vapor then flows under pressure to a turbine/generator for electricity production.

SECTION II

FY 1982 ACCOMPLISHMENTS IN TECHNOLOGY DEVELOPMENT

A. CENTRAL RECEIVER TECHNOLOGY

Systems experiments and analyses in the central receiver area included the 10-MWe Central Receiver Pilot Plant near Barstow, California; the Small Solar Power Systems Project near Almeria, Spain; and the Molten Salt Electric Experiment under construction at the Central Receiver Test Facility in Albuquerque, New Mexico.

The 10-MWe pilot plant (Figure 1), the world's largest solar electric generating station, is a cooperative effort between the U.S. Government, state governments, and utilities to demonstrate technical feasibility, economic potential, and environmental acceptability of the solar thermal central receiver concept. The plant integrates operation of the following major systems: collector, receiver, thermal storage, master control, turbine/generator, and beam characterization. Early in 1982, start-up and testing were hampered by long periods of cloud cover. A major milestone was reached in April 1982 when the plant first delivered electricity to the Southern California Edison grid. This accomplishment signaled the official conclusion of the construction phase. Routine weekend power production began in July, and a two-year test and evaluation phase was initiated in August 1982. Three activities are being performed concurrently during this phase: checkout of all plant operating modes, upgrading of operational displays and incorporation of automatic control, and testing and evaluation of plant performance.

Operation of the central receiver system of the International Energy Agency Small Solar Power Systems Project near Almeria, Spain, has been limited during FY 1982 by bad weather and hardware problems. For example, lightning struck a power line connected to the site, leaks occurred in the motor of the sodium pump that supplies sodium to the steam generator from the hot storage vessel, condensation seeped into the cylinders of the power conversion system steam motor, and sodium leaks occurred in the cold storage tank. Because much time and effort has been expended to ready the plant for operation, only a portion of the performance evaluation has been conducted.

Five repowering advanced conceptual designs were completed by DOE contractors during FY 1982. The contractor teams led by El Paso Electric, Rockwell Energy Systems Group, McDonnell Douglas, Bechtel, and Arizona Public Service refined and updated their earlier designs and made changes to improve the economics of these first-of-a-kind plants. As the last stage preceding final detailed design and construction, four repowering preliminary cost-shared design contracts were awarded in September, 1982, to Amfac Energy (conceptual design by Bechtel), Arizona Public Service, El Paso Electric, and Rockwell Energy Systems Group. The site-specific preliminary designs are for repowering facilities that are potentially economically competitive with fossil-fueled plants. The conceptual designs selected have the greatest chance for construction in the next five years in the absence of further government funding.

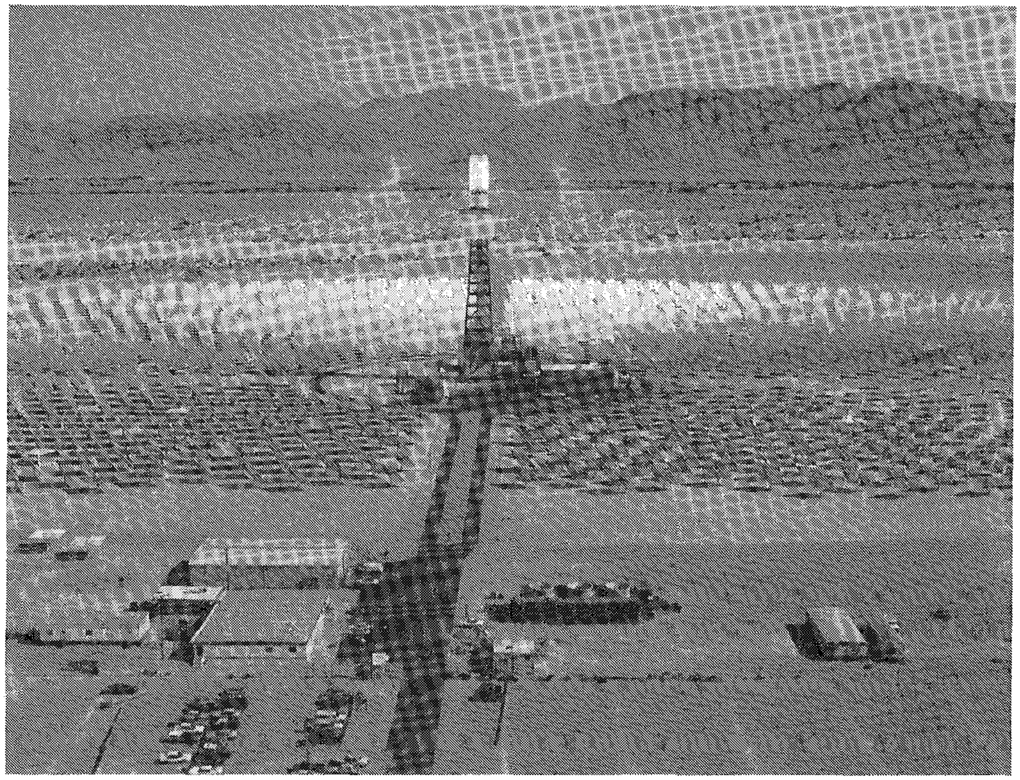


Figure 1. The 10-MWe Central Receiver Pilot Plant near Barstow, California

A molten salt system experiment, being built at the Central Receiver Test Facility (CRTF) in Albuquerque, New Mexico, will integrate the major components of a molten salt electrical power generating system (Figure 2). The objectives of this project are to verify the technical feasibility of a molten salt central receiver system and to familiarize utilities with molten salt system operations and maintenance. The experiment is now in Phase I of a three-phase program. Phase I covers construction and checkout of the experiment. In Phase II, the system will be operated and tested by utility personnel for six months. Phase III, which is optional, covers operation for an additional two-and-a-half years in either its existing configuration or with new test hardware. Because of multi-sponsor funding, much effort was devoted in FY 1982 to establishing the management structure to coordinate the project. Work was initiated and nearly completed to refurbish the molten salt receiver. Work also began on the salt piping design and steam generator design and procurement.

FY 1982 accomplishments in central receiver component technology development included heliostat performance/requirements optimization, sodium-cooled receiver evaluation, solid particle receiver investigation, and completion of the molten salt thermal energy storage experiment.

Two study contracts, conducted by Martin Marietta Corporation and McDonnell Douglas Astronautics Company, were undertaken to optimize heliostat

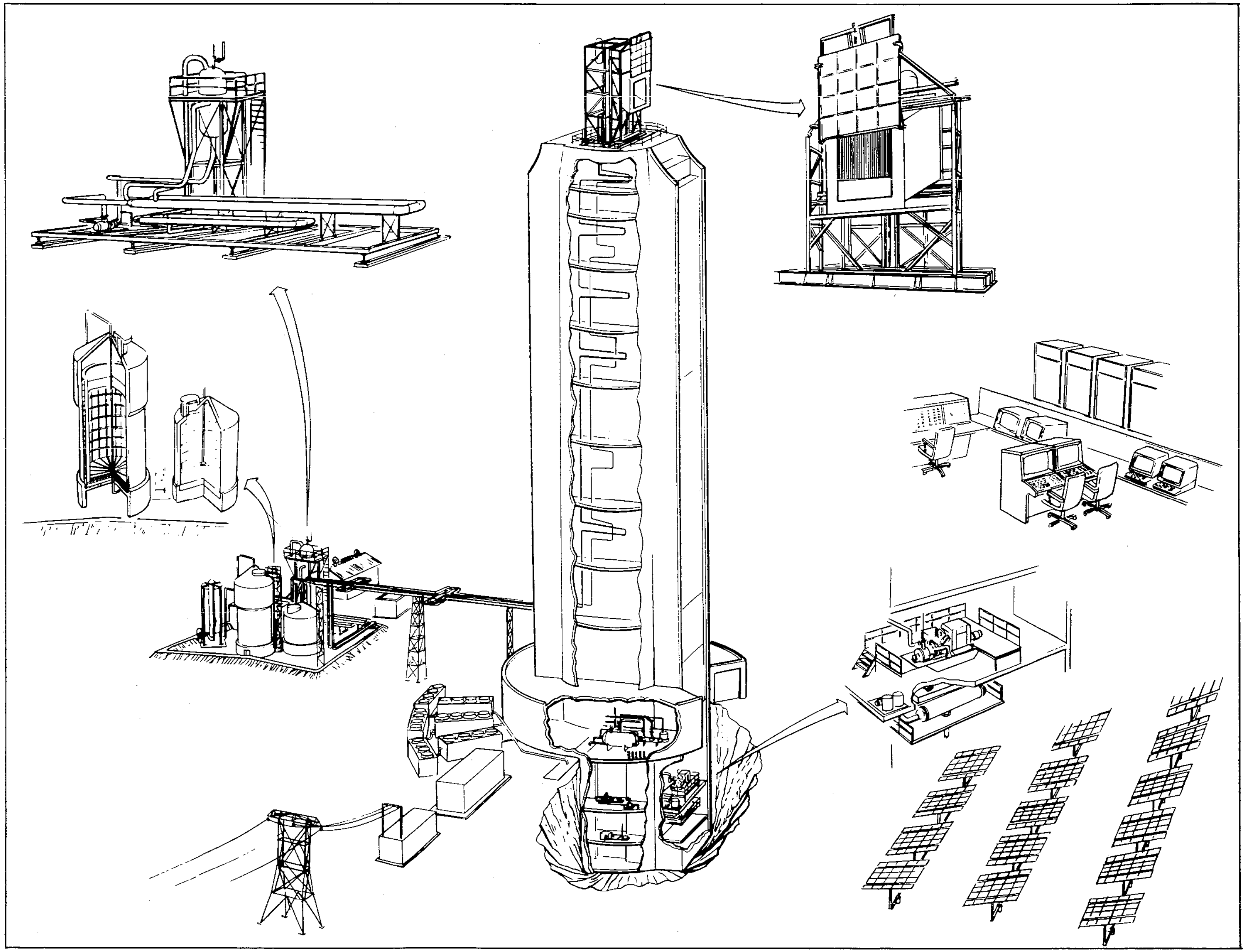


Figure 2. Illustration of the Molten Salt Electric Experiment

performance and requirements in an effort to reduce heliostat costs. The following conclusions and recommendations resulted from the study:

(1) It is more cost effective to design heliostats for strength rather than for stiffness and also to design them to design-code wind speeds and pay for repair of damage caused by severe winds rather than design and manufacture the heliostats to withstand the severe winds. Furthermore, when heliostats are redesigned for strength, the optimal mirror area increases significantly.

(2) The 40-m/sec wind horizontal angle of attack can be reduced from 10 degrees to 6.5 degrees to match measured data.

(3) If heliostat pointing or beam quality errors are increased by a factor of two or three for an entire field of heliostats, the cost of the energy collected is not reduced (i.e., the lower cost of the heliostat is offset by the additional energy spillage on the target). However, if heliostats with varying pointing accuracies were installed in the same field, costs could be reduced by using less accurate heliostats close to the tower.

(4) When heliostats are in operating position, there is an appreciable reduction in wind loads for heliostats located away from the edge of the field. Therefore, lower-cost foundations and pedestals could be used for interior field locations.

(5) A reduced operating temperature range is possible for the sites that were studied. This smaller range can benefit mirror modules that defocus with temperature changes.

A sodium-cooled test receiver program (Figure 3) was funded jointly by the Rockwell International Energy Systems Group (who funded the construction of the receiver) and the U.S. Department of Energy. Testing of this receiver was conducted at the CRTF between October 30, 1981, and March 12, 1982, with a total of 75 hours of test time. During the testing, no major problems occurred in the receiver subsystem. Major accomplishments included operation at a solar flux density greater than 1.5 MW/m^2, operation at design temperatures of 288°C (550°F) inlet and 593°C (1100°F) outlet, achievement of a maximum power level of 2.9 MWt at 595°C (1103°F), and demonstration of satisfactory receiver control.

The use of solid particles as the working fluid in a high-temperature solar central receiver system was also examined in FY 1982. This study focused on identifying the critical parameters that govern the technical feasibility of the concept for commercial-scale applications. Potential receiver designs were examined, a conceptual design was proposed, material handling equipment and vendors were identified, and eight candidate materials were selected for consideration. In addition, an estimate of the cost of energy delivered from a solid-particle central receiver system indicates that energy costs compare favorably with those of high-temperature air systems and supports further work on the concept.

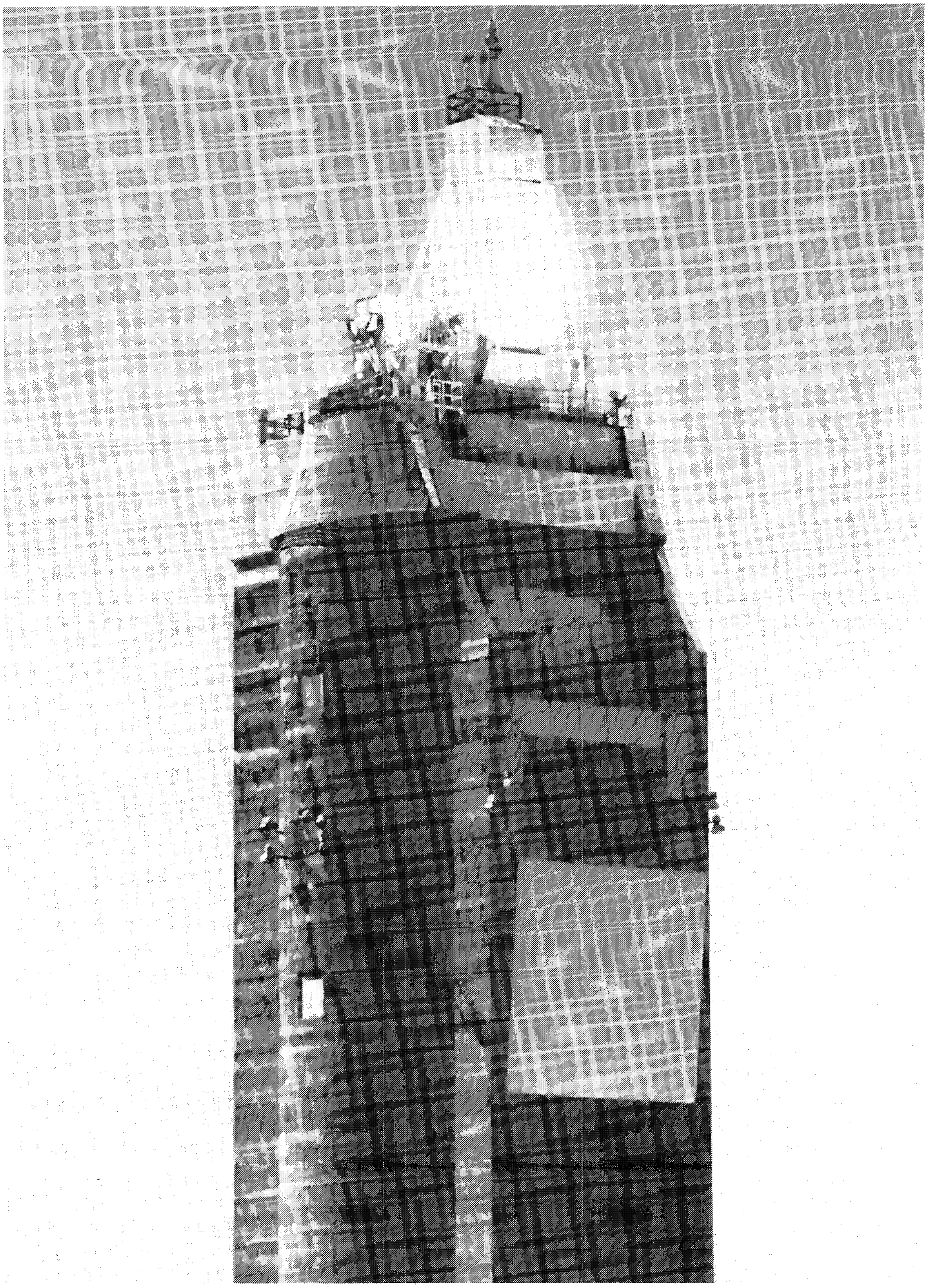


Figure 3. Sodium-Cooled Test Receiver at the CRTF

A molten salt thermal energy storage subsystem research experiment was conducted in FY 1982. The objectives of this project were to analyze and experimentally resolve all important issues related to the design and development of a cost-effective subsystem for thermal energy storage using molten nitrate salt as the sensible heat storage medium. Testing of the baseline design, which uses separate cylindrical hot (565°C, 1050°F) and cold (288°C, 550°F) tanks, was accomplished between January and April 1982. Problems were experienced with control valve performance, drying of the castable insulation supporting the tanks, and higher-than-expected thermal losses from the cold tank. The latter may be due to degraded tank insulation, which could have been caused by water being driven out of the castable foundation during curing. However, as a result of this experiment as well as design studies performed, the technical feasibility of the baseline configuration has been established. The estimated cost for a 1200 MWt-h storage system is 10.8$/kWt-h.

B. PARABOLIC DISH TECHNOLOGY

Fiscal year 1982 was one of significant accomplishments in hardware development for the parabolic dish-electric project. Two modules based on different heat engine technologies provided the Southern California Edison Company (SCE) utility grid with electricity, and the first pre-production parabolic dish concentrator was fabricated, assembled, and is now under test at the Parabolic Dish Test Site (PDTS) in California's Mojave Desert.

A number of Stirling-cycle power conversion assembly (PCA) configurations have been operated at the focus of a parabolic test bed concentrator (TBC). One configuration, using a Fairchild-Stratos hybrid receiver and a United Stirling of Sweden (USAB) engine (Figure 4), successfully operated in both hybrid and non-hybrid modes using solar and natural gas heat inputs until heater head brazing failures caused test termination. Funding limitations precluded redesign. Three different versions of USAB receivers, designed to use only solar energy, successfully operated with a USAB engine on a TBC. Noteworthy accomplishments included a number of successive sunrise-to-sunset operating days that provided the SCE grid with 20 kWe at a normalized solar insolation level of 1000 W/m^2. During one test, 24 kWe was generated by the PCA at an insolation level of 965 W/m^2, corresponding to a solar-to-electric conversion efficiency of approximately 29% (from sunlight incident on the concentrator to electricity from the generator).

As a result of a DOE Program Opportunity Notice (PON), a team of industrial and university contractors headed by Advanco Corporation entered into a cooperative agreement with the DOE Albuquerque Operations Office to design, build, and test a parabolic dish-electric module using a Stirling-cycle PCA. The module will be designed and constructed under the planning and direction of Advanco.

An organic Rankine-cycle (ORC) PCA, consisting of a receiver (by Ford Aerospace and Communications Corporation) and an ORC engine (by Ford's subcontractor, Barber-Nichols) with an integral Simmonds Precision permanent magnet alternator, was operated on a TBC at the dish test site. (See Figure 5.) The engine produced over 15 kWe (at an insolation level of 950 W/m^2), which was

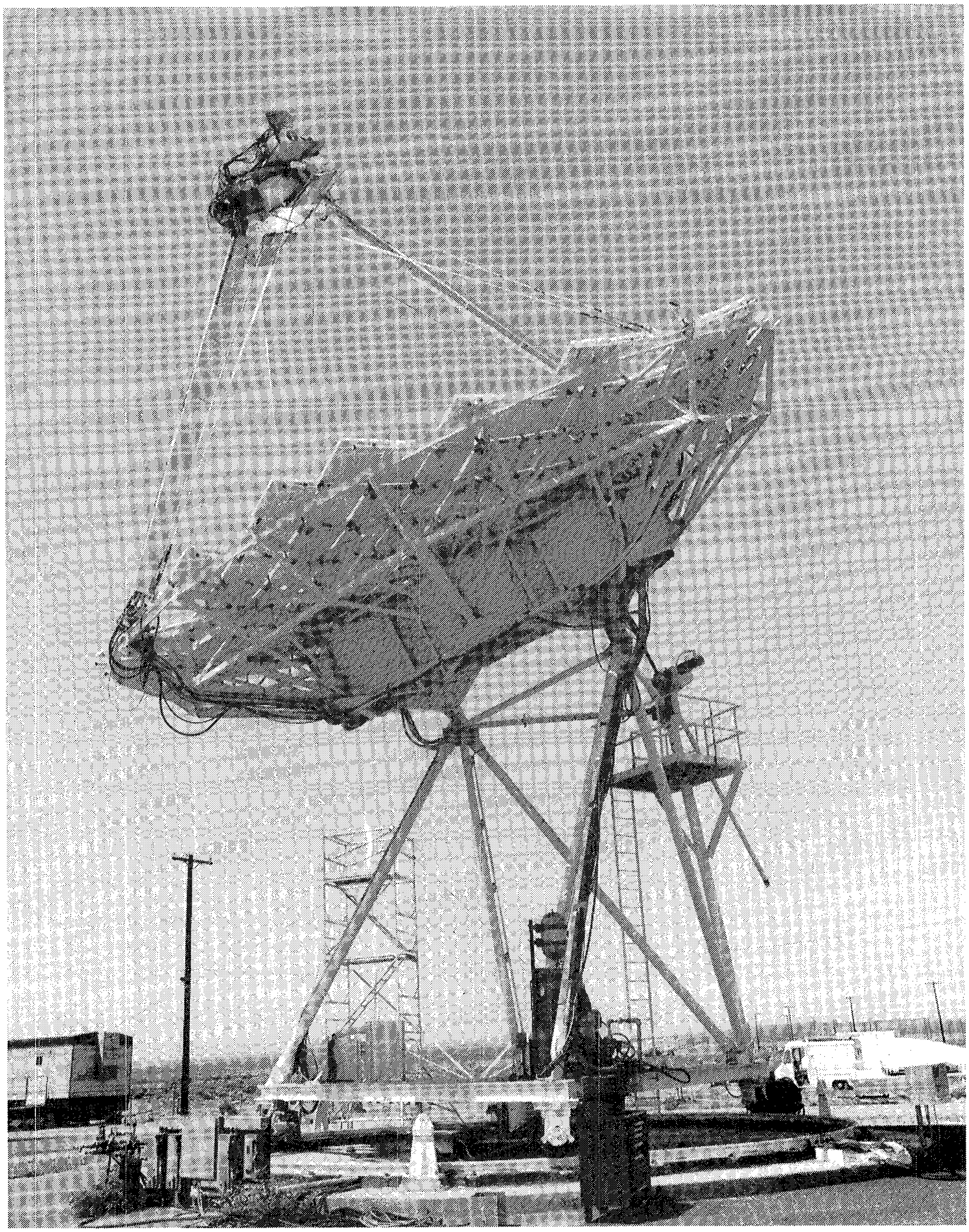


Figure 4. Stirling Engine Testing at the Parabolic Dish Test Site

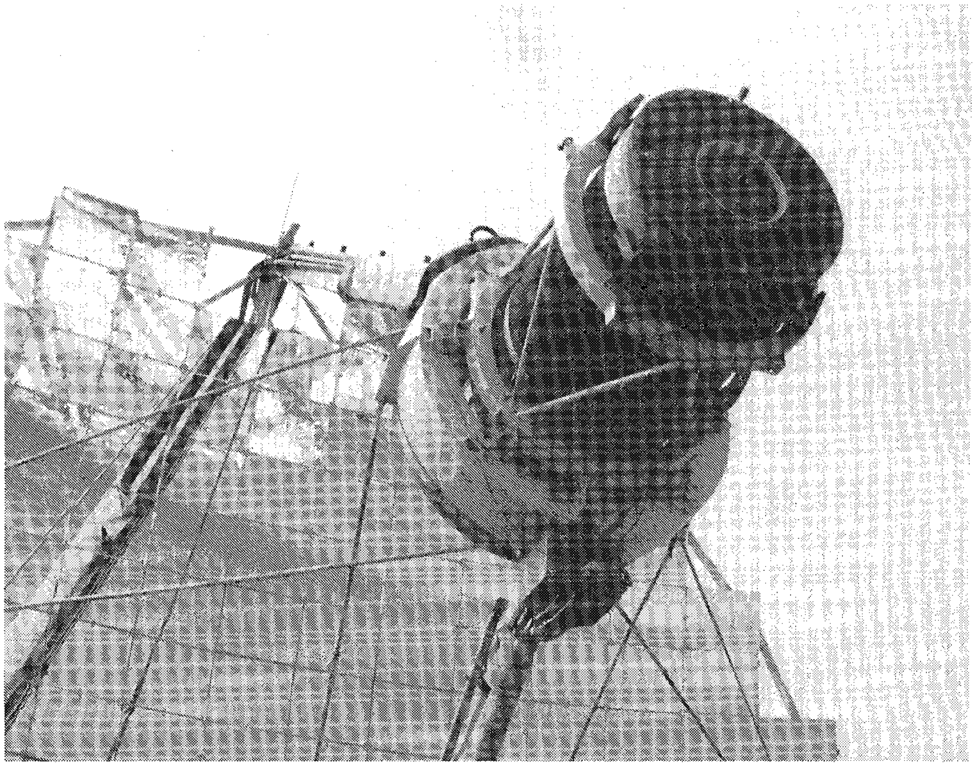


Figure 5. Organic Rankine-Cycle Engine Under Test at the Parabolic Dish Test Site

supplied to the SCE grid. Throughout low, intermittent, and high insolation levels, the ORC PCA operated smoothly, and the control system performed well during engine start-up, operation, and shutdown. After 33 hours of operation, the PCA was removed and disassembled. Inspection revealed excessive bearing wear and electrical arcing between the winding and housing of the permanent magnet alternator. Work is progressing on a bearing redesign to correct the wear problem, and the arcing problem in the permanent magnet alternator is under investigation.

The ORC PCA is a prototype of a solar thermal electric generating unit that will be combined with a parabolic dish concentrator and deployed in the field at Osage City, Kansas, in the first Small Community Solar Experiment.

A prototype parabolic dish concentrator, called PDC-1, was fabricated and erected at the PDTS during FY 1982. The 12-m (39-ft)-diameter dish was designed by General Electric Company and fabricated and built by Ford Aerospace and Communications Corporation and its subcontractors for operation with an ORC PCA at temperatures of about 400°C (750°F). Initial tests indicate that the performance of PDC-1 will meet design specifications.

The Brayton engine effort in FY 1982 also showed progress in system and hardware development. The systems contractor, Sanders Associates, fabricated a receiver for use with a Garrett Turbine Engine Company Brayton-cycle engine (Figure 6), which will be tested at the PDTS in early 1983. The Garrett solar

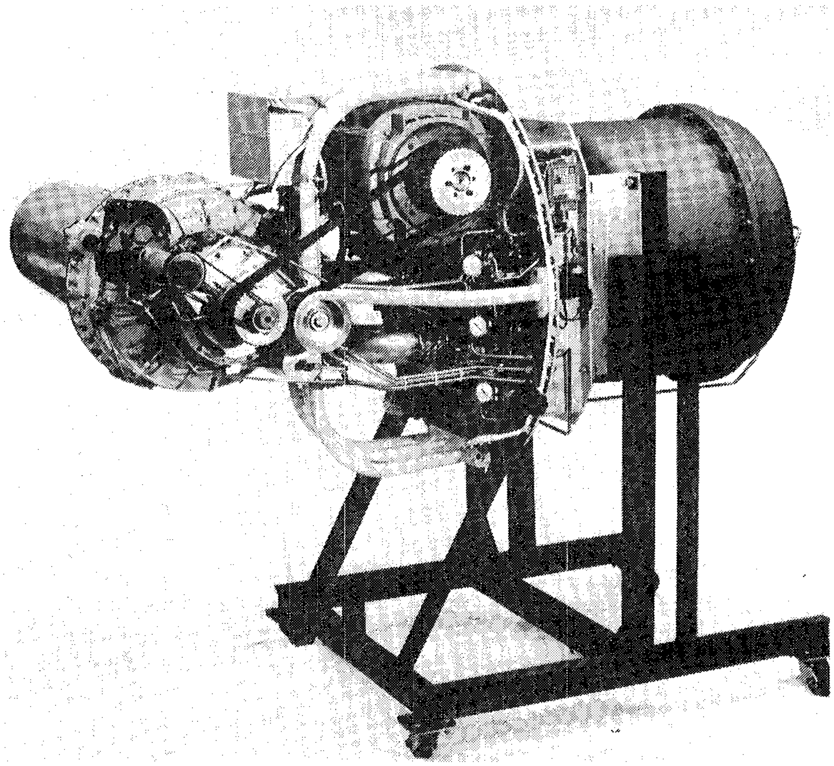


Figure 6. Brayton-Cycle Engine Built by the Garrett Turbine Engine Company

engine is a modified automotive advanced gas turbine engine. Development of the automotive and solar engines are under the direction of NASA's Lewis Research Center.

Sanders also conducted trade studies that resulted in a recommendation to develop a module for use in the 1980's consisting of the following components: a small Brayton-cycle subatmospheric gas turbine engine (presently under development by Garrett AiResearch California Company for the Gas Research Institute), a small Sanders receiver, and one of a number of privately-developed small dishes (6 to 8 m in diameter). Sanders further recommended a parallel effort to develop a module using an 11-m (36-ft)-diameter dish with a Sanders receiver and a "solarized" automotive Brayton engine. Work on an 11-m (36-ft)-diameter parabolic dish being designed by Acurex for use with a Brayton engine was suspended in FY 1982.

In the thermal dish area, an effort was initiated in mid-FY 1982 to review thermo-optical design principles, piping field layout design concepts, reflector/structure design concepts, and mirror coatings development. An analysis of a thermal dish field with 50,000 ft^2 of aperture area was performed by Jacobs Engineering Group, Inc., using the Shenandoah Solar Total Energy Project as a base. System parameter values were assumed and cost sensitivity was determined with respect to pressure drop in the main header piping for various header pipe sizes.

A study was made of production technologies used in fabricating high-performance trough reflector/structures to evaluate their adaptation to fabrication of dish reflector/structures. The concepts included stamped sheet metal panels, sheet molding compound, sagged glass, and honeycomb (stressed skin) structures. Each approach was analyzed regarding the necessary changes, advantages and disadvantages, and trade-offs. The interrelationship of three basic components must be considered: (1) the main structural framework that supports the reflector panels, (2) the reflector panels, and (3) the reflector material (silvered glass or aluminized film) and its method of application.

Three field experiments are being conducted to evaluate the performance of parabolic dish systems in three applications: electric power generation, cogeneration (total energy), and industrial process heat. These system experiments are discussed in the following paragraphs.

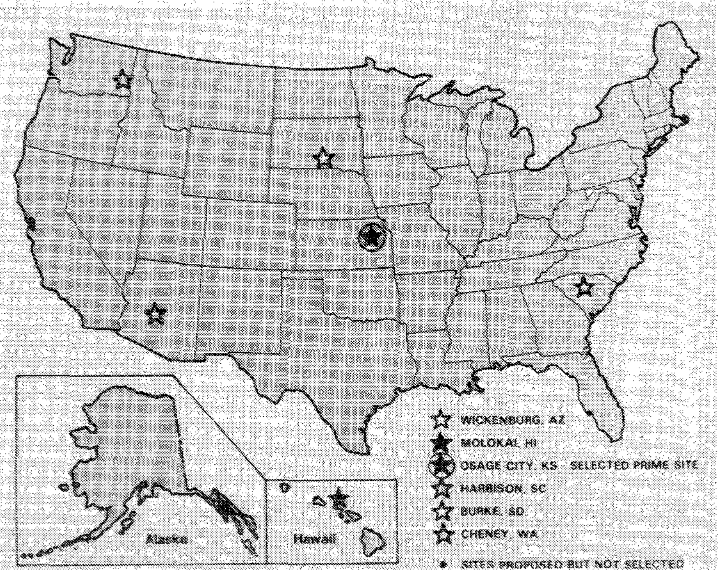
The Small Community Solar Experiment (SCSE) was initiated in 1977 when Congress appropriated funds to build an experimental solar-electric power plant as a first step in addressing the needs of the small community sector. Ford Aerospace and Communications Corporation was selected to develop the organic Rankine-cycle technology for this experiment. (Refer to previous paragraphs for a discussion of engine development.) In FY 1982 Congress appropriated $4 million to construct the experiment. During the course of the year, DOE proceeded with plans to build a 100-kWe plant, a size considered sufficiently large to satisfy most of the technical requirements of the experiment while meeting the intent of Congress to minimize cost.

Concurrent with the development of the organic Rankine-cycle module, the process for selection of an experiment site was carried out. During FY 1982, DOE selected Osage City, Kansas, as the prime site and Molokai, Hawaii, as the alternate site. These two sites were chosen from a field of 44 communities submitting proposals. Osage City is an ideal setting for the experiment because it is representative of a large number of small cities throughout the country (Figure 7). It has its own generation capability, purchases power when economically advantageous, and its insolation is about average for the nation. DOE is negotiating with Osage City for a site participation agreement to be implemented in FY 1983.

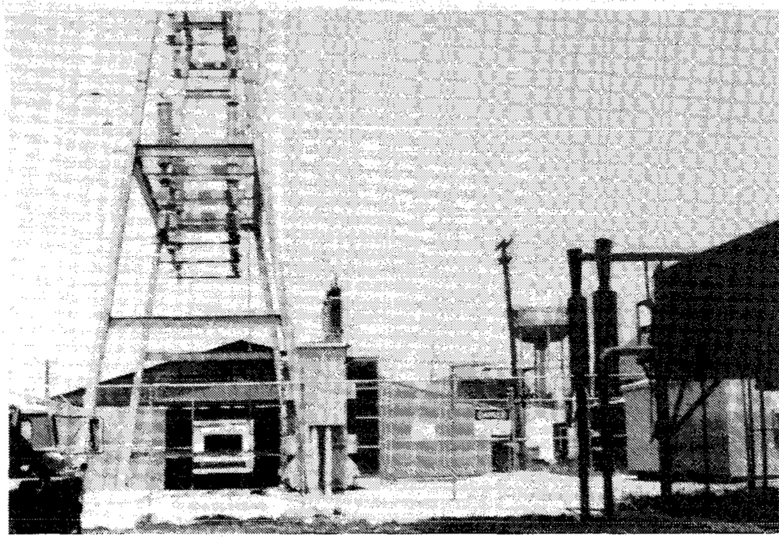
In FY 1982, construction of the Solar Total Energy Project (STEP) at Shenandoah, Georgia, was completed, and system acceptance and start-up activities were initiated. The total energy plant, shown in Figure 8, is a first-of-a-kind use of parabolic dishes. The project's objectives are to assess the interactions of solar total energy technology in an industrial application with an electric utility interface; to acquire and disseminate cost, performance, and technical data; and to promote industrial experience with solar total energy systems. The system uses 114 collectors, each 7 m (23 ft) in diameter. It will provide 400 kW of electrical energy, 180°C (356°F) steam for knitwear processing, and 115°C (239°F) exhaust steam to power an absorption-type water chiller to cool the plant. As FY 1982 closed, the Georgia Power Company was providing site management, and their personnel were being trained to operate the facility. During this period, STEP energy production totaled 18 MWh electricity, 22,000 ton-h of air conditioning, and 244,000 lb of process steam. Major milestones during

- MUNICIPAL UTILITY
- LOCATED IN CENTRAL U.S. – EASILY ACCESSIBLE
- 6-MWe PEAK DEMAND
- LOCAL GENERATION FROM DIESEL OR NATURAL GAS – 10-MWe PEAK CAPACITY
- FIVE UNITS: 1–2.8 MWe EACH
- PURCHASE POWER FROM KANSAS POWER AND LIGHT IN WINTER
- SERVES A POPULATION OF 2800
- NUMBER OF EMPLOYEES: 8 PLUS LINE CREW

SCSE SITE SELECTION



EXISTING PLANT



NEW SITE

Figure 7. The Small Community Solar Experiment, Osage City, Kansas

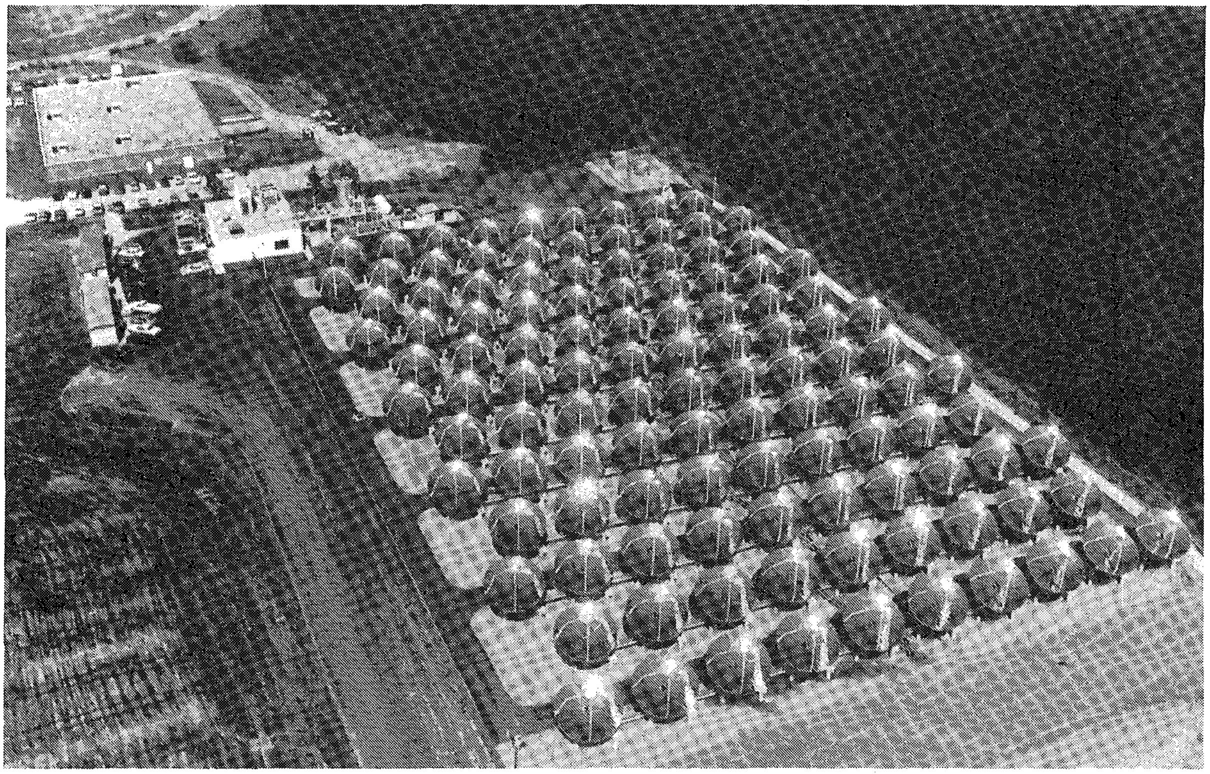


Figure 8. Aerial View of the Solar Total Energy Project, Shenandoah, Georgia

FY 1982 were (1) site dedication in May, (2) collector field placed into automatic sun tracking in August, and (3) cooperative agreement for operation of the dish plant signed by the Georgia Power Company and the Department of Energy in September.

Problems identified during checkout and start-up included failure of outdoor-rated drive motors and potentiometers due to water infiltration during construction, failure of mechanical equipment due to intermittent service and thermal cycling, inadvertent thermal damage to collectors and other field equipment due to misdirected reflections from out-of-focus collectors, and instability of the collector tracking algorithm due to a too-slow command/response sequence. These and other problems will be addressed and corrected in FY 1983, and the lessons learned shared with the solar community.

The Capitol Concrete Experiment, which produces process heat, is located at the Capitol Concrete Products block plant in Topeka, Kansas. The project features a Fresnel mirror solar collector designed and built by Power Kinetics, Inc. (Figure 9). Applied Concepts Corporation is the prime DOE contractor and system designer. In application, solar-heated steam is delivered to the block plant's central steam system, which provides energy to the plant's autoclave for curing freshly formed concrete blocks and similar products.

Several technical problems were identified and addressed during checkout and the short operating period. These problems included a loss of focus

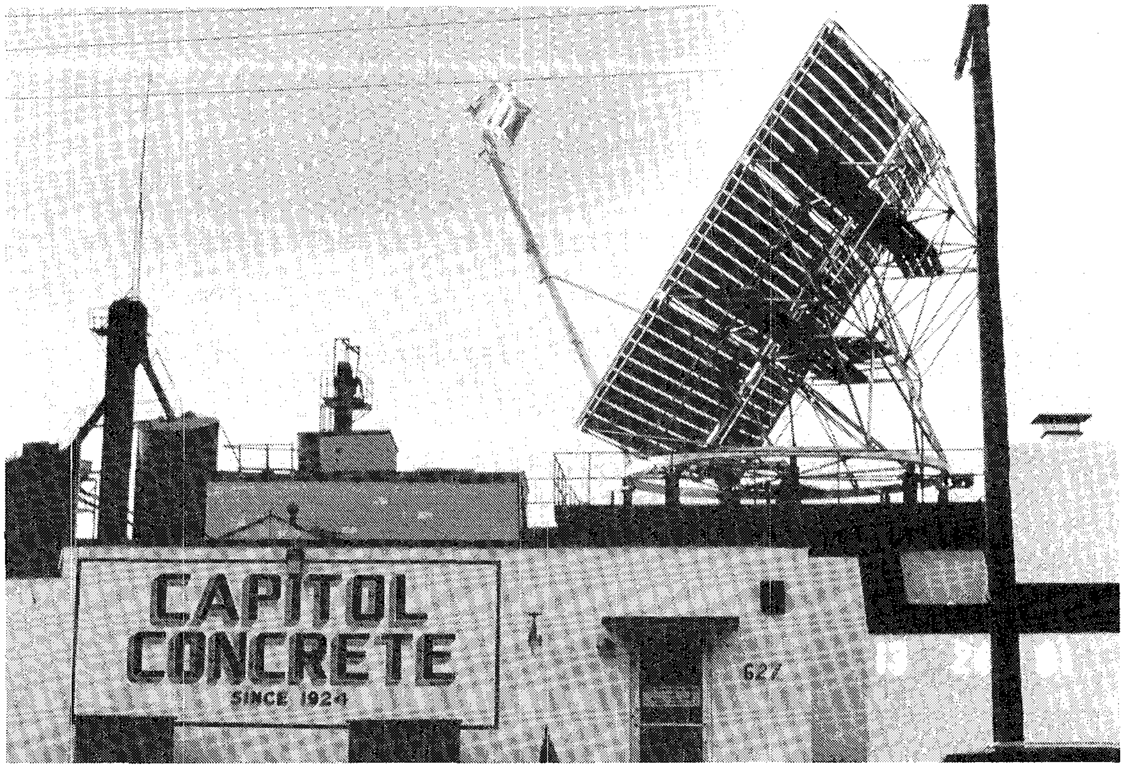


Figure 9. Power Kinetics Collector Installed at Capitol Concrete Products

accuracy at low sun angles, failure of the water level sensor and flow rate instrumentation, and debugging difficulty in the data acquisition system. Ownership and operational responsibility was assumed by Capitol Concrete Products in November 1982.

C. PARABOLIC TROUGH TECHNOLOGY

In FY 1982, work continued on a number of projects to further develop parabolic trough technology including the Performance Prototype Trough, components developed under a line-focus Program Research and Development Announcement, the 150-kWe Solar Irrigation Project, Modular Industrial Solar Retrofit systems, the distributed collector system of the Small Solar Power Systems Project, and several industrial process heat (IPH) projects.

Development of the Performance Prototype Trough (PPT) began in 1979 based on previous parabolic trough collectors with the goals of improving peak performance to 60%, decreasing costs by incorporating mass-production techniques into the design, and increasing lifetime to 20 years. In 1980, an engineering prototype trough achieved 60% peak efficiency while mass production technologies were being investigated. Components and four different structural designs were obtained from industry, and prototypes fabricated from soft tooling were evaluated. In FY 1982, the PPT project culminated in the assembly of a 24-m drive string of each of the four designs to form a ΔT string with a tracking and control system (Figure 10). System performance tests were conducted on the ΔT string and each individual drive string.

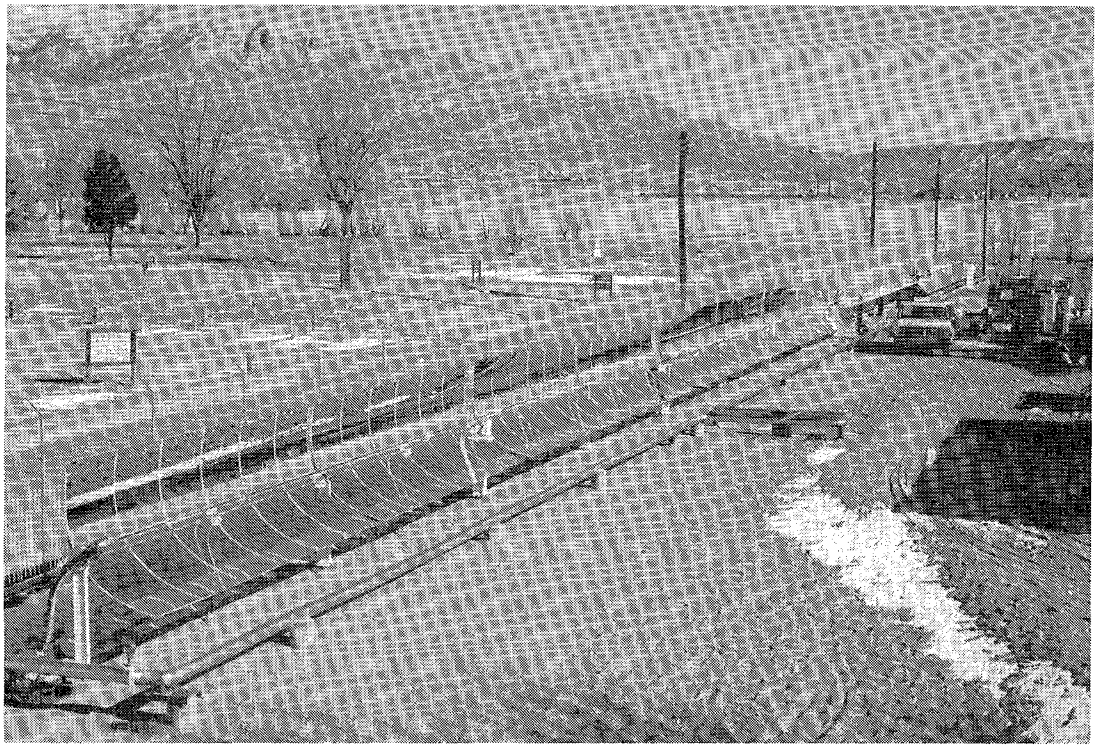


Figure 10. PPT ΔT String with Tracking and Control System

The four mass-production technologies used for fabrication are stamped sheet metal, sheet molding compound, sagged glass/steel frame, and honeycomb sandwich. Prototype reflector structures were fabricated, inspected for accuracy, and environmentally evaluated prior to fabrication of the PPT system. Most critical components were fabricated by industrial sources, including the Budd Company, Parsons of California, Corning Glass, and Schott America Glass. Performance testing was conducted during FY 1982. Noontime efficiency and all-day efficiency were determined based upon test conditions and test results.

A Program Research and Development Announcement (PRDA) was issued to industry in 1980 with the objectives of (1) accelerating the development of mass-producible collectors by manufacturers of existing trough collectors, and (2) giving the component manufacturers the opportunity to develop improved products. Goals are set forth in terms of peak performance, cost, and lifetime. Cost-sharing PRDA contracts were awarded to Acurex Corporation for collector, tracker, and control system development; to Solar Kinetics and Suntec Systems for collector development; and to Winsmith for speed reducer development. Final contract reports will be completed in FY 1983.

The 150-kWe Solar Thermal Irrigation Project located near Coolidge, Arizona, continued to be operated by the University of Arizona during FY 1982. The system has operated as an engineering experiment since its dedication in November 1979. Figure 11 is an aerial photograph of the installation, for which DOE completed its participation in September 1982.

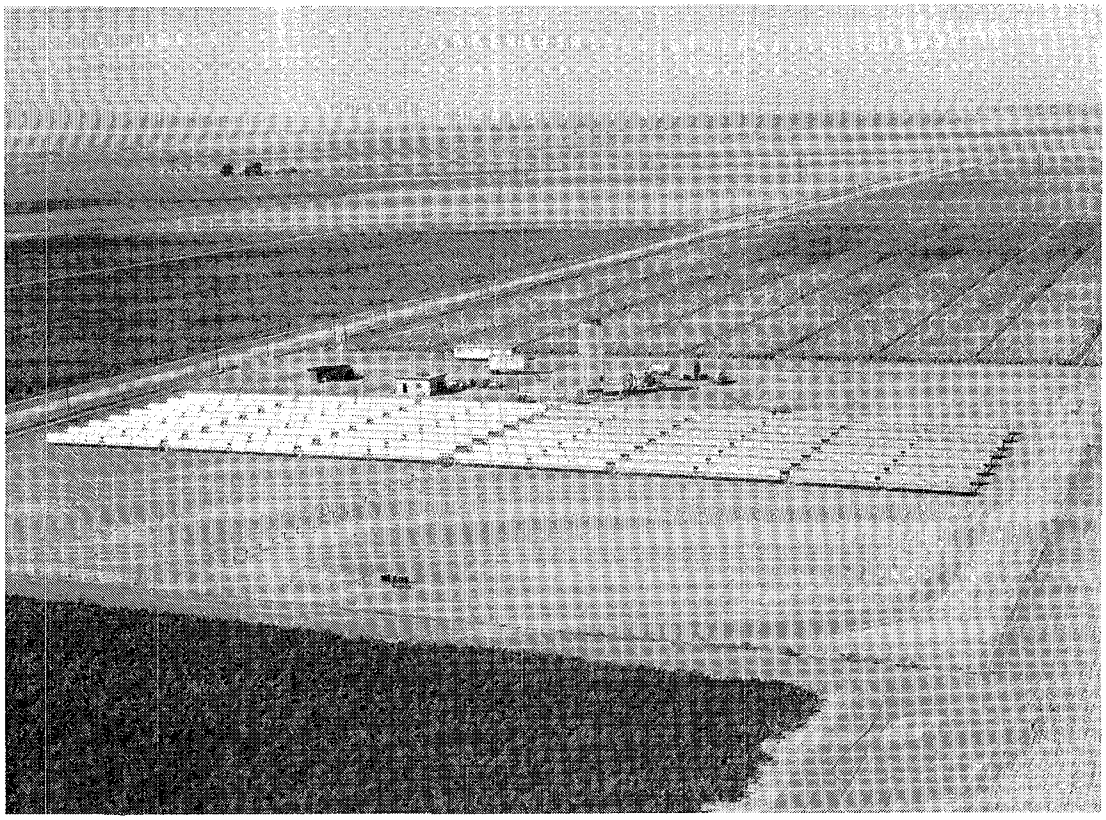


Figure 11. 150-kWe Solar Irrigation Project, Coolidge, Arizona

The Modular Industrial Solar Retrofit (MISR) Project made five competitively selected contract awards late in FY 1981 to industry for the design, construction, and installation of modular solar thermal systems for qualification testing. The systems use modular hardware and are representative of full-sized MISR systems in all respects except for the size of the collector field. One system has been installed at the Solar Energy Research Institute (SERI) test site in Golden, Colorado (Figure 12), and four systems have been installed at Sandia National Laboratories in Albuquerque, New Mexico (Figure 13). The Foster Wheeler system at SERI is installed, and evaluation testing is progressing. In Albuquerque, the BDM and Acurex systems are installed and under test. Systems by Custom Engineering and Solar Kinetics were partially installed during FY 1982.

Each of the five MISR system designers was awarded an additional contract to develop two MISR/plant interface designs with competitively selected companies. Eight of the ten interface designs were completed.

The distributed collector system of the Small Solar Power Systems Project in Almeria, Spain, was designed and built by Acurex Corporation with additional collectors supplied by M.A.N. of West Germany. The plant became operational the first part of FY 1982 although failures with non-solar equipment have delayed completion of a comprehensive performance evaluation. Observations thus far indicate that the solar-specific equipment is performing close to expectations.

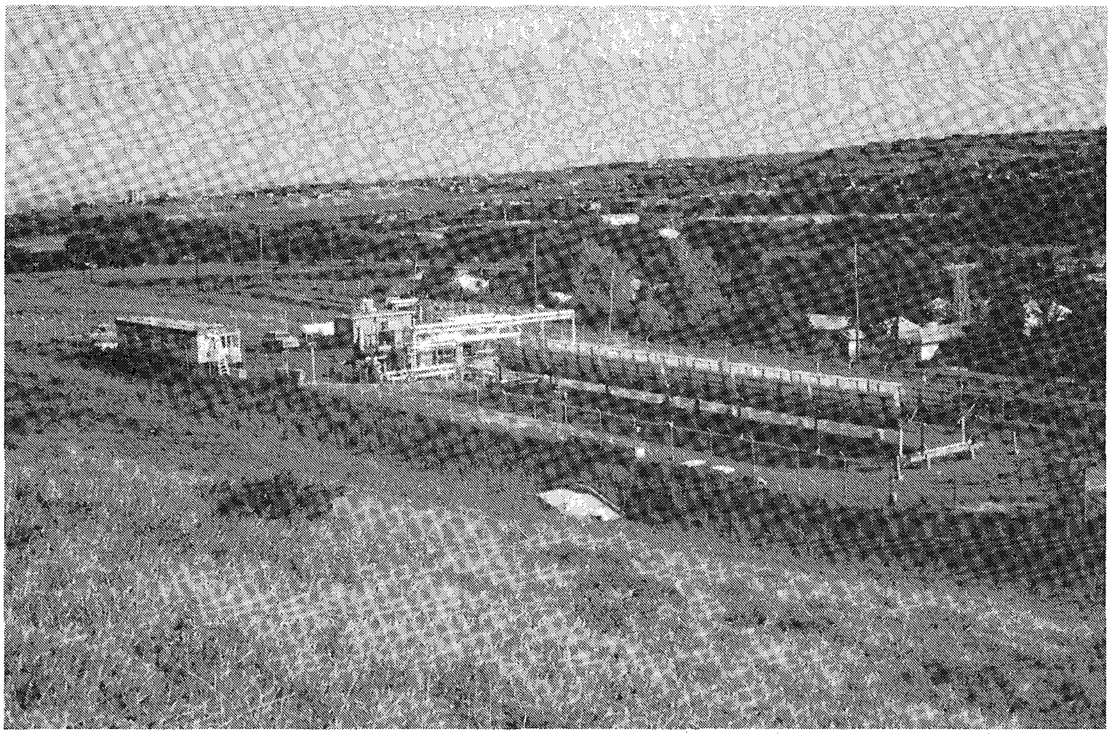


Figure 12. MISR Qualification Test Site in Golden, Colorado

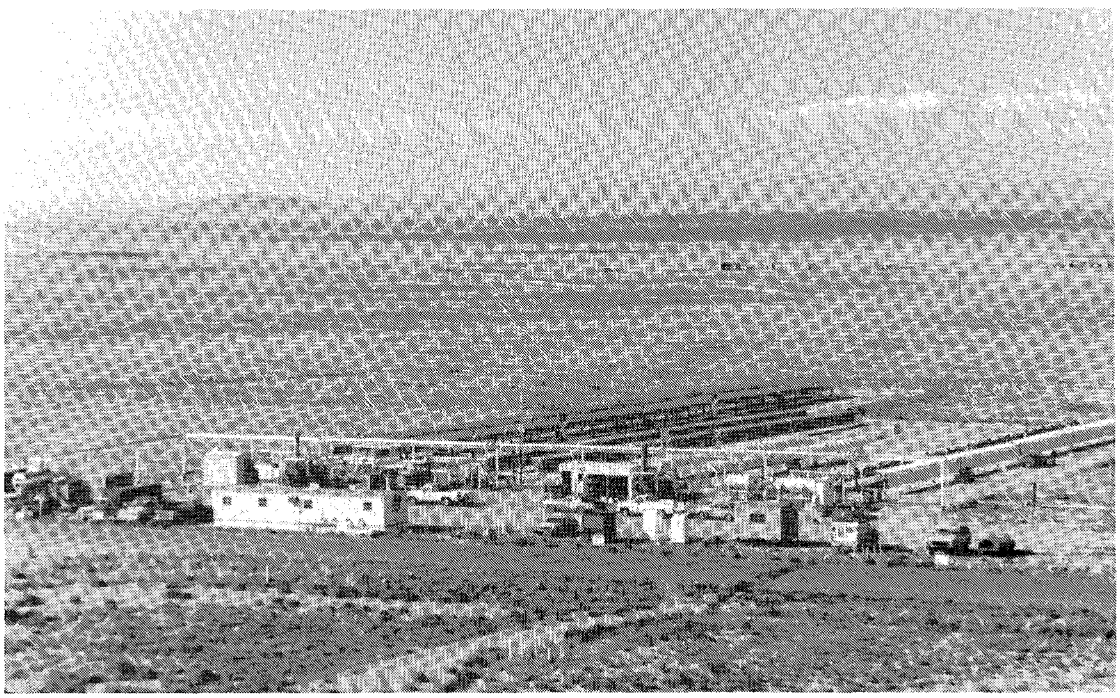


Figure 13. MISR Qualification Test Site in Albuquerque, New Mexico

DOE initiated an Industrial Process Heat (IPH) Program in 1976 to evaluate the technical feasibility of solar thermal energy for industrial process heat applications. Since then, there have been 17 solar IPH systems installed in four phases at industrial plants throughout the country. These systems have employed a variety of collector types including flat plates, evacuated tubes, and parabolic troughs. DOE's contractual involvement in some of these IPH experiments has been concluded, and the systems have either been dismantled or transferred to the site participants. At the end of FY 1982, seven systems using parabolic trough collectors remained under contract to DOE. The seven, listed in Table 1, are in the operational phase.

These experiments encompass the design, installation, and operation of solar IPH systems at industrial sites where the energy produced is supplied directly to the plant's energy distribution lines. The systems, which are instrumented for detailed data collection, are operated under DOE funding to obtain experimental data on performance, reliability, and operation and maintenance (O&M) costs. After the operational period, the systems will be transferred to the industrial hosts for continued operation where they will remain a source of energy for the industrial plants and will serve as examples of solar energy applications for other prospective users.

During FY 1982 the experiments listed in Table 1 began operation. Although difficulties were encountered with solar collectors, steam production equipment (pumps, valves, and piping), and with data acquisition systems, five of the seven experiments operated routinely. At the end of the year, Caterpillar Tractor was awaiting minor collector repairs, and Ore-Ida Foods was awaiting repair of the main circulation pump. The experiment installation at the United States Steel (USS) Chemical Company, Haverhill, Ohio, is shown in Figure 14.

D. OTHER TECHNOLOGIES

Two other solar thermal technology options in addition to central receiver, parabolic dish, and parabolic trough systems were pursued during FY 1982. These are hemispherical bowls and salt-gradient solar ponds. In addition, agricultural applications for solar thermal technology were examined.

1. Hemispherical Bowls

The hemispherical bowl concentrating solar collector concept, also referred to as the fixed mirror distributed focus (FMDF) collector, is being evaluated at a facility near Crosbyton, Texas (Figure 15). The Crosbyton bowl, referred to as the Analog Design Verification System (ADVS), designed and built for DOE by a team of researchers from Texas Tech University of Lubbock, Texas, and E-Systems, Inc., entered its third year of testing in FY 1982. The ADVS has an aperture of 20 m and is constructed of a mosaic of 438 silvered glass facets, each about 1 m^2, that are stressed to a spherical shape and bonded to paper honeycomb backing structures. The receiver consists of a cylindrical structure 5.5 m in length, around which tubing is helically wrapped. Water is pumped through the helical tubing where it is boiled and superheated.

Table 1. Solar IPH Project Summary

Project	Location	Contractor	Aperture Area, m^2	Collector	Heat Transfer Fluid	Operating Temperature, ^oC	Steam Pressure, kPa
Home Laundry	Pasadena, CA	Jacobs Engineering	604	Del-Jacobs	Water	220	760
Southern Union Refining Co.	Lovington, NM	Energetics Corp.	937	Solar Kinetics, Inc.	Texatherm	190	1170
Lone Star Brewery	San Antonio, TX	Southwest Research Institute	878	Solar Kinetics, Inc.	Therminol	250	860
Ore-Ida Foods	Ontario, OR	TRW	884	Suntec	Water	250	210
Dow Chemical Co.	Dalton, GA	Foster-Wheeler Development Corp.	923	Suntec	Dowtherm	260	1030
USS Chemical Co.	Haverhill, OH	Columbia Gas	4683	Solar Kinetics, Inc.	Therminol	220	360
Caterpillar Tractor	San Leandro, CA	Southwest Research Institute	4683	Solar Kinetics, Inc.	Water	110	240 (water)

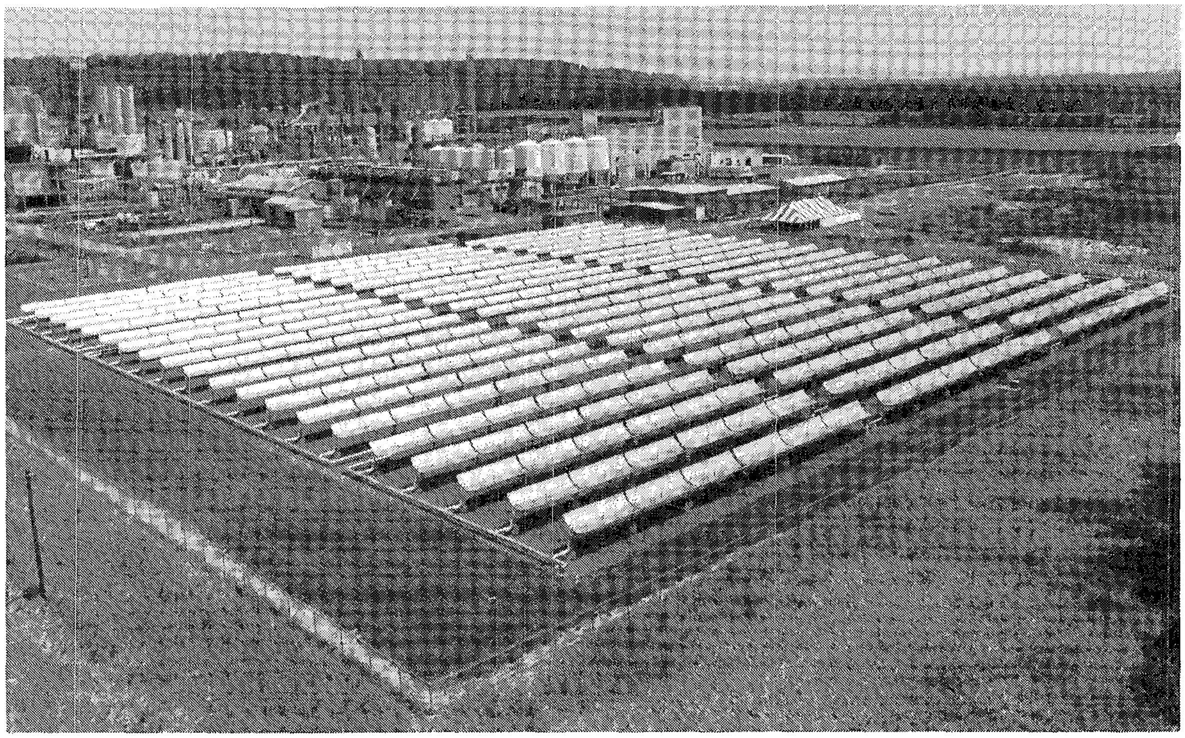


Figure 14. Solar IPH Experiment at the USS Chemical Company

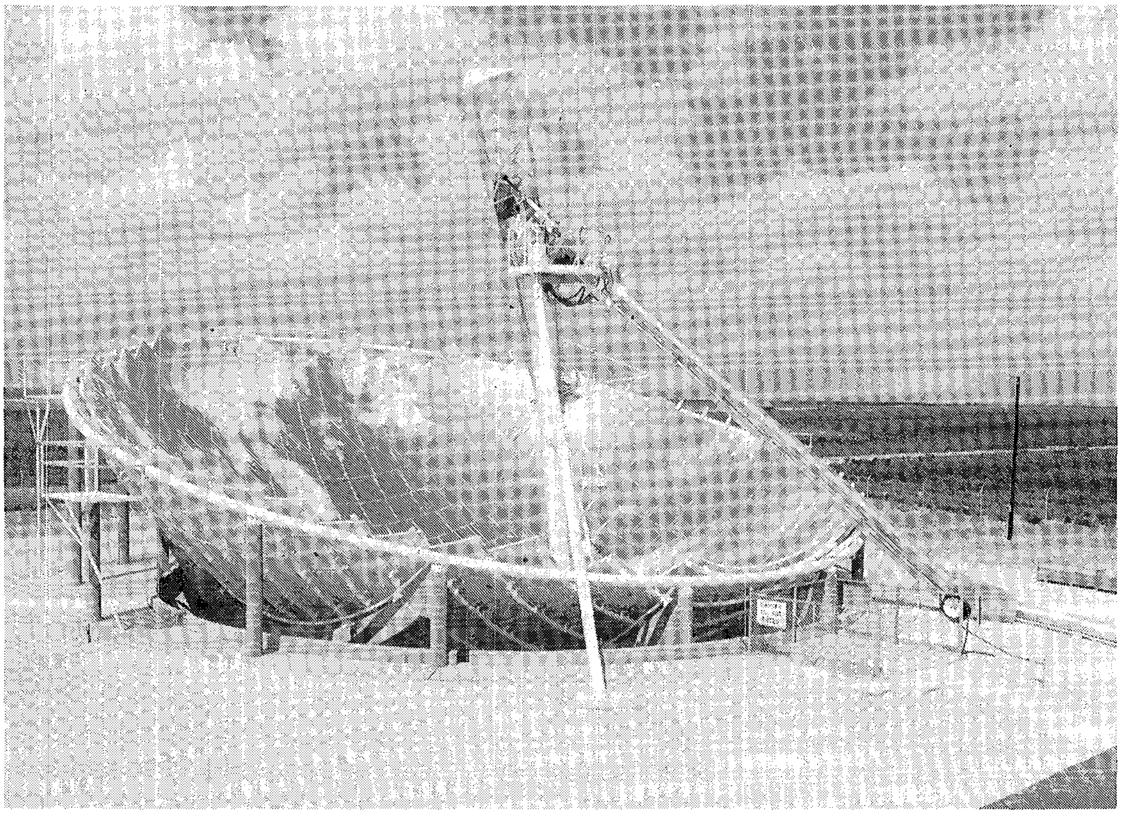


Figure 15. Hemispherical Bowl in Operation at Crosbyton, Texas

The most significant technical problem identified during operation has been the so-called "mirror hot-spot." The mirror facets at the base of the focal line have been found to absorb enough energy -- during infrequent periods when the receiver is not in place -- to heat and crack from thermal stress. Texas Tech and E-Systems have used the Crosbyton bowl facility as a test bed to evaluate active protection measures and the durability of alternate mirror facets. There have been some encouraging results from an improved mirror using an aluminum honeycomb sandwich structure, but further study and development are needed.

Other significant investigations have involved the development of lower-cost components. These have included larger individual facets and a concept called the "super panel," which consists of large multi-faceted, factory-assembled panels. The super panel would reduce the amount of field labor at a bowl construction site by permitting the installation crew to install a much larger area of reflective surface in a single operation.

A preliminary design was completed of a 5-MWe power plant, which would employ ten 60-m-diameter bowls at an estimated cost of about $32 million. A bowl 60 m in diameter is considered by the project team to be an optimal size based on cost-effectiveness.

2. Salt-Gradient Solar Ponds

Research addressing a number of technical problems and issues relating to salt-gradient solar ponds continued in FY 1982. The rate of extraction of mass and heat from solar ponds, development of a direct contact heat exchanger, and a study of ways to control the gradient layer of solar ponds have been recognized as research areas of critical importance in the development of a salt-gradient solar pond technology base.

The Solar Energy Research Institute (SERI) conducted studies to accurately measure the effects on the gradient layer of a pond when hot brine is extracted from and returned to the storage layer. To accomplish research objectives, a test tank simulating a vertical slice of solar pond was constructed. Flow rate, withdrawal, and return port locations are varied to characterize pond dynamics. Testing will be completed in FY 1983 and the results made available to designers of operating ponds.

During FY 1981, SERI researchers determined the economic benefits and technical feasibility of using a direct contact heat exchanger to couple a solar pond to an organic fluid Rankine power cycle. A suitable working fluid was selected, and a conceptual design of a direct contact heat exchanger was developed. In FY 1982 laboratory setups to measure bulk heat transfer coefficients and maximum flow-through rates in packed and unpacked columns were designed. Two measurement facilities to verify the concept are planned for FY 1983: a 2-ft-diameter column at the University of Utah and a 6-in.-diameter column at SERI.

Solar salt pond research and development has reached a point where the technical and economic feasibility of constructing a large solar pond power plant can be considered. At the beginning of FY 1982, two feasibility studies were in progress, one for the Salton Sea in California and one for the Truscott Brine Lake in Texas. Two other sites were also being considered although in less detail: the Great Salt Lake and the basin of the lower Colorado River. Pacific Northwest Laboratory (PNL) undertook a two-year study scheduled for completion in FY 1983 that compares the four sites and will identify the most suitable location for the development of a large (5-MWe) engineering test facility.

During FY 1982, sponsorship of the Salton Sea Solar Pond Project was transferred solely to DOE when the cosponsors, Southern California Edison Company and the California Energy Commission, could no longer participate. DOE will continue to research the Salton Sea site and will fund a power plant cost and design study in FY 1983.

In FY 1982, site-specific studies were conducted for the Salton Sea site. Water clarity, soil-brine microbiological activity, clay permeability, and corrosion were subjects of study. The Salton Sea is a body of water that supports fish and plant life and as a result contains organic matter that colors the water and restricts light penetration. Activated carbon treatment is a commercially available process that will clarify the water.

3. Agricultural Process Heat Technology

Active and passive solar thermal systems were successfully demonstrated throughout the U.S. in a number of agricultural applications, including greenhouse heating, crop drying, food processing, and heating for livestock shelters.

During FY 1982, tests demonstrating the effect of operating a greenhouse night curtain based on light rather than time of day resulted in a saving of 10% in heating needs. The yield from tomato crops grown in solar heated soil in a heat conserving greenhouse was greater than control groups in late winter and early spring. In another experiment, an increase of 6% in marketable fruit resulted from spring tomatoes grown in an experimental greenhouse using exhaust air rich in CO_2 from a swine house. During the Spring 1982 growing season, this experimental greenhouse used 20% as much fuel as the control greenhouse.

Drying experiments were conducted on papaya and banana slices with a hybrid solar-biogas system, which dried the fruit in less than a day; a solar-only system requires two sunny days for drying. Design criteria for solar drying systems were developed using computer simulations: With a 50% solar energy requirement, resulting system sizes are 156 m^2 of collector area, 56 m^3 of storage for an air/rock system, and 128 m^2 and 22 m^3 for the water system.

A solar hot-air collector system was constructed to directly surface dry fresh citrus or regenerate solid desiccants. The desiccants, activated alumina or silica gel, were utilized for energy storage during periods of low insolation. Collector efficiencies averaged 44.1%, with an overall efficiency for desiccant regeneration of 12.3%.

A solar brooding system for chickens, consisting of a line-focusing, pressure stabilized collector and a heat storage exchanger, operated unattended at efficiencies up to 71% with a peak output of 22.5 kWt. Operation during a third winter has confirmed the feasibility of using a combination of active and passive collectors to heat pens for young pigs. Heat was maintained by the solar system for up to one week of overcast weather.

SECTION III

RESEARCH

A. MATERIALS RESEARCH

Materials research in FY 1982 continued to explore the potential for reducing the life-cycle cost of solar thermal systems by developing a technology base for low-cost optical materials. The primary research and development (R&D) activities were focused on understanding mechanisms of degradation in silver/glass mirrors and development of innovative reflector materials for concentrators. These R&D activities will provide significant information on lifetime characteristics and degradation mechanisms of commercially available silver/glass mirrors and will identify designs that can reduce the weight and cost of concentrators, which comprise approximately 60% of overall system cost.

In FY 1982, SERI and PNL accomplished the following: (1) development of a test procedure for ranking the relative durability of commercially and laboratory prepared mirrors; (2) implementation of this procedure by exposing mirror samples to ultraviolet (UV) light, elevated temperature, humidified pollutants, and mechanical stress at levels above normal exposure; and (3) characterization of samples after exposure to determine the adverse effect of both expected and simulated environments on the mirror properties and to rank them in order of their degradation resistance.

This laboratory testing and analysis of the degradation mechanisms in silver/glass mirrors revealed that the combination of water, oxygen, and impurities present in all mirrors using current manufacturing processes results in some corrosion of mirrors. However, the rate and, hence, time-to-failure cannot be predicted from the limited data collected to date. Further research is needed to (1) find a way to eliminate the impurities present in commercially made mirrors, (2) eliminate water from mirror modules, or (3) develop an advanced mirror made by a different process where the variables of manufacture can be more carefully controlled.

Based upon information obtained in the mirror durability testing and degradation mechanism studies, scientists formulated a patent disclosure for a potentially long-life silver mirror using an Inconel backing. If the predicted long life can be demonstrated in the laboratory, the mirror could be economically produced using existing vacuum metallurgical technology.

Fracture toughness and stress corrosion properties of Corning 7809 glass were measured. This glass, which was developed by Corning with support from the DOE Solar Thermal Program, can be drawn into very thin sheets. The study showed that this glass is better able to resist the growth of cracks that might lead to delayed failure under high stress than can ordinary soda-lime float glass.

Seven combinations of commercially available aluminum or silver metallized polymers were subjected to accelerated testing at 80°C in UV and humidified pollutants. The superstrate polymers included teflon, acrylic, polycarbonate, and silicon silicate and backing materials of polyester, acrylic, mylar, or Inconel. The aluminized products withstood the accelerated testing much better than the silver polymers. Considerable research is required to understand the degradative processes in silvered polymers so that the advantage of the increased reflectance of silver can be utilized.

B. ADVANCED COMPONENTS

A major step toward large-scale use of solar thermal energy is the development of advanced, cost-effective components to collect, convert, and use that energy source. The Advanced Components Program conducts research and development to establish a technology base that enables the use of less expensive materials and/or smaller quantities of materials, made into high-performance, long-life receivers and concentrators at minimum cost.

The concentrator in a solar thermal system greatly influences the cost and durability of the system, and thus impacts both life-cycle cost and rate of return. Concentrators account for about 60% of the projected costs for solar thermal process heat and electric generation systems. Two innovative, high-risk collector concepts having the potential to greatly reduce heliostat costs were investigated in FY 1982. Polymer enclosed (or domed) heliostats were studied using a systems analysis comparison with glass/metal heliostats, and a stretched membrane concept (where a thin metallic or polymer film stretched on a support frame forms the collector reflective surface) was investigated. The study reveals that polymer enclosures and reflectors can greatly reduce the cost of delivered energy from systems using second-generation heliostats. Savings of up to 40% could be realized if expected results are obtained from current polymer materials research. Major materials needs and research issues being addressed are associated with both the enclosure and the enclosed reflector. Enclosure materials research in FY 1983 will emphasize enhanced mechanical strength and lifetime, better specular transmittance, lower surface reflectance, and anti-soiling characteristics. Reflector materials efforts will emphasize enhanced specular reflectance of metalized polymers and both mechanical and environmental durability.

SERI research and development efforts on stretched membranes for heliostat reflective surfaces combined design, engineering, cost/performance analysis, and testing. Structural design aspects of stretched membranes and support structures, including analysis of linear and nonlinear deformation, buckling of the support frame, thermal mismatch considerations, focusing effects, wind spillage effects, and the optimal strength and sizing of the membrane support structure were studied. Based on these analyses, researchers designed, fabricated, and tested a number of bench-scale and field-test-scale hardware elements. Analysis and testing show that the stretched membrane concept appears capable of providing high optical quality surfaces (less than 2.0 rms surface error).

Central receiver systems currently under test are potentially cost-effective for electric power generation and industrial process heat, but are limited to a maximum temperature of approximately 600°C (1100°F). For industrial process heat and for fuels and chemicals production applications, heat at temperatures above 600°C is needed. In order to achieve that temperature, it is necessary to develop central receiver systems that use either liquid metals, liguid glass, or molten salts that can withstand high temperatures. Candidate materials are hydroxides, carbonates, chlorides, or a gas that can pass through the receiver.

During FY 1982, SERI analyzed previously proposed high-temperature air receivers. Results of the analysis indicate that delivered energy costs for a high-temperature air receiver, where air is heated in tubes, are considerably higher than for lower temperature molten nitrate salt systems due to the lower thermal efficiency of air systems. The work also resulted in generation of a concept for a high-temperature direct absorption cavity receiver using a liquid as the heat transfer medium. Development of this concept will continue by analyzing the thermal performance of the direct absorption cavity receiver.

C. FUELS AND CHEMICALS

In FY 1982, fuels and chemicals research built on the previously conducted exploratory research that determined the utility and applicability of solar thermal energy to primary fuel and chemical processes. Analytical investigations directed at determining whether solar thermal energy offered any unique or advantageous elements that could be beneficial to the fuel or chemical industry demonstrated the technical value of high-temperature flux and heating rates for specific reactions.

During an assessment to identify the technical barriers that prevent industry from capitalizing on the potential of solar thermal fuels and chemicals production, several major fuel and chemical processes were examined in great detail. It was learned that there are common technologies missing among the processes. A program structure was developed to focus on these "core technologies" because an appraisal of their technical feasibility will permit applications for a wide range of fuel and chemical processes.

D. ADVANCED RESEARCH

The Solar Thermal Advanced Research Program was established to foster innovative ideas and concepts within established priorities through cooperative participation by researchers in universities and industry. FY 1982 activities targeted to achieve the long-term goal of cost competitiveness of solar thermal systems and components were carried out through research projects at the Georgia Institute of Technology and the University of Houston and preparation of an innovative research PRDA (Program Research and Development Announcement) to be issued in early FY 1983.

At the University of Houston, design of a pilot cyclic catalytic converter to test the feasibility of transmitting high solar flux from the outside of a central receiver to the inside of a catalytic bed using sodium heat pipes was completed and fabrication of parts for the unit started. Other investigations provided conclusive experimental evidence that photo effects play both beneficial and detrimental roles in defining the long-term stability at operating temperatures of various solar materials. In the area of thermochemical storage cycle research, the decomposition of $ZnSO_4$ was studied in a flow system over the temperature range of 840 to 950°C (1544 to 1742°F). $ZnSO_4$ decomposition in a NaCl melt was found to be not suitable for an energy storage cycle. Other processes are being investigated.

The Advanced Research Program at the Georgia Institute of Technology is directed toward providing a technical base for the use of concentrated solar energy to produce high temperatures that will be used for increasing thermal conversion efficiencies of thermodynamic cycles and production of fuels and chemicals. During FY 1982, initial tests at the Advanced Component Test Facility on a single-pass, entrainment-type reactor verified its proper operation in a concentrated solar flux. Tests of candidate high-temperature window materials showed that, in general, transparent materials are superior to translucent materials, although the latter show potential for better chemical and erosion resistance. Testing and analytical modeling of ceramic and other high-temperature materials were well underway in FY 1982.

The Innovative Research Program of the Advanced Research Program was established to develop innovative solutions to problems of using solar thermal technology that would result in quantum improvements in performance, cost, or applications of solar thermal systems. A PRDA seeking new and advanced ideas applied to materials research, thermal and chemical science, and engineering development in support of the solar thermal research program goal was approved. The PRDA will be released during the first quarter of FY 1983 and contract awards made later in the fiscal year.

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