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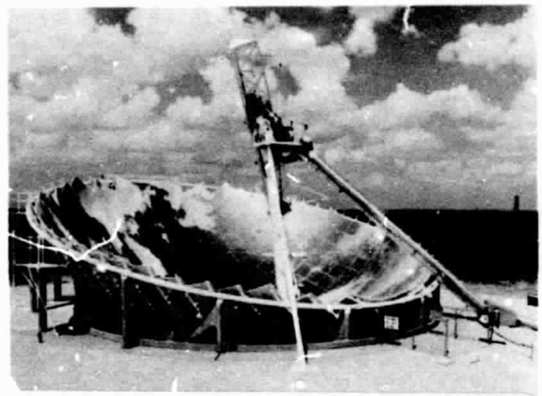
Solar Thermal Technology

Annual Technical Progress Report FY 1981

Volume I: Executive Summary



June 1982

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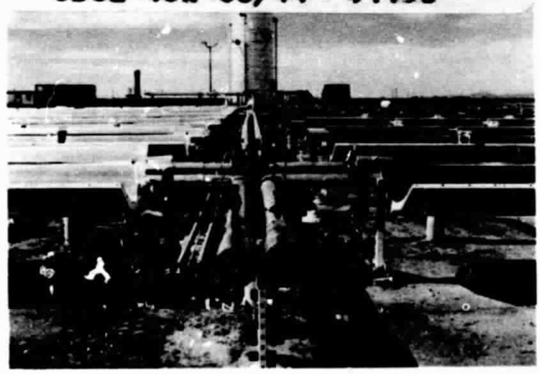

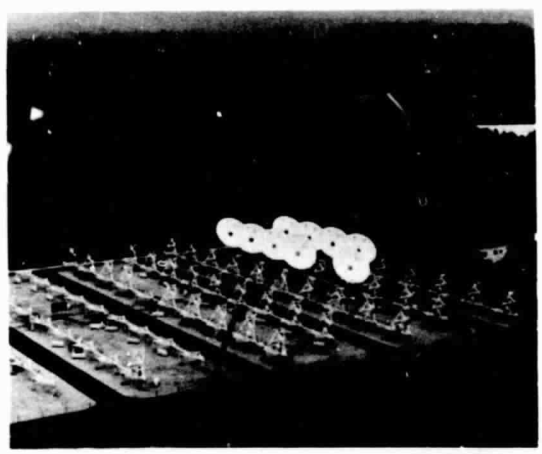

Prepared for the U.S. Department of Energy Through an Agreement with National Aeronautics and Space Administration by Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

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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.

CONTENTS

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EXECUTIVE SUMMARY

INTRODUCTION

Solar thermal systems are developing as a potentially significant energy source. Of all the solar technologies (including photovoltaics, wind and biomass) solar thermal systems offer the greatest diversity in terms of temperature ranges, applications, and storage options. The U.S. Department of Energy Solar Thermal Technology Program was created to establish a foundation upon which private industry could build a mature technology. By pursuing the research and development required for solar thermal technology, the STT Program has advanced subsystems and components into the stage of technical feasibility. The Program has moved the technology as a whole closer to the goal of mass-producible, cost-competitive components and systems, thus ensuring that it can contribute significantly to the national energy mix.

SYSTEM DESCRIPTION

Solar thermal technologies use the sun's radiant energy to produce heat, which can be used directly in industrial and agricultural operations, be converted to mechanical or electrical power, or ultimately be applied directly in chemical reactions for production of fuels and chemicals. The DOE Solar Thermal Technology Program is developing five types of solar thermal concepts, each aimed at specific applications: the central receiver, parabolic dish, parabolic trough, hemispherical bowl, and salt-gradient solar pond.

The first four concepts employ reflective-surface concentrating collectors which focus the sun's rays on a receiver where the radiant energy is converted to heat. Concentrating the radiant energy significantly increases the temperature achievable at the receiver. The central receiver system employs a number of mirrors and only one receiver; systems employing dishes, troughs and bowls are referred to as distributed receiver systems, because each mirrored collector has its own attached heat receiver, creating a distribution of receivers throughout a field of collectors.

In central receiver systems, a field of tracking mirrors (heliostats) intercepts and redirects sunlight to a receiver mounted on top of a centrally located tower. The redirected energy is used to heat or vaporize a fluid (water in present systems; gas, molten nitrate salt, or liquid sodium in future systems). This fluid is circulated through the receiver and is then either passed through a heat exchanger to heat a working fluid or used directly as the working fluid. The heated working fluid can be used as process heat for industrial or agricultural applications, or to drive turbines to generate electrical power.

Point-focusing systems use parabolic-shaped dishes that track the sun in two axes and concentrate the radiant energy on a receiver at the focal point of the paraboloid. Each autonomous module can produce 10 to 25 kWe or 50 to 150 kWt, and can be used alone or in multi-module systems. Fluid circulating through the receiver is heated and can be converted directly to electrical energy by using a heat engine/generator at the receiver. As an alternative, the total thermal energy from a field of collectors can be piped off and fed to a central heat exchanger, then used directly or converted into mechanical and/or electrical energy.

Parabolic troughs concentrate the sun's radiant energy along a line at the optical focus of the trough where an absorber tube is placed. A working fluid flowing through the absorber tube is heated by the sunlight. The STT Program has focused on developing tracking rather than stationary troughs.

The hemispherical bowl concept uses a stationary, hemispherically shaped mirror to focus radiation along a movable linear heat receiver which must track the sun. Water circulating through the receiver is heated and turns to steam that can be used as process heat or to drive turbines to generate electricity.

The fifth solar thermal concept is the salt-gradient solar pond, which uses an artificially constructed salinity gradient in a shallow (2 to 5 m) body of water to trap incident solar energy. The salinity gradient suppresses global natural convection in the pond, and provides insulation to reduce conductive and radiant heat losses. The entrapped solar energy can be extracted for thermal applications and electricity production.

POTENTIAL APPLICATIONS AND CURRENT STATUS

Collectively, solar thermal concepts are complementary and can address a wide range of applications: process heat, electrical generation, cogeneration, repowering existing electric power plants, and the production of fuels and chemicals.

Solar thermal systems have the potential to capture a share of the industrial market with applications such as parts and can washing, bleaching, air-conditioning, potato frying, beer brewing, latex production, sterilizing, enhanced-oil-recovery and oil refining. Parabolic

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troughs, which are mainly low- to medium-temperature systems, are ideal for this market; several complete trough systems have been installed in the field, with support from the DOE STT program, giving users first-hand experience. In part due to these efforts, parabolic trough systems are now entering the commercial marketplace. Other solar thermal technologies are also expected to penetrate the process heat market as they are proven.

The next area that solar thermal systems could be expected to penetrate is electrical generation, in hybrid systems that use solar to repower or retrofit a utility or industry currently using a fossil-fired system, or in stand-alone systems. Other solar thermal applications are for cogeneration and total energy systems, each of which produces both heat and electricity. Central receivers, parabolic dishes, hemispherical bowls, parabolic troughs, and solar ponds are all potential candidates for electrical applications.

The DOE has funded 20 site-specific conceptual designs for repowering, retrofit and cogeneration with central receivers in the past two years; five studies for advanced designs are now in progress and due to be completed in FY 82. These studies will incorporate the most recent technical developments in components and subsystems, and verify that the performance estimates for the initial designs are based on the performance characteristics of commercially available equipment. Electrical generation projects now being built include the world's largest solar electric power plant (a 10-MWe central receiver pilot plant) near Barstow, California, and a total energy parabolic dish project at Shenandoah, Georgia. Second-generation components developed by industry are currently being tested at five operational solar test facilities.

A final use being studied for solar thermal systems is the production of transportable fuels and chemicals from renewable feedstocks. This technology has been investigated on a laboratory scale and several candidate processes have been identified. However, it will take many years to fully develop it on a commercial scale.

FY 81 ACCOMPLISHMENTS

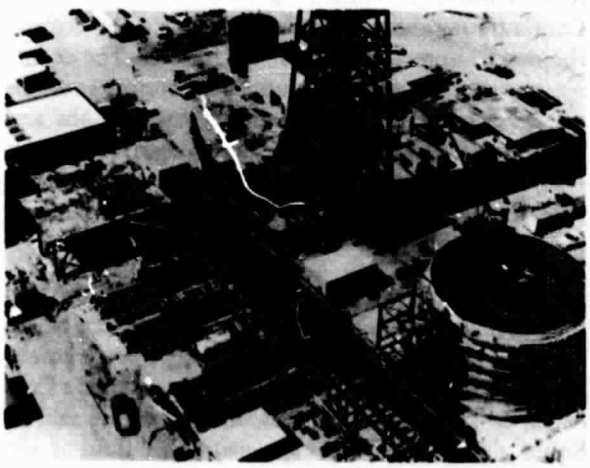
Central Receiver

In the central receiver field, two plants for electrical generation were being built with DOE funding during FY 81: the 10-MWe Solar Central Receiver Pilot Plant near Barstow, California, and the Small Solar Power System (SSPS) Project being built by the International Energy Agency (IEA) in Almeria, Spain.

The former is the first application of solar central receiver technology integrated into a full system for power generation within the United States. It is also the largest solar application in the world and will supply enough annual energy to the electrical grid to power about 2000 homes. The project is jointly funded by the DOE, Southern California Edison, the Los Angeles Department of Water and Power, and the California Energy Commission; McDonnell Douglas is the system facility design integrator. Its objectives are to establish the technical feasibility of such a plant, to obtain sufficient data to indicate the potential for economical operation of commercial plants of similar design, and to determine the environmental impact of these plants.

By the end of the fiscal year, the complete field of 1818 heliostats was in place, the receiver panels had been installed on the tower, the thermal storage tanks were completed and filled with oil, the control room equipment was installed and control-to-component wiring completed, and control systems checkout had begun. First turbine roll is scheduled for 1982.

Heliostat Field at 10-MWe Solar Central Receiver Pilot Plant Near Barstow, California



Aerial View of Storage, Piping and Control Room at 10-MWe Solar Central Receiver Pilot Plant

The SSPS Project compares the performance of two side-by-side systems, one a central receiver system (CRS) and the other composed of parabolic troughs. The project was begun in 1977, and nine member countries of the IEA, including the U.S., are cooperating in the effort. The CRS uses liquid sodium as the primary heat transport fluid both in the receiver and for storage. Although liquid sodium is being evaluated by the DOE STT Program as a potential heat transport fluid, no central receiver plant using this fluid is under construction in the U.S., so the IEA SSPS Project will provide the central receiver program with complementary plant operations and maintenance data in this area. The 93 heliostats in the field are modified versions of the first-generation heliostats developed by Martin Marietta for the Barstow plant; the sodium receiver is a German-designed cavity type. At the end of FY 81 the plant was conditionally accepted by its operating agent and the test and operations phase was scheduled to begin.

Field of Heliostats and Parabolic Troughs at Small Solar Power System Project in Almeria, Spain

Advanced component technology development also continued in FY 81. Four manufacturers have provided detailed designs for second-generation heliostats; created conceptual designs for large-scale factory production; delivered two prototypes each; and submitted detailed cost estimates. The prototypes have been evaluated for optical and structural performance, environmental survival, all potential operational modes, and life-cycle considerations. This test program is continuing in FY 82.

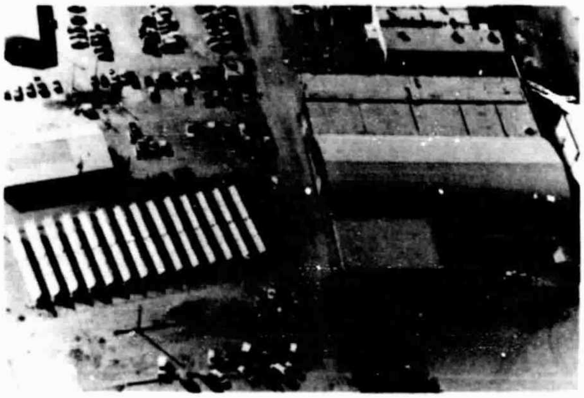
Two advanced receiver concepts were also tested: a cavity receiver using a molten nitrate salt heat-absorbing fluid, and an external receiver using liquid sodium. The first receiver completed over 500 hours of testing in FY 81, with sunlight-to-heat conversion efficiencies of up to 90%. Test and evaluation of the second receiver is continuing.

Central Receiver Tower at Small Solar Power System Project in Almeria, Spain

Parabolic Troughs

Three trough systems producing mid-temperature steam for industrial process heat were completed and two of these were brought on-line in FY 81. Each consists of a field of approximately 1,000 m^2 (10,760 ft^2) of collectors providing steam to an industrial plant steam line. The systems that began operation in FY 81 are: the Lone Star Brewery in San Antonio, Texas, designed by Southwest Research Institute, which uses roof-mounted Solar Kinetics collectors to provide saturated steam at about 860 kPg (125 psig) to the existing steam line, and the Ore-Ida Foods Plant in Ontario, Oregon, designed by TRW, which uses Suntec collectors to supply steam at 212°C (415°F) to the main plant steam line, where it is used to fry potatoes. The third system, at the Dow Chemical Plant in Dalton, Georgia, was scheduled for dedication in November 1981. This Foster Wheeler-designed system uses Suntec collectors to supply steam at approximately 1034 kPg (150 psig) for use in making latex foam. Construction of a similar-sized plant at the Southern Union Refinery in Lovington, New Mexico, was delayed, but the plant should be completed in FY 82. The system, being built by Energetics, Inc., uses 900 m^2 of Solar Kinetics collectors to generate steam for the refining process.

Roof-Mounted Parabolic Troughs at Lone Star Brewery, San Antonio, Texas



Parabolic Trough System at Ore-Ida Foods Plant in Ontario, Oregon

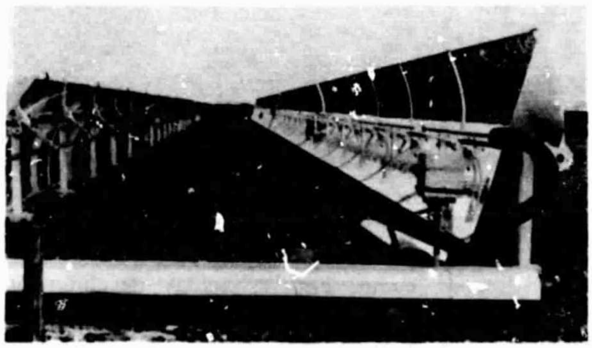
Parabolic Troughs Installed at Dow Chemical Plant in Dalton, Georgia

Construction continued on two large, cost-shared process steam projects: one at the U.S. Steel Chemicals Plant in Haverhill, Ohio, for which the prime contractor is the Columbia Gas System Service Corporation, and one at the Caterpiller Tractor Corp. in San Leandro, California, designed by the Southwest Research Institute. Both use approximately 5,000 m^2 of Solar Kinetics, Inc. collectors, and both are scheduled to be completed by mid-FY 82.

The final plant under construction at this time is at the Home Laundry in Pasadena, California, which is expected to be completed in FY 82. This low-temperature steam project was designed by Jacobs-Del Solar Inc., and uses about 600 m^2 of the trough collectors.

Four early systems, producing hot air/hot water below 100°C (212°F), are being upgraded to bring them to the state of the art and improve performance. These systems are at Gilroy Foods, Campbell Soup, La Cour Kiln, and Riegel Textiles.

Another major trough project is the distributed collector system (DCS) that forms half of the IEA SSPS referred to under the central receiver section. The DCS is the largest operational solar thermal electric power plant using parabolic trough technology, providing 500 kWe to the local electric grid. In FY 81, acceptance testing was completed and the test and operation phase had begun. Plant operational and maintenance data obtained will complement information obtained through the DOE domestic trough program. The field of troughs contains about 5362 m^2 of collectors in two sections: one composed of single-axis tracking collectors from the American company, Acurex; the other, double-axis tracking M.A.N. (Maschinenfabrik Augsburg - Nürnberg) collectors from Germany



Single-Axis Tracking Parabolic Troughs at the Small Solar Power System Project

Double-Axis Tracking Parabolic Troughs at the Small Solar Power System Project

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The 150-kW solar irrigation project near Coolidge, Arizona, was the world's largest operating solar thermal electric power plant at the time of its dedication (November 1979). It continues to operate successfully, supplying electrical energy to the local electrical cooperative in exchange for power to run three 50-hp irrigation pumps on the Dalton Cole Farm. In FY 81, the system operated in excess of 90% of the good-weather time, supplying 160,000 kWh of electricity to the utility grid. It is currently operating on a fully automatic basis, with facility personnel present only to perform routine tests and maintenance checks.

In the Modular Industrial Solar Retrofit (MISR) Project, a sample design and complete specifications for MISR line-focus modular systems for IPH applications were completed. Subsequently, a MISR supplier-user conference was held, at which the specifications, guidelines and sample design were presented to industry. Five contracts with industry to design and develop MISR systems were let at the end of FY 81.

Four lightweight but durable trough structures employing glass reflective surfaces were designed and evaluated for conformance to stringent requirements as part of the Performance Prototype Trough project. After fabrication, the collector prototypes were evaluated with laser ray trace and accelerated environmental testing. In addition, a black chrome, selective absorber/emitter coating, durable in long-term operation at 350°C, has been produced at commercial plating facilities.

Hemispherical Bowls

The hemispherical bowl has been successfully demonstrated on a small scale in Crosbyton, Texas. The Crosbyton Solar Power Project began in 1976, with an effort by the City of Crosbyton and Texas Tech University to develop a 5-MWe solar hybrid electric power plant to serve the city. That conceptual design was the basis for the Analog Design Verification System (ADVS), which was completed in January 1980: a 20-m-diameter bowl, consisting of 438 spherically curved glass mirror panels, each about 1 m square, focusing the sun onto a movable 5.5-m-long receiver.

In FY 81, the ADVS completed 20 months of operation, with a measured peak efficiency of 63% at nominal steam conditions, and first generated electricity for the local grid. The analysis techniques and computer codes used in the project to date have been able to accurately reproduce the experimental result.

Crosbyton Solar Power Project Using Hemispherical Bowl

Parabolic Dishes

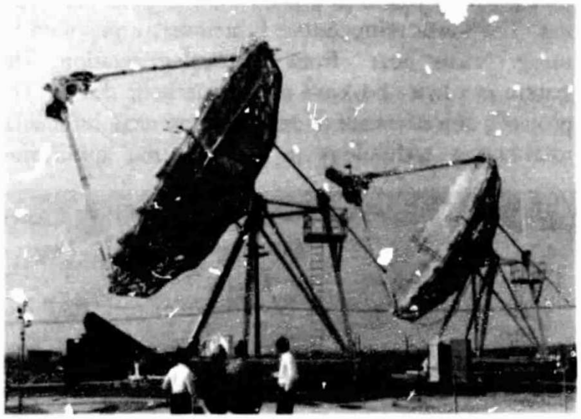
Significant progress occurred in two major areas of the parabolic dish program in FY 81. The first parabolic-dish solar total-energy plant neared completion; successful operation of the plant will provide a model for other potential industrial users. On another front, development of an efficient and cost-effective receiver/engine combination was advanced by successful testing of three engine concepts (Brayton, Stirling and Rankine cycles) at the Parabolic Dish Test Site (PDTS).

The Bleyle of America, Inc., knitwear factory in Shenandoah, Georgia, is the first industrial application of the solar total-energy concept, that is, a solar system that provides electrical power, process heat, and cooling. The lower temperature functions are provided by using "waste heat" from electrical generation. The system 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

Solar Total-Energy Plant Under Construction in Shenandoah, Georgia, May 1981 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, 117°C steam for knitwear processing, and 100°C exhaust steam for space heating and cooling. Construction of the plant was nearly complete by the end of FY 81, and it is expected to be fully operating by spring, 1982.

At the PDTS, a Brayton-cycle air receiver manufactured by Garrett AiResearch Manufacturing Company and a high-temperature Brayton-cycle ceramic air receiver designed and fabricated by Sanders Associates, Inc. were successfully tested. The former produced air at 816°C (1500°F) at pressures between 240 kPa (35 psia) and 343 kPa (50 psia), at efficiencies between 70 and 80%. The Sanders receiver produced outlet temperatures from 871° to 1427°C (1600° to 2600°F) at efficiencies from 60 to 80%. This exceeded last year's goal of demonstrating operation at 137[illegible]°C (2500°F). These receivers will subsequently be integrated with Brayton engines for further testing.

A Garrett AiResearch steam Rankine receiver was tested in March 1981 at the PDTS, demonstrating stable operation over the full performance range. A Stirling-cycle receiver, manufactured by United Stirling of Sweden, was beginning solar-driven tests at the end of FY 81.



Parabolic Dishes Under Test at Parabolic Dish Test Site

Solar Ponds

The Regional Applicability Study was completed in FY 81, and the final report was due for distribution in FY 82. The study focused on the general characteristics of 12 geographic regions. 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 economic viability in several southern high-insolation regions for large-scale electric power and municipally financed thermal applications.

For the Salton Sea Experiment, the Phase I Feasibility Study Report and a draft of the Phase I Final Report were issued; Phase IA, Conceptual Design, will begin in FY 82. In other pond work, a small research pond was designed and construction begun at Los Alamos Scientific Laboratory in Albuquerque, and a one-dimensional numerical model of a salt-gradient pond was developed. Analytical and experimental studies on heat extraction from solar ponds are being conducted at SERI in Colorado.

Research and Advanced Development

The solar thermal Research and Advanced Development (R&AD) program is aimed at developing a technology base that will expand the applications of solar thermal technology. Materials research, fuels and chemicals, and applied thermal research were the main components of this program, and are briefly discussed below.

Materials Research. In materials research, improving the endurance of mirrors in solar applications is a top priority. A matrix approach to testing mirrors (MATM) experimental plan was developed. The environmental conditions which cause the most mirror degradation -- humidity, temperature, thermocycling, ultraviolet radiation, environmental pollution, and mechanical force -- are incorporated in the matrix. Tests will be conducted in three phases. Phase I tests, completed in FY 81, confirmed the general validity of the approach, and showed that samples can be reliably ranked in order of their expected outdoor performance.

Additional mirror work included developing alternative approaches to the conventional wet chemical process for manufacturing mirrors, and developing metallic coatings for protecting conventional silver-glass mirrors.

Other areas of materials research included:

(1) Developing a selective absorber coating that would maintain stable performance above the normal limits of black chrome.

(2) Reducing the cost and weight of materials used in concentrators.

(3) Studying the losses from dust accumulation

(4) Characterizing transparent and reflective materials samples.

(5) Studying containment materials in high-temperature applications.

(6) Evaluating polymers being considered for mirrors and mirror enclosures.

(7) Assessing ceramic materials.

(8) Studying the effects of a freeze/thaw environment on cellular glass.

Fuels and Chemicals. Under the SunFuels program, fuels and chemicals work was conducted to explore new alternatives for producing energy-intensive liquid and gaseous fuels and chemicals from renewable resources. Controlled pyrolysis of oil shale using direct solar heat was shown to be technically feasible. High-temperature catalytic and non-catalytic reactors were studied, as were various solar fuels and chemicals from renewable resources; and market assessment studies were performed.

Applied Thermal Research. In the final area, applied thermal research, the primary focus was on identifying the mechanisms of heat losses in order to develop means of minimizing them. The combined effects of high operating temperatures and large receiver dimensions were addressed; experimental facilities designed to measure convective heat transfer in thermal receivers were constructed and checked out.

A high-temperature ceramic solar receiver to be used with parabolic dish concentrators was also developed as part of the thermal research effort. Extensive tests of this receiver, developed by Sanders Associates, Inc., showed that properly designed ceramic elements can be used in high-temperature, high-flux environments.